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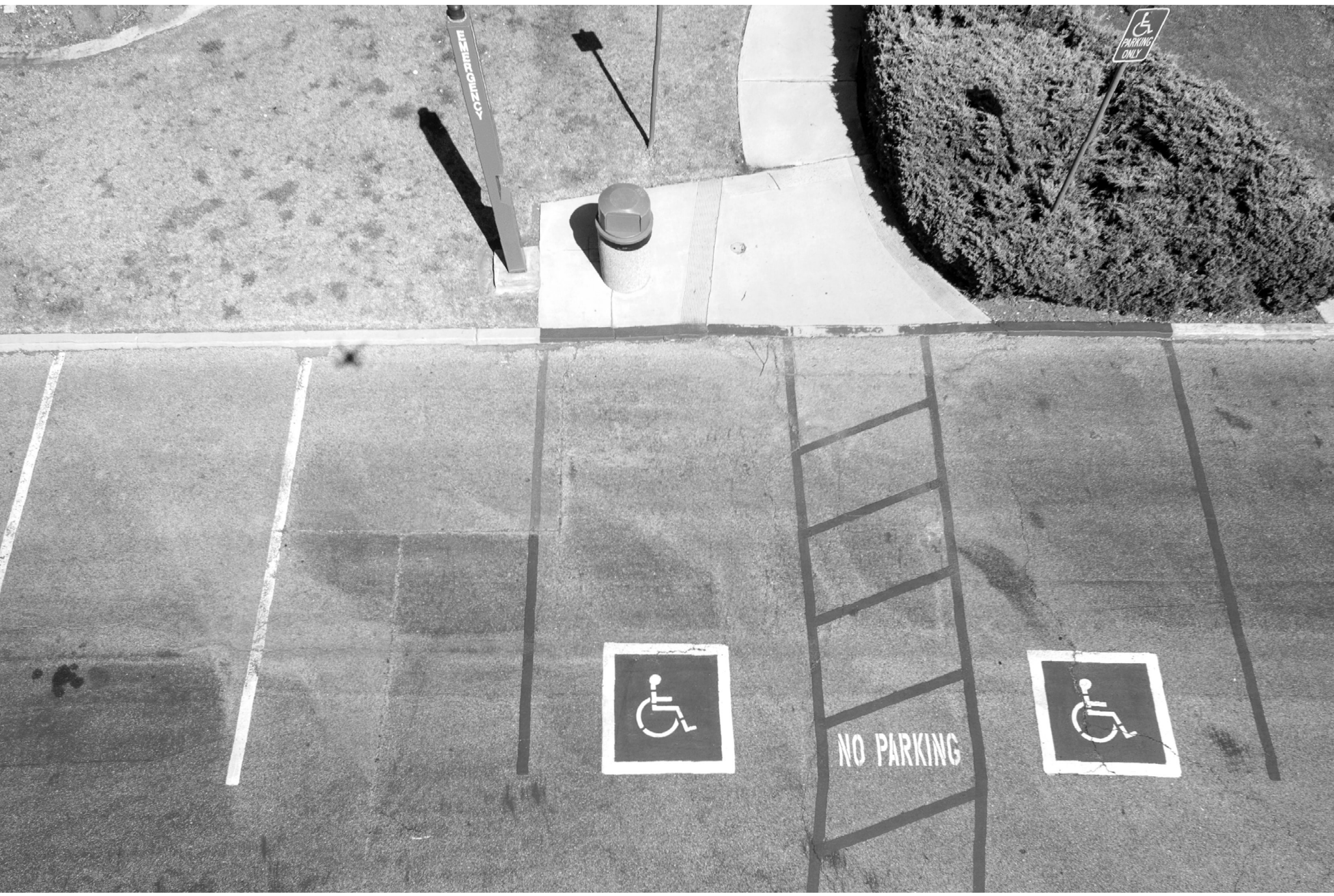
Gaps and Opportunities in Accessibility Policy for Autonomous Vehicles

William Riggs, PhD
Anurag Pande, PhD



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14. ABSTRACT

Nearly 1 in 5 people in the US have a disability (more than 57 million) (U.S. Census Bureau), and people with disabilities use the automobile as a travel mode at significantly lower rates than people without disabilities (Bureau of Transportation Statistics). While autonomous vehicles are being built with the purpose of curbing people's need to operate the vehicles, 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.

