Driverless Cars and Accessibility

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Designing the Future of Transportation for People with Disabilities

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Table of Contents

Executive Summary

Fully automated vehicles, when they begin to be deployed in significant numbers, will offer the potential to usher in enormous positive changes. Anticipated benefits include lowered traffic fatalities and injuries, as well as potentially expanded access to transportation for those who cannot drive or those who face significant barriers to driving. For individuals who cannot legally obtain a driver's license, fully automated "driverless" vehicles offer the opportunity to become more mobile and independent. Access to transportation means access to jobs, education, and healthcare, which is a major challenge for people with disabilities.

Individuals with disabilities are a unique but sizable demographic. According to the U.S. Census, nearly one in five people in the United States have a disability. They also represent significant pent-up demand for transportation services. As a result, it is anticipated that there will be a notable increase in travel should fully automated vehicles succeed in expanding mobility access. The Policy Institute of AARP (formerly the American Association of Retired Persons) estimates that one-third of U.S. residents do not drive, and recent research suggests that if non-drivers, such as older adults and people with disabilities, were to gain access to automated vehicles, U.S. Vehicle Miles Traveled (VMT) could increase up to 14 percent (Harper). To put this in perspective, U.S. VMT growth usually hovers around one percent annually.

Automated vehicles not only improve access for people with permanent disabilities, such as people who are blind/low vision or mobility impaired, but also for those who face temporary disability. Nearly everyone experiences disability at one time or another, often the result of injury, sickness, or aging. Furthermore, access to transportation may also help older adults remain in their homes to age in place, and independence in mobility not only often improves the lives of those who achieve it but also reduces associated burdens and stress on care-giving family members.

There is plenty of assistive technology that can be integrated into automated vehicles, but standards, architectures, and practices must evolve to help industry address accessibility and some of the unique problems that removing the driver from the car present. The immediate issue for driverless vehicles is how to manage emergencies and other contingencies. Interfaces that enable exchange of information in an unambiguous manner between a highly-automated vehicle and passengers are critical. Passenger-vehicle interfaces must account for the needs and limitations of those with communicative and physical disabilities to be accessible and safe for everyone.

Removing the driver also implies new processes for automating passenger support. Whether in cars, taxis, or buses, often it is the driver who supports riders with disabilities in troubleshooting issues associated with ingress/egress, seating, and securement. For future driverless vehicles to be accessible, automation of operations should not just apply to the driving task, but also to how the vehicle is dispatched, how it parks or docks, how it manages passengers entering and exiting, and how it secures passengers in seating. In a driverless future, that role may need to be filled by a combination of assistive technologies and possibly abled-bodied fellow passengers who are sufficiently educated and willing to assist and troubleshoot when necessary.

A "fully accessible" and "fully automated" vehicle must address challenges beyond the purview of the vehicle, extending into transportation infrastructure. For instance, for individuals with disabilities to –

in practice – independently utilize an autonomous vehicle, problems associated with door-to-door wayfinding, signage, and street-side pick-up/drop-off must also be dealt with. For those who face physical barriers, such as those with mobility or vision impairments, wayfinding around obstacles in the built environment to rendezvous with vehicles or to arrive to at transit/taxi stops will still be a challenge. Mobile device based assistive applications that tag (or otherwise identify and report on) obstacles in built environments can be valuable tools to help mitigate this challenge. Automated vehicles may also need street-level data in order to successfully locate, navigate, and park at accessible pickup and drop-off points along sidewalk corridors.

The Americans with Disabilities Act (ADA) of 1990, along with state and local provisions, drive accessibility requirements in transportation, with ADA applying to both public and private ground transportation offered to the general public. There are nearly 325 million vehicles in the United States, roughly a $1.5 trillion asset (Bureau of Transportation Statistics). Most of these mobile assets are parked 90 percent of the time, and therefore idle. Assuming automated vehicles can push the per mile cost of vehicle ownership below a certain threshold, they may slowly shift personal mobility from individual car ownership to shared-use/ownership mobility, also referred to as "mobility on demand." The attendant implication is that accessibility, which for the most part has been addressed in public transportation since passage of the ADA, will likely be re-examined in the context of for-hire, demand responsive, micro-transit, and other newer categories of mobility, especially as they compete with or complement traditional fixed-route public transit.

However, ADA was never envisioned to address specific requirements; it has been up to researchers, standards bodies, and industry to fill in the blanks. To encourage manufacturers to produce accessible designs for automated vehicle systems, a continued dialogue needs to occur between ecosystem leaders in fields such as transportation, healthcare, and consumer electronics. Interfaces between mobile devices (and mobile device peripherals, such as refreshable Braille, hearing aids, and other assistive technologies), vehicle controls, and mobility aids (e.g. wheelchairs etc.) will need to be envisioned, standardized and deployed. Such collaboration is necessary to ensure there are no gaps in mobility from door-to-car-to-door.

This report summarizes current challenges that people with disabilities face and speculates as to which requirements might be necessary for a "fully automated" and "fully accessible" vehicle to indeed be accessible. There are still gaps in accessibility and plenty of lessons learned from several decades of experience with ADA in transportation. Therefore, new vehicle designs that incorporate fully automated driving systems, particularly those supporting demand-responsive passenger service (to include shared-use ride-hailing, micro-transit, and para-transit services), represent a unique opportunity to reexamine the needs of people with disabilities.

There is significant market growth potential for accessible vehicle systems – both personally-owned vehicles and ridesharing. According to a 2019 study, there are up to 15.4 million vehicle-owning households estimated to be travel limited and 6.3 million wheelchair users. The same study estimates that for transit, more than two million accessible vehicles would be needed for ridesharing fleets (Analysis Group). It concluded that because of the magnitude of this demand, there is likely an opportunity to lower the cost of these vehicles through direct design and manufacturing, ostensibly by avoiding complicated and expensive retrofitting for accessibility.

Over time, these numbers will scale up with the growth in vehicle automation. Analysts predict that by 2040 there will be 33 million driverless vehicles sold globally (IHS Markit). Given the potential dramatic changes that shared-use mobility portends, this report recommends that a concerted research and standards/architecture development effort, and a focus on universal design strategies for "fully accessible and fully autonomous vehicles," must be undertaken now.

Introduction

Mary Barra, CEO of General Motors, declared in 2017: “I have no doubt that the automotive industry will change more in the next five to 10 years than it has in the last 50” (Kilcarr). The automotive industry heretofore focused less on technology and more on mass production and mass marketing. Automotive technology has evolved over long periods of time, improving incrementally.

As a result, cars, trucks, and buses now are safer, more fuel efficient, and less polluting than they were 20 years ago. Vehicles are designed to be crashworthy, able to protect occupants from the force of a collision, but the development of vehicle crash-avoidance technology and driving automation has been relatively dramatic and discontinuous. The National Highway Traffic Safety Administration (NHTSA) estimated in 2015 that 94 percent of crashes are the result of driver error (NHTSA). New crash avoidance and driving automation technologies show promise to dramatically lower traffic fatalities and injuries.

Fully automated vehicles, vehicles that require no (or very limited) human input to operate safely, are still years away. Industry differs on estimates but suggests sometime in the 2020s. Current test vehicles still require licensed drivers as a fallback, similar to the use of autopilot and flight management systems in aircrafts. When the technology matures to the degree where “driverless” vehicles can be supported in wide varieties of contexts -- from rural highways to crowded and chaotic city streets, then the burden of safety will shift from the individual driver to the vehicle designer, manufacturer, and operator.

Automated vehicles have the potential to transform personal mobility for everyone. Whether persons with disabilities can benefit from this transformation depends on how early and to what extent the vehicle manufacturers take accessibility into consideration in the design process of their vehicles (“Fully Accessible and Automated Vehicles Charrette”).

Almost a fifth of the population have a mobility, sensory, cognitive, or other impairment (“Data Analysis”). Expectations among members of this community are that automated technology will remove stubborn and persistent barriers to mobility. Individuals with disabilities already face numerous personal challenges regarding access to health care, education, and employment (“Disability and Socioeconomic Status”). Relatively limited access to *accessible* motorized transportation, including suitable alternatives to personally owned vehicles, compounds these challenges (“Fully Accessible and Automated Vehicles Charrette”).

The diversity of needs among people with disabilities also complicates efforts to find solutions. The type and severity of impairment greatly determines which technology solution is right for any given individual. In an industry that focuses on both marketing their products to the broadest audience and meeting the complex requirements of regulators, the auto industry often defers to specialists to develop and introduce accessibility solutions that can be installed (after sale) in the vehicle aftermarket.

Although automakers do engineer some models to ease post-sale modifications to accommodate drivers with disabilities, the costs of such modification can represent a significant barrier to adoption. Some specialty car and bus makers also sell accessible vehicles for the mobility impaired; however, the cost of such vehicles may often still represent a barrier to adoption. Additionally, the design of these vehicles may not meet the needs of individuals with more complex disabilities.

Universal design may address a number of challenges. Universal design refers to technology design that can accommodate the widest range of potential users, including people with disabilities. New design concepts intended to make life easier for people with disabilities, however, can be useful more generally as well. For example, with respect to road infrastructure, sloping edges to sidewalks instead of steep-dropping curbs were intended to accommodate wheelchair users, but they also help people wheeling luggage or baby strollers. Furthermore, a well-designed "multimodal input" application, such as that on a computer or mobile device, can be used by people with a wide variety of impairments. In mobile devices, visually or mobility impaired users may primarily rely on voice modality with some keypad input, while hearing-impaired users may primarily rely on visual modality with some speech input.