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Gaps and Opportunities in Accessibility Policy for Autonomous Vehicles

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William Riggs, PhD and Anurag Pande, PhD

1. Introduction

Nearly 1 in 5 people in the US have a disability (more than 57 million) (*1*), and people with disabilities use the automobile as a travel mode at significantly lower rates than people without disabilities (*2*). 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 specifically designed for their needs (*2*). 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 (*3*).

1.1 AV Policy at the Federal, State and Local Level

Presently, there is no specific federal law that governs AVs (*4*). Though legislation has been initiated in Congress, there is still a strong debate within the Senate on the regulation level, safety concerns, and preemption of the state regulations. However, it is quite 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 as well as vehicle safety standards, the US Department of Transportation (USDOT) is paying a great deal of attention to encouraging the development of AVs. Stakeholder forums on AVs have been hosted by USDOT 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 "Ensuring American Leadership in Automated Vehicle Technologies: Automated Vehicles 4.0" in December 2019 (*5*).

On the state level, there are several jurisdictions that have passed certain 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. There are some states that have provisions for automated vehicles to function on public roads, while others offer a testing framework. There are some states like California that 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 are 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 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 (*6*).

While autonomous vehicles are being built with the purpose of curbing people's need to operate the vehicles, 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.

1.2 The Endeavor towards Autonomous Vehicles for Disabled People

In the year 2012, Google released a video of its automated car transporting a blind man to a taco shop as well as to his dry cleaners (*7*). 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 to be able to access life and travel options at par with individuals without disabilities. Under the right kind of circumstances, automated vehicles can offer a decrease in social isolation, access to vital services, and personal independence (*7*).

An elaborate report titled "Self-Driving Cars: Mapping Access to a Technology Revolution" was produced by the National Council on Disabilities in 2015 (*8*). It explored the potential of self-driving cars to alter the lives of the disabled in great detail. 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.

1.3 Context of VTA AAV Gaps and Opportunities Assessment

The objective of this white paper is to recommend specific policy and wording changes in relevant ADA regulations to accommodate and properly regulate automated transit services represented by the Santa Clara Valley Transportation Authority (VTA) AAV (Accessible Autonomous Vehicle).

The VTA AAV research and demonstration project aligns with VTA strategic goals to promote new sustainability solutions and evaluate new mobility solutions. The AAV project intends to work with the public, especially people with disabilities and older adult population to get feedback on the technology from veterans at the Veterans Administration (VA) Hospital. The project will demonstrate how AV technology makes a small transit vehicle more responsive to the needs of the people with disabilities or older adult community. The platform that will be used for the VTA AAV project was built by Local Motors with a BraunAbility ADA compliant ramp and Strategic AI video analytics. It was developed with active engagement form the disabled community.

Figure 1. VTA AAV Accessibility Testing, Source: VTA

1.4 Methodology

To assess this work, our team engaged in a two-step process. First, we evaluated numerous sources and developed a rigorous background of how the Americans with Disabilities Act and relevant research could inform trends of autonomous vehicles—particularly autonomous transit and paratransit. We did a detailed review of the Americans with Disabilities Act of 1990 and Section 504 of the Rehabilitation Act of 1973, 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)

We also looked carefully at VTA's AAV Playbook (a comprehensive document outlining the Accessible Automated Electric Vehicle project findings) and appendices, as well as a review of 49 CFR Sections 37 and 38, to 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. We evaluated the potential accessibility features that assume the absence of a driver/operator. This evaluation explores if potential innovations fit into categories and looked at how vehicles could meet and potentially exceed ADA requirements. Much of this is tiered from Table 2.8 in the VTA Playbook.