Additionally, inclusive design has the potential to benefit everyone. The majority of people, over the course of their lifetime, will directly (personally) or indirectly (via a friend or family member) experience "situational" or "conditional" impairment, especially in later stages of life, as health declines. Accessible and appropriate transportation is critical to allowing the growing population of older adults to age in place, at home.

Several terms have emerged in recent years that describe similar, though somewhat distinct, design concepts. The terms 'accessible' and 'universal design' are approaches that can result in products that are easier for everyone to use, including older adults and people with disabilities. Universal design, embraced by some parts of the tech industry, has not been as vital in automotive, with a few notable exceptions. The tech industry has been more accommodating because platforms, such as those of mobile devices, improve quickly with software iterations. Automakers, on the other hand, rely mostly on specialized hardware, with safety requirements largely limiting design freedom, especially with respect to seating, securement, and occupant protection, and to a lesser extent driver controls and ingress/egress.

This paper addresses how automated vehicles offer the potential to improve accessibility, not just from the perspective of vehicle design, but also considering new models for mobility. Personally-owned vehicles are expensive assets that are largely idle, parked most of the time. Demand-responsive transit, micro-transit, and ride-hailing models may change the economics of more tailored transportation services, potentially lowering costs and improving service quality. As personal mobility models may change, a research, architecture and standards development effort must be spearheaded by industry to address how accessibility can be designed and incorporated into future highly automated vehicles.

The Necessity of Stakeholder Engagement and Dialogue

People with disabilities who are unable to drive, along with other similarly situated groups, represent a large pent-up demand for transportation services. AARP's Policy Institute estimates that one-third of U.S. residents do not drive, which include people with disabilities and more than one in five individuals over 65, but also children, people with incomes too low to afford a vehicle, and others (Lynott). According to a Carnegie Mellon study published in 2016, if nondrivers, seniors, and people with medical conditions could access automated vehicles, VMT could increase 14 percent. That would add approximately 295 billion miles of driving in the United States annually (Harper).

In November 2016, ITS America conducted a charrette in Washington, D.C. on the topic of "The Future of Autonomous Vehicles and the Disability Community." Representatives of disability communities identified and shared prevalent transportation challenges and accessibility concerns related to automated vehicles. The charrette was followed by a series of interviews that provided in-depth discussions on specific accessibility considerations for automated vehicles. The broad categories of participants represented in the charrette include:

- **Those with Permanent Communicative Disabilities:** Persons with communicative disabilities, including those with difficulties seeing, hearing, and speaking, stressed the importance of sound human-machine interaction to allow for a crisp and clear exchange of information between the vehicle and passenger.
- **Those with Permanent Physical Disabilities:** Persons with physical disabilities, including those using mobility-aid devices, highlighted the need for consideration regarding the physical design of vehicles, specifically the need to design a vehicle that allows a mobility-impaired individual to independently ingress/egress and use restraint systems for occupants and mobility-aid devices.
- **The "Conditionally Impaired" (the injured, including veterans, older adults, and others)** These individuals may have any physical or communicative disability or a combination of disabilities as the result of injury or aging. Failure to assess accurately people's ability to drive has become a public health concern, as the prevalence of medical conditions that may impair driving increases with age.

Representatives from other organizations representing seniors, veterans, and other individuals who experience disability participated in the charrette as well. The unifying theme is the inability to operate a motor vehicle and the impact that it has on people's lives.

Not included in the charrette, but still very important to consider, are individuals with cognitive disabilities. Cognitive, mental, and emotional difficulties can manifest in the kinds of activity limitations described already in summary. However, it is also useful to look at mental functioning separately. Many individuals are affected by multiple disabilities. For example, deaf-blind individuals may require accommodations beyond a combination of those for blind and deaf people. With respect to human-machine interface, deaf-blind accommodations may include haptic display of information.

Overall, the participants stressed the need to build a vehicle that is intuitive, simple, and user-friendly. Furthermore, the participants raised the importance of the vehicle being able to easily adjust itself to the user's needs. All disability advocacy and research groups interviewed stressed the need for automated vehicle designers to consult with their groups as early and as often as possible to ensure that accessibility needs are properly evaluated, and requirements are integrated into design. Charrette discussion, as well as follow-up interviews of selected participants, are reflected in this paper. (See the Appendix for a list of participants.)

In 2018, Congress last considered legislation to enable the U.S. Department of Transportation to evaluate the safety of automated vehicle systems before they can be widely deployed. In addition, the legislation addresses how states and municipalities may regulate the automated vehicles, with respect to their traditional roles in licensing, registration, safety inspection, and traffic control and enforcement.