Table 1. Accessibility Solutions (From VTA Playbook)

Feature #	Accessibility Solutions	Feature
4.3	Level Boarding	Staff manually adjusts vehicle to curb height and curb gap at stop and adjusts suspension to match if possible
4.9	Automated Ramp	Exterior Button to deploy ramp
4.10	Automated Ramp	Interior Button to deploy ramp
4.11	Automated Ramp	Steward Screen to deploy ramp
4.22	Passenger Safety	Ample lighting in the interior when boarding
4.26	Passenger Safety	Audio announce door opening
4.27	On-vehicle Validation	Vehicle opens door
4.33	Automated Ramp	Vehicle deploys ramp manually
4.51	Manual Wheelchair Restraint	Safety attendant manually assists passengers with wheelchair securement
4.57	Passenger Safety	Audio announce to wear seatbelts for all
4.63	Automated Ramp	Ramp interlocked with door position (only deploy ramp if door open)
4.64	Automated Ramp	Ramp interlocked with vehicle drive system (vehicle moves only if ramp is stowed)
4.66	Passenger Safety	Audio announce door closing
5.5	Passenger Safety	Ample lighting in the interior when riding
5.29	Remote support	Ability to store video for more than 30 days to evaluate incidents
5.32	On-vehicle Information	Audio announce next stop when vehicle starts moving at current stop
5.34	On-vehicle Information	Audio announce next stop 35 m before vehicle arrives there
5.35	On-vehicle Information	Audio announce stop when vehicle arrives there
5.42	On-vehicle Information	Audio announce in different languages
5.43	On-vehicle Information	Video display information in different languages
6.3	Level Boarding	Staff manually adjusts vehicle to curb height and curb gap at stop and adjusts suspension to match if possible
6.4	Automated Ramp	Interior button to deploy ramp
6.5	Automated Ramp	Steward screen to deploy ramp
6.9	Passenger Safety	Ample lighting in the interior when exiting
6.13	Passenger Safety	Audio announce door opening
6.14	Passenger Safety	Audio announce door closing
6.23	Automated Ramp	Vehicle deploys ramp manually
6.35	Automated Ramp	Exterior button to retract ramp
6.36	Automated Ramp	Ramp interlocked with door position (only deploy ramp if door open)
6.37	Automated Ramp	Ramp interlocked with vehicle drive system (vehicle moves only if ramp is stowed)

Building on this background, we develop a rating framework to evaluate how and to what extent vendors and technological frameworks (itemized as Case Studies) address accessibility requirements. The work provides insights beyond an assessment of a specific project or technology and allowed for a detailed exploration of the gaps and opportunities for these advancing technologies.

2. Background

2.1 Lessons from ADA and the 20th century

The disparities between travel experience of the able-bodied and disabled individuals persist three decades since the passage of the American Disabilities Act (ADA), and are 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 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 is starting to unfold ***provides an opportunity to develop a transportation system that treats accessibility as a guiding principle, not as an afterthought***.

Ensuring access at this stage is more cost-effective in the long run compared to retrofit in light of subsequent regulations. Early attention to accessibility may be a precondition to achieving the potential of AAVs to substantially increase independent mobility for consumers with disabilities, noted by Claypool et al. (*3*). Unfortunately, the existing literature on human factors doesn't provide a framework to empirically examine the inclusive design needs of the emerging AAV ecosystem (*9*). Cregger et al. (*10*) recommended the development and testing of new alternatives and aids for accessibility features onboard AAVs that consider a full range of disabilities.

This call for early integration of accessibility into automated platforms makes the Accessible Automated Vehicle (AAV) Pilot Demonstration Project a timely and important project. Addressing accessibility requirements at the pilot stage can ensure that the inclusive design principles are an integral part of the AV revolution and exceed the minimum regulatory requirements.