There is concern as to how automation will affect job growth as robots replace drivers, and concerns that robots, although designed for safety, may fail in ways that human drivers would not, such as in extremely rare but ethically ambiguous scenarios (e.g., unavoidable crashes where drivers make difficult choices).

These issues are important but are a larger problem in robotics in general. Accessibility, however, is a concrete problem in transportation and legislation being considered by Congress has energized a large community that sees automated vehicles as a unique opportunity to address underserved populations that struggle with transportation access to jobs, healthcare, and education.

Challenges for Accessibility in Road Transportation

In 2010, 56.7 million people in the United States reported having a disability. This represents roughly 18.7 percent of the population, making the disability community the largest "minority" group in the country (Brault). With disability often comes challenges of accessibility – the capability of a device, service, or environment to allow use by all persons, regardless of disability. Transportation is an area of concern with respect to accessibility as, for a large subset of the disability community, many modes of transportation remain either inaccessible, unreliable, or ill-suited ("The Future of Autonomous Vehicles and the Disability Community").

Limited access to accessible transportation often results in fewer opportunities for employment, housing, healthcare, and education, which ultimately hinder an individual's ability to live independently. Six million Americans with disabilities have difficulties accessing transportation, contributing to 1.9 million people with disabilities being homebound (U.S. Census Bureau). Furthermore, individuals with a severe disability are five times more likely to experience persistent unemployment than those without a disability (U.S. Census Bureau).

The population size of Americans who are 65 or older is projected to more than double by 2050 (Ortman). With the large aging population, the number of people impacted by disability is only anticipated to rise, as the probability of disability at age 80 and older is sevenfold that at ages 15 to 24. (Brault). Accessible and appropriate transportation is critical to allowing this growing population group to age in place.

The interdependence between driving and independent living has yet to be fully understood. In North America, the degree to which a person has unfettered mobility is largely determined by his or her access to personal motorized transportation. As a result, persons with disabilities (particularly those that inhibit one's ability to drive) often have less mobility. According to a survey conducted by the Bureau of Transportation Statistics in 2002, the top reason Americans with disabilities cited for being homebound was the inability to afford or use a personal vehicle. More than one third of persons with disabilities report that they are not active drivers – a rate almost triple that of those without disability. This is coupled with the fact that 45 percent of persons with disabilities report not having access to a vehicle (BTS, 2003).

Furthermore, vehicle cost can present a relatively significant burden to individuals with disabilities. The challenge of vehicle affordability can be explained by the fact that many people with disabilities experience more limited opportunities to earn income relative to those without disabilities and are often burdened by significant associated costs, such as medical expenses and the cost of retrofitting vehicles. Additionally, the median family income of workers with disabilities is about half of the median of those without disabilities, for individuals ages 18 to 64 (Van de Water). This can be explained by an individual's potentially limited ability to work, possible constraints in work location and/or schedule, and other factors. An inability to commute to and from work may also be exacerbated by the lack of personal, motorized transportation. As a result of any or all of the above, despite the fact that persons with disabilities travel far less than those without disabilities, transportation costs take up a disproportionately large percent of household budget ("The Future of Autonomous Vehicles and the Disability Community").

The unaffordability of vehicles suitable for use by those with disabilities only partially explains the high numbers of inactive drivers. In many cases, disability hinders an individual's ability to obtain a driver's license, such as in the case of those who are blind or low vision. However, even for those who can drive, the availability of suitable vehicles, such as wheelchair accessible vehicles, may be lacking. Significantly, many attribute driving cessations to age-related reasons.

The lack of personal motorized transportation translates to persons with disabilities being far more dependent on public transportation, third-party modes of transportation, and other individuals able to drive. In general, all three transportation options can be inhibitive in terms of time and reliability. Additionally, providing accessible public transportation is not cheap. Demand-response transit, also known as paratransit, has enormous operating costs: operating at over seven times the cost of a regular bus, per unlinked passenger trip (Goodwill).

In order to meet the needs of individuals with communicative and physical disabilities, it is necessary to understand the challenges people with disabilities face. Below is a summary of some of the needs across the blind/low vision, deaf/hard-of-hearing, and mobility impaired communities:

Blind and Low Vision

In 2010, 8.1 million people in the United States had difficulty seeing, including 2.0 million people considered blind (Brault). In most states, people with vision acuity less than 20/40 are not able to obtain an unrestricted driver's license ("Blindness and Vision Impairment"). As a result, blind and low-vision individuals have been highly dependent on alternative modes to private, motorized transportation, specifically walking and public transportation, even more so than individuals affected by other types of disability.

Due to this reason, the vision-impaired community is anticipated to experience significant mobility transformation through the development and deployment of automated vehicles. The anticipated benefit, however, assumes the utilization of automated vehicles that do not require a driver's license to operate, or require that the user be responsible for any dynamic driving task, potentially even in emergency fallback scenarios.