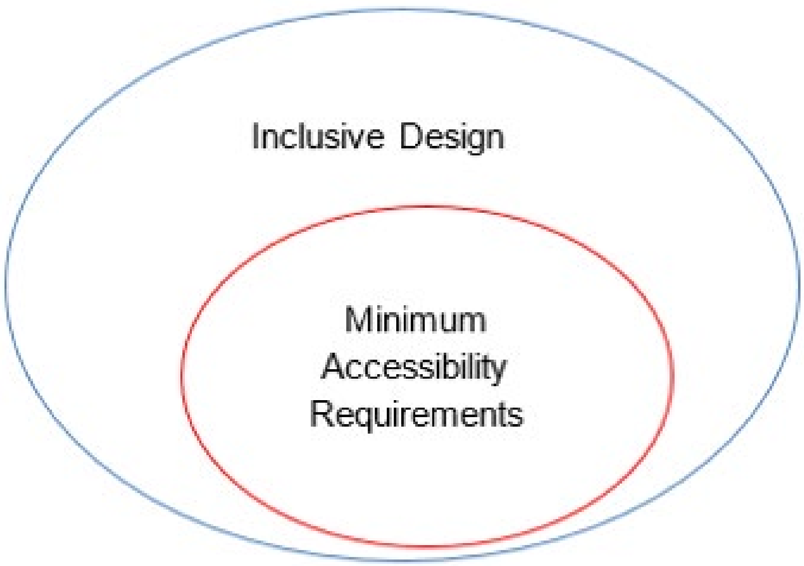

Figure 2. Minimum Accessibility Requirements as a Subset of Inclusive Design Principles

2.2 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 (*3*). 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 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 AAV pick up point
  - Waiting at AAV pick up point
  - Navigating from AAV drop off point to end 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 human attendant relates to the design of the vehicles themselves.

2.3 An Accessibility Checklist

Disability Rights Education & Defense Fund provides an actionable accessibility checklist (*11*). The checklist is reorganized below by the three distinct areas of concern, Information System Design, Infrastructure Design, and Vehicle Design. While some of these clearly have immediate feasibility for implementation by public and private sector parties (e.g. curb infrastructure and vehicle design) these areas are highlighted as a core focus in ensuring accessible automation.

- **Information System Design**
  - "Anti-discriminatory data & privacy requirements (only sharing disability/health status, or locations visited with permission)
  - Where's my ride, including finding it when it arrives (how will the car know you are blind? Could it detect a dog or a cane?)
  - Human Machine Interface Accessible Apps to hail the AAV (Section 508 compliant)
  - Micro-navigation needs for Blind riders— how will you know the car has arrived?
  - User-enabled remote destination selection and trip monitoring with video and GPS for users with intellectual disabilities" (*11*)

- **Infrastructure Design**
  - “Alternate (accessible) drop off points for access (e.g., near curb ramps)
  - Minimally complex directions and control identifiers compatible with portable devices (phones, tablets, ‘smart-glasses’) with customized assistive technology, such as paperless Braille display for deaf/blind users
  - Accessible operating surfaces (within reach; tactile cues, etc.)” (*11*)
- **Vehicle Design**
  - “Provides both print/visual (adjustable size/contrast by user) and audio I/O Voice-controlled systems (e.g., change route, unlock doors, lower/raise windows, etc.)
  - Orients user to drop off point including access features, directions to destination with orientation landmarks, construction, etc.
  - Provides space to stow wheelchair if transferring
  - Lower floors to accommodate wheelchairs (don’t put tech under the floor)
  - Lift/ramp and securement system, or support for aftermarket modification
  - Accessible securement for non-disabled people with limited upper body mobility, e.g., seat belts
  - Accessible door handles, storage spaces (opening and closing the trunk or hood)
  - Provides information (visual and audio) about the environment surrounding the vehicle
    - Location, route, certain landmarks (e.g., Bay Bridge Toll Plaza), etc.
    - Weather, route conditions
    - Incidents (how will car communicate in an emergency?)
    - Deviations from route or why the ride may be stopping” (*11*)

The checklist has concrete ideas for ensuring accessibility for individuals with different disability types and therefore provides actionable guidance beyond the high-level guiding principles.