For people with low vision, state authorities may advise a driver who fails the driver license visual acuity test to seek specialist advice to improve visual acuity. Some states may offer restricted licenses on a case-by-case basis to drivers who, even with correction, cannot achieve the visual acuity standard.

Representatives from the blind and low-vision community expressed the importance of considering the following when designing automated vehicle systems:

- Human-machine interface of the vehicle – specifically, that the interface includes equivalent audio and/or other non-visual methods of communication
- Orientation and wayfinding to and from the vehicle
- Exposure to obstacles (e.g. street furniture) and traffic as a pedestrian

The blind and low-vision community identified orientation and wayfinding as an area of critical concern, as this is a challenge that they foresee being exacerbated as drivers are eventually removed from vehicles. There are existing technologies that assist with orientation and wayfinding, but the majority help users go to and from static points (as opposed to dynamic ones). Furthermore, the blind and low-vision community would greatly benefit from information on obstacles, traffic signs, and oncoming traffic in their wayfinding paths.

Representatives of the blind and low-vision community shared that there is significant anxiety and concern regarding the human-machine interface of automated vehicle systems. Even without the driving task, there are many tasks that require vehicle passengers to use their vision. These tasks range from confirmation of the correct vehicle and en route updates on trip status, to adjustments of in-vehicle temperature and other controls. In terms of screen text, screen readers can easily be applied to "read" computer screens and "speak" the text (Burgstahler). Refreshable braille, which provides line-by-line translation of screen text into braille, may also be used. Additionally, for some low-vision individuals, text enlargement features may be of assistance.

A frequently expressed concern regarded the communication of graphics, particularly maps in navigation systems, which has traditionally been the weakest. To address this, auditory and haptic feedback should be incorporated for communicating graphics. Furthermore, there is concern from the blind and low-vision community regarding emergency situations and failsafe systems. The Federal Automated Vehicles Policy of 2016, as well as the update issued in 2017 by NHTSA (Automated Driving Systems 2.0), encourage development of a safety assessment which highlights the necessity for human-machine interfaces to communicate information in a clear and crisp manner.

If automated vehicle systems are to offer mobility to the vision impaired, manufacturers or operators will need to consider orientation and wayfinding, as well as human-machine interface challenges, for this community to be able to safely and independently complete a door-to-door trip.

Deaf and Hard-of-Hearing

In 2010, about 7.6 million people in the United States (approximately 3.1 percent of the population) experienced a hearing difficulty, including 1.1 million people who had severe difficulty hearing (Brault). The ADA entitles deaf and hard-of-hearing individuals to be able to obtain a driver's license, as well as possess and operate a motor vehicle, in all 50 states (Hamilton). However, many deaf drivers rely on their ability to visually see their passenger when they are engaged in sign language (Hamilton). This, in turn, can increase the risk of driver distraction for those with hearing loss.

Representatives from the deaf and hard-of-hearing community expressed the importance of considering the following when designing automated vehicle systems:

- Human-machine interface of the vehicle – specifically, that the interface includes equivalent visual and/or textual methods of communications
- Designers to take careful consideration of sound events to ensure that crucial information is available by a non-auditory means that is accessible for deaf and hard of hearing users. It is also critical that these alerts be noticeable, so that passengers can respond to them in real-time. (For

instance, visual cues and other displays of auditory information should be able to catch the attention of a user who may not be looking directly at the screen involved.)

- Access to and/or compatibility with assistive hearing devices, such as hearing loops for hard-of-hearing drivers, and other personal communication interfaces such as those offering speech to-text/text-to-speech capability
- Dangers associated with exposure to traffic as a pedestrian

Emphasis for the hard of hearing and deaf community appears to be on the development of multimodal interfaces, which, as the name implies, are designed to support a range of perceptual capabilities.

Mobility Impaired

In 2010, roughly 30.6 million Americans ages 15 years and older (about 12.6 percent of the U.S. population) had limitations associated with ambulatory activities of the lower body. This includes, but is not limited to, individuals who have difficulty walking or climbing stairs and those who require the use of a wheelchair, cane, crutches, or walker. In 2012, there were an estimated 3.6 million U.S. wheelchair users (U.S. Census Bureau).

Representatives from the mobility impaired community expressed the importance of considering the following when designing automated vehicle systems:

- Human-machine interface of the vehicle – specifically, that the interface can accommodate users who experience a range of physical challenges, such as difficulties associated with fine motor control or speech
- Challenges associated with inaccessible routes (e.g. street furniture, streetscape) or obstacles on the way to/from vehicle (including navigating through traffic as a pedestrian)
- Independent and safe ingress and egress methods
- Independent and safe use of occupant protection and mobility aid device restraint systems (e.g. Wheelchair Tiedown and Occupant Restraint Systems)

Emphasis for the mobility impaired community is primarily focused on facilitating and enabling independence of movement and control. Another major concern is the degree to which mobility-impaired users will be able to independently use occupant and mobility aid device restraint systems. Furthermore, physically adjusting oneself (for comfort or safety) inside the vehicle or en route to the vehicle could present challenges, due to any of several physical limitations.

Independent ingress and egress are of particular concern because some injuries occur while entering or exiting the vehicle. Inaccessible streets and sidewalks present another challenge. As a result, individuals with disabilities may need to be selective of where the vehicle is parked in order to accommodate ingress and egress.

Like communicative disabilities, human-machine interface was an area of concern for mobility-impaired individuals, as they may face a wide range of challenges associated with ambulating, fine motor, and speech. Challenges with fine motor control could inhibit use of a touch screen, app, or other control associated with the vehicle. Challenges with speech (should there be a need for voice command or verbal interaction with the vehicle) could also arise, including for persons with speech differences caused by disability.

The cost and complexity of accommodating persons with disability can be significant. The cost of retrofitting (meaning vehicle modification), in general, can be near $60,000. Only certain models of vehicles can accommodate having their floor lowered, for instance, for wheelchair users. Then the vehicle must go to another vendor to be outfitted with equipment for specialized instrumentation or driving controls.

Factory installed mobility solutions do exist, but they are limited in scope and capability. For example, Toyota offers factory installed power rotating lift-up Auto Access Seat in their Sienna model. This seat rotates 90 degrees then extends from the vehicle and lowers to a convenient transfer height, making for easy entry and exit for passengers only without assistive devices such as wheelchairs.

Accommodating assistive devices is also a challenge. For instance, the interface between mobility aids, such as wheelchairs, and the vehicle can be problematic. Mismatches can occur. A wheelchair might only be ordered every five years – it could be that when a specified wheelchair was ordered, it may not have considered mobility restraints and other in-vehicle interfaces. Furthermore, some wheelchairs are more difficult (if not impossible) to accommodate, which can present a fundamental barrier to both usability and occupant protection (Manary).

Certain modifications that improve the accessibility of a vehicle may also create additional difficulties. For example, the weight added to the vehicle in the process of supporting wheelchairs and other assistive systems, such as deployable ramps, puts strain on the transmission, brakes, etc. -- particularly if the gross vehicle weight rating (GVWR) or gross axle weight rating (GAWR) is exceeded (Schoppman). Deployable ramps also vary in their pitch and slope from the vehicle, which impacts whether a wheelchair is compatible and whether the ramp is, in fact, supportive of ingress/egress.

Finally, an aftermarket service provider might have to enable, re-enable, or disable additional features – a process that can, itself, generate problems for the user. For example: in many instances, when the floor of a vehicle is lowered, the sensors that deploy airbags may be made inoperative in the process. (Manary). Particularly, all lowered-floor vehicle conversions must meet FMVSS, meaning all airbags must be functional. Only an aftermarket modifier/mobility equipment dealer is legally permitted to make airbags inoperative, and even then, airbag functionality is not "eliminated" – it is usually controlled by a sensor and on/off switch (Schoppman). Additionally, there have been many problems with interoperability between wheelchairs and retrofitted vehicles. These aftermarket modifications can therefore result in fundamental problems with respect to both usability and occupant protection (Manary).

NHTSA rule "Modifications to Accommodate People with Disabilities" 49 CFR Part 595 Subpart C sets forth exemptions from the "make inoperative" provision to permit, under limited circumstances, vehicle modifications that take the vehicles out of compliance with certain FMVSS when the vehicles are modified to be used by persons with disabilities after the first retail sale of the vehicle for purposes other than resale. Subpart C, "Make Inoperative Exemptions, Vehicle Modifications to Accommodate People with Disabilities," was established to facilitate the safest possible automotive mobility outcomes for drivers and passengers with physical disabilities. It should be noted that aftermarket modifications guided by "Make Inoperative Exemptions" do not necessarily negatively impact occupant safety, but in fact provide options to improve both usability for people with disabilities while addressing safety.

The "make inoperative" exemption was promulgated to facilitate the modification of motor vehicles so that persons with disabilities can drive or ride in them. The provision involves information and disclosure requirements and limits the extent of modifications that may be made. ("Make inoperative" prohibition means a vehicle manufacturer, distributor, dealer, or repair business generally may not knowingly make inoperative any part of a device or element of design installed in or on a motor vehicle in compliance with an applicable federal standard (see 49 U.S.C. 30122))

Only a few vehicles in the marketplace meet all applicable FMVSS from the factory, with no modifications that could jeopardize the vehicle's structure or safety features. The MV-1, often deployed in taxi and paratransit fleets, seats five and is dedicated to transporting all passengers, with or without mobility challenges but recently ended production. Sales of the Mobility Ventures MV-1 increased 35 percent in 2016; these vehicles have been purchased in bulk by New York City and Chicago paratransit providers, as well as taxi or rideshare companies in those cities. BraunAbility, Vantage Mobility International, and REVability generally take existing automotive platforms and outfit them for accessibility.