2.4 Background Literature

Inclusive Mobility Design Lab (IMDL) at the University of Michigan provides an interactive portal (*12*) to document existing research and identify knowledge gaps in the context of accessibility of AAVs (specifically a low-speed Autonomous Shuttle (LSAS)). There are 66 studies categorized 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, are listed below:

- Information System Design
  - Plan Route
  - Pay Fare
  - Identify Correct Vehicle Station
  - Identify Correct Vehicle to Board
- Vehicle Design
  - Board Vehicle
  - Move to Seat or Securement
  - Secure and/or Retrieve Belongings
  - Secure Passenger/Maneuver from Securement

- Ride Vehicle
- Indicate Stop
- Identify Correct Stop for Alighting
- Exit Vehicle

These tasks may be mapped to the seven trip-making stages identified in the AAV Playbook. However, this list from the IMDL portal does not address the elements of infrastructure design of transportation facilities, including sidewalks, curbs, and street crossings (*9*). Hence, three of the trip-making stages of the AAV playbook—Navigating to AAV pick up point, Waiting at AAV pick up point, and Navigating from AAV drop off point to end destination—are not adequately covered by the portal. The disability types included in the review provided by IMDL is quite comprehensive and includes:

- Cognitive and/or Developmental Disability
- Auditory Impairment
- Visual Impairment
- Wheeled Mobility Devices
- Ambulatory Impairment
- Older Adults
- Extremes of Size and Weight

It should be noted that almost all the research listed at the IMDL portal is conducted on traditional transit modes because a very limited set of studies exist on AAVs. In general, wheeled mobility devices and ambulatory impairments have significant literature addressing the challenges, whereas research on cognitive and developmental disabilities is more sparse. The combinations of disability type trip making stage (from the AAV playbook) 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.

2.4.1 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., Telecommunications Act and subsequent judicial interpretation) have extended accessibility mandates to the newest technology (*4*). 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 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 within “ride request” apps, and it is probable that this pathway could provide a comparable standard of service for mobile application / information systems UX design.

2.4.2 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 (*9*). In a driverless environment, the vehicle design will need to address this issue.

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 (*13*). The criticality of these elements depends on the size of the AAVs. Maneuvering through 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 (*14*) 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 (*15*). Haptic feedback refers to technology that can engage people’s sense of touch to enhance the interaction with onscreen interfaces (*16*). On driverless vehicles, reconfigurable spaces/seating will need to accommodate a wide range of rider needs and preferences. Sensing of 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 (*13*). That does not imply that costs for innovating fare payment systems should be born 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 (*17*).

Research webinars from the US Access Board in Spring 2021 (*13*) documented the effects of ramp slope and multi-segment ramp configuration on human performance during ramp ascent and descent. The ramp slope and configuration are critical for disabled individuals to board and alight the vehicles independently. 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, engaging 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, deaf individuals who want to talk but the voice interface doesn't understand a deaf-induced accent may prefer a tactile interface. A key research priority would be vehicle interface design with a robust yet limited set of gestures and signs for command & control. For deaf individuals, 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 (*13*).

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.). For these individuals, many of the 'general' solutions won't work. Therefore, the design needs to have a spectrum of interface solutions within each person's abilities (*13*).

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, who may be easily confused, or who may have no ability to give clear instructions. A trained-human-in-the-loop option may be required for such scenarios, and 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 user's abilities 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 (*18*) and providing an independent assessment of complex issues such as privacy, surveillance, individual expression and data sharing.

3. Conclusions from Background Research

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 of them currently supported by the vehicle operator.

The AAV project by VTA is an important step in ensuring accessibility as the transportation system moves towards automation because it is easier and more cost-effective to do so upfront rather than as an afterthought to avoid lawsuits. With 15% of Americans having some disability concerns, this represents a significantly large market segment. This research to serve disabled individuals may also support America's aging population as cognitive and physical disabilities increase with age.

To ensure that the disabled individuals are appropriately served at each trip-making stage identified in the AAV playbook, the design of transportation facilities, sidewalks, and street crossings are also essential to consider (*9*). The environmental facilitation that may support easier boarding and alighting includes (*13*):

- "Deploy ramp to curb wherever possible, and ideally at corners or sidewalks that have enough clear space.
- Standardize pick-up and drop-off conditions to allow loading to the curb.
- The pick-up and drop-off location ideally will be curb height but must have enough clearance to allow passengers to maneuver onto and off of the ramp easily." (*13*) This presents an opportunity for better curb management and collaboration between agencies/entities in using limited curb space.

To expand the limited body of research in this area, we recommend two research approaches: i) A series of focus groups with persons with varying types of disabilities who experienced a ride on the AAV, and ii) Observing the individuals with disabilities using the AAV system in a naturalistic environment. Again, given the limited curb space available in urban areas, collaboration between the industry and agencies responsible for the infrastructure would be crucial towards creation of accessible environment. The collaboration may include shared use of accessible transit infrastructure (Also, See Section 7).

The research in this area also needs to inform as well as keep up with the latest guidance provided by US Access Board. A key mission of the US Access Board to develop and maintain accessibility guidelines and standards under ADA. This includes design requirements for facilities in the private and public sectors, transportation vehicles, telecommunications equipment, and Federal electronic and information technology (*19*).

4. 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 planned to organize the discussion by four different service models: 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 (*20*). 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 (*21*). As a result, research indicates that these two will be the primary business models of these technologies.

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. As shown in Table 2, 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 2. Applicability of AAV Technology to On-demand Microtransit and Paratransit Services

	Accessible Safety Features	Wheelchair 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

5. Case Study Application and Validation

To extend beyond this background evaluation, we evaluated the strengths and weaknesses of eight conceptual AAV platforms. As the number of AAV fixed-route neighborhood circulator and fixed-route long haul systems are limited, these are clustered based on the on-demand microtransit and paratransit model. As the cases reveal, the most common platform currently under development involves microtransit options. These cases are summarized in Table 3. Details for each case study are in the Appendix provided as a separate Excel Attachment.

Table 3. Accessibility Features by Case

Accessibility Features (VTA AAV Playbook)	May Mobilty	Waymo / Braun	VW Sedric	Renault EZ-GO	Kenguru	Detroit EVO	US Army / Catapult	JTA/ Olli 2.0
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)

5.1 On-Demand Microtransit Cases

5.1.1 Case 1 – May Mobility's Prototype of Wheelchair-Accessible AV

May Mobility 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, where the shuttle will be operating (*22*). The design put across by May mobility will comprise 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 was aware of the need for design improvements right from the initial round of feedback. Specific improvements like increasing the length of the mounting ramp to offer steadier disembarking and onboarding along with optimized drop-off and pick-up points are required. There are still ongoing plans for making necessary improvements before the vehicles are deployed. However, these vehicles will soon be operating in the Grand Rapids and Columbus provinces of Ohio.

5.1.2 Case 2 – Waymo / Custom Chrysler Pacifica

Waymo recently announced that it would be including 100 customized hybrid Chrysler Pacifica minivans to its new experimental fleet of automated cars designed in partnership with Braun Ability (*23*). When the news of Chrysler adding the sleek novel Pacifica to its present offering of the famous Town & Country came out, Waymo jumped at the chance to create the most accessible adaptation on the present market. Waymo wanted to prove that the technology does not have to be utilized in pod-like vehicles that could never accommodate a ramp for wheelchairs. Individuals with disabilities could use automated cars in everyday lives if they collaborated with more oversized vehicles, allowing passengers of all types. It has long been Google/Waymo's aim to serve individuals with disabilities who cannot drive. The CEO, John Krafcik, mentioned that the opportunity to work in close quarters with engineers from Fiat Chrysler Automobile (FCA) would enhance their chances to bring travel destinations within reach of disabled people.

5.1.3 Case 3 – Volkswagen Sedric

The Sedric concept car is one of the more luxurious autonomous cars presented in our case studies. 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 there are no details available on access and securement logistics. Volkswagen is also 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 (*24*). This initiative will incorporate feedback into their autonomous car design to ensure that they meet mobility requirements for underserved disabled populations.