Architecture, standards, and know-how regarding both mobility aids and vehicle interfaces are important. Standards include the Society of Automotive Engineers (SAE) J2249 (Wheelchair Tiedown and Occupant Restraint Systems, or WTORS for short), RENSA W19 (Wheelchairs Used as Seats in Motor Vehicles), and others. There is a cottage industry that modifies vehicles and mobility aids, between those responsible for modifying the wheelchair to those responsible for modifying the vehicle. Outside of this community, very few people can foresee all the different uses and potential challenges to creating a system that works flawlessly.

Furthermore, according to Dr. Manary of the University of Michigan Transportation Research Institute, when a vehicle is modified to accommodate a mobility device, the occupant protection piece is often left to the very end and given little time or attention. In an interview with us, Dr. Manary stated that, in some cases, "less than 10 minutes" is given to modifying the belt system, and similar safety features (to address factors like dexterity, reach, range of motion, physical frailness, flexibility limitations, etc.) (Manary).

Modifications for accessibility may also conflict with each other. For example, adding hardware to the wheelchair that allows it to dock in a vehicle may create incompatibilities elsewhere. To implement a vehicle docking interface, for instance, wheelchair ground clearance might need to be reduced, which has the unintended consequence of making it more difficult for one to move the wheelchair through a door or other ground thresholds found in buildings, streets, and sidewalks (Manary).

Flexibility in making vehicle modifications is useful, but expensive. Iteration in the modification process is also expensive. Furthermore, particularly for those who buy a new vehicle, getting the modification process right the first time is critical - they may be stuck with that vehicle for a long time and it is costly to go through the process more than once (Manary).

Another challenge with respect to vehicle modification is that assistive technologies are evolving quickly, which makes "accessible systems" in vehicles somewhat of a moving target. For example, wheelchairs are getting larger and heavier, and ramps and door openings in vehicles may not be keeping ups with those trends (Manary).

Lastly, there are can be significant financial challenges associated with mobility impairment. Paying for wheelchairs and other assistive devices is often expensive and complicated. Additionally, public assistance or insurance coverage of mobility devices is sometimes limited to home use – for instance, assistance may not pay for products or services that involve activity away home, which unfortunately often includes transportation. (Manary)

Public and Private Transportation Services and Accessibility

The American with Disabilities Act (ADA) of 1990 is a civil rights law, prohibiting discrimination against individuals with disabilities in all areas of public life and protecting equal access – including equal access to transportation. The ADA applies to public transportation agencies such as transit (fixed route and demand responsive) and intercity passenger services (all modes).

Regulations related to the ADA apply to public transportation. The law, however, was never intended to get into the specifics of how to make transportation functionally accessible and usable. U.S. Code Title 49, part 38, subparts A, B, and G implement ADA in transportation and cover both general requirements for transportation vehicles and specific requirements for buses, vans, and "systems," as well as "over-the-road" (e.g. intercity) bus systems. Subpart H includes specific requirements for driverless Automated Guideway Transit (AGT) vehicles and systems, sometimes called "people movers," operated in airports. Requirements are called out in transit and other transportation projects where federal funding is made available. Accessibility in transit for the most part focuses on removing physical barriers. As a report published by Carnegie Mellon University points out:

> "Assistive technologies in the transit modality for people who use wheelchairs are heavily skewed towards devices designed to mitigate physical barriers. These traditionally fall into grade change barriers, wheelchair parking and securement, and fare management. Some transit environments employ assistive technology in support of non-physical barriers." (Giampapa, 21)

Furthermore, in an ideal transit environment, all grade changes are managed through universal design techniques, ramps, and well-maintained elevators and escalators. In reality, the age of transit stations, variability in fleets (or the rolling stock of cars), and the physical environment at transit stops create instances in which vehicle-mounted lifts and ramps are necessary.

Paratransit is mandated by the ADA. All public transit agencies that provide fixed route service must also provide complementary ADA paratransit service for individuals with disabilities who are unable to use traditional fixed-route service due to their disability and who have been certified as eligible.

NHTSA does support ADA in a few FMVSS. FMVSS 403 and 404, for example, address Platform Lift systems. ADA's role in occupant protection is less pronounced. In general, among those concerned with accessibility, there is more attention paid to usability, putting occupant protection as an important, but secondary problem (Manary). In the Rehabilitation Engineering and Assistive Technology Society of North America (RESNA), there has been a push for both more independent use features and crashworthy wheelchair-anchored lap belts that can interact with a vehicle-anchored shoulder belt to eliminate a lot of the poor belt routing and unwanted physical contact (Manary).