5.1.4 Case 4 – Renault EZ-GO

First introduced in 2018, Renault's concept vehicle has level 4 autonomy (*25*). The EZ-GO 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 ride-sharing apps such as Lyft or Uber. The EZ-GO features a large door opening with an adjustable ramp and claims that it is wheelchair and stroller accessible. Interior photographs of the concept car in Geneva show that there are straps for securing a wheelchair or stroller once inside.

5.1.5 Case 5 – Kenguru

The Kenguru is an accessible automated car design initiated in Hungary (*26*). The vehicle is a small and hollow one-person vehicle, best suited for city travel. The car is wheelchair accessible, allowing users to roll in their chair more easily than a person walking and getting the car. Once a user is inside, they can simply 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. However, the market for accommodating specialty wheelchair cars is relatively small in the present global scenario. Nevertheless, the market will expand as these vehicles can be shared within a taxi fleet for all people who need them. With self-drive and electric power, it is convenient to develop a car with a hollow shell and a flat floor. These developments also make it easy to incorporate spaces in the vans.

5.1 Paratransit Cases

5.2.1 Case 6 – Detroit Medical Campus / Navya Shuttle Evo

Navya's Shuttle Evo has also been deployed in downtown Las Vegas, the University of Michigan campus, Texas A&M campus, and Oslo, Norway (*27*). The electric shuttle can fit fifteen people and run for nine hours. The most recent fleet deployment at the Detroit Medical Center Heart Hospital campus was unveiled in August 2020. 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.

5.2.2 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 (*28*). The US Army Tank Automotive Research, Development, and Engineering Center (TARDEC) is presently 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 located about half a mile away.

5.2.3 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 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 (*29*). JTA specified "Full ADA compliance" as first of the

"Golden 20" requirements in the Request for Proposal issued in October 2019 for AV solutions appropriate for the U^2C Project.

6. 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 a transit center curb management solution to be developed. VTA will 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, Web and Phone backend system.

7. Summary and Next Steps

As this evaluation illustrates, AAVs offer a considerable promise of mobility to the disabled population. However, to realize this promise, a careful review of the regulatory regime and guidance of potential changes to the rules is required. AAV may increase the significance of providing onboard information to such passengers. AAVs will provide increased service with new forms of on-demand passenger travel options for those with disabilities. An example of such an AAV from May Mobility is illustrated in Figure 2.

Figure 3. May Mobility AAV Arlington, VA, Source: https://twitter.com/May_Mobility/status/1390410067023962125

Many of the standard features in vehicles have the potential to be enhanced and improved with automation. 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 (*30*). 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 to be certified as *508 compliant* (*31*) for web content accessibility, and communications must be *HIPAA* (*32*) compliant. The best practices in this area also include assessing the accessibility of all content against the latest international *Web Content Accessibility Guidelines (WCAG)* (*33*).

The evaluation shows that the need for refinement to the existing technology privacy considerations where a trained-human-in-the-loop may be required. Additional points of considerations include:

- Most vendors are assuming fares and fare boxes become digital. This should be a universal standard to allow for the elimination of fare boxes from the vehicle/vehicle vestibule.
- Likewise, the design simplicity of vehicles must 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.
- Exploration of slope standards and including them in any requests for qualifications. A University at Buffalo study on ADA slope requirements and wheelchair capabilities would be critical to highlight in any contracts or regulations (*13*).
- 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.
- Establishing a dialogue with AAV developers on user experience studies and focus groups could be a valuable source of learning for the industry, as well as the VTA, 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 enhance and build 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) that 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 service with existing transportation infrastructure.

These items will ensure that vehicles balance safety and accommodation and that regulators are most 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 to maximize accessibility. For AAV applications this means using advanced solutions in a manner that provides 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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9. Appendix

Case Study Tables Provided in the Excel Attachment.

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About the Author

William (Billy) Riggs, PhD, AICP, LEED AP is Associate Professor at University of San Francisco. He is a global expert and thought leader in the areas of autonomy and smart transportation, housing, economics, and urban development.

Anurag Pande, PhD is a Professor of Civil Engineering at California Polytechnic State University, San Luis Obispo. His research interests include before-and-after evaluations, traffic operations, and safety of all road users.

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