For transit or other passenger vehicles, aftermarket modification is guided by standards regarding locking systems, stabilizing systems, and general design pertaining to how the vehicle connects to the mobility device. One such standard is that the vehicle must be large enough to accommodate a chair and allow people to get in and out viably.

There are, however, automated systems being developed for wheelchair restraints – but they are not totally automatic. Automated securement will still require travelers with disabilities to put on seatbelts. There is likely a need for more technology to be developed before fully automated securement and belting systems are ready for use. Alternatively, or at least in the meantime, passengers riding in the vehicles can perform these functions for others with fewer qualifications (Steinfeld).

The most promising system may be a seat-belt deployment system, or SBDS. SBDS allows drivers seated in wheelchairs to use the vehicle manufacturers' (OEM) lap/shoulder belt restraint in a nearly passive mode (pre-buckled seat belt activated by an accessible button) while eliminating obstacles on the vehicle floor that can interfere with maneuvering a wheelchair into the driver space. It remains to be seen whether this design can be adapted for passengers in other seating positions. (Schneider)

However, it is worth noting that vehicle modification can significantly change the vehicle's weight, in some case adding stress surpassing what the original vehicle was designed to regularly withstand. This may cause the vehicle to wear faster or function less optimally. For example, drivers of wheelchair accessible versions of the New York City "Taxi of Tomorrow," an aftermarket modified Nissan NV200, reported that the weight of the vehicle wore down the tires faster than usual (Fitzsimmons, 2015).

The Special Case of Taxi, Ride-Hailed, and Demand-Responsive Carriers

Demand-responsive transportation is defined as any system that operates without fixed route/fixed schedule service. Examples of demand-responsive services include shuttle, livery, and similar non-fixed systems. Ride-hailing is a term to describe booking rides and paying for car service through a smartphone app with a transportation network company (TNC), such as Uber or Lyft. Microtransit is defined as a privately-operated transit system. Microstransit supplements the operations of public transit agencies along select routes. Microtransit providers include Bridj, Via, Lyft Shuttle, and others.

There are 300,000 taxi drivers and 750,000 Uber drivers in the United States; Lyft has nearly 1.4 million drivers in the United States and Toronto (U.S. Department of Labor and Kerr). If you assume there is roughly one vehicle for every two drivers, which is a critical assumption, a conservative estimate for the total number of these vehicles is one million. By comparison, there are roughly 100,000 public transit vehicles, which includes all demand-responsive vehicles (US Department of Transportation - BTS).

The issue is whether and how ADA rules apply to both ride-hailing and taxi services. In the past, ride-hailing companies have argued they are technology companies that source rides, not transportation firms, and are therefore not subject to ADA rules. Furthermore, ADA contains an exemption for taxi companies on wheelchair-accessibility rules, but some localities will introduce their own requirements for accessibility.

Microtransit operators distinguish themselves from traditional public transit operators by maintaining flexibility in terms of operational decisions (e.g. routes and stops, dispatch, rider interaction), often because they do not have the funding or regulatory constraints that commonly affect public transit operators (except for ADA, which still applies to private demand responsive operators). Transit or microtransit systems may deploy on city streets; low-speed automated shuttles have been introduced more commonly on private roads or campuses.

ADA applies to all public transportation, and as a result more than 99 percent of bus public transportation is accessible as a result of ADA (Hersey). Accessible taxis, however, are not nearly so common. Taxis hailed from the street are not considered public transit or demand responsive. Taxis differ from demand responsive in that they generally carry more people, and passengers may have less control over their journey (and journeys may divert en route for new bookings), which is also not as it is a "shared" conveyance as opposed to an exclusive vehicle for hire.

While public transit is largely accessible as a result of ADA, the ADA has an unusual carve-out that excludes most forms of taxis. Although taxi automobiles are excluded from ADA requirements, "new vans" are not (42 U.S.C. § 12184(a)-(b)). The term "van" is not explicitly defined in the ADA, and the definition has not been addressed yet by the courts. So often if accessibility requirements of taxis are addressed at all, it is not through the ADA. Often local taxi or public utility commissions will impose their own requirements on for-hire vehicles. It is not totally certain whether a new class of vehicles, such as robo-taxis or other ride-hailed automated vehicles that carry multiple passengers, would or would not violate provisions laid out in the ADA. However, a future legal challenge in the courts may resolve this uncertainty (Casey).

Still, ride-hailing firms are making efforts. In some of their service markets, Uber runs uberWAV and uberASSIST to source "accessible rides" from their drivers or existing taxi services. UberWAV allows riders who use wheelchairs or scooters to request a ride in a wheelchair-accessible vehicle (WAV). UberWAV drivers are also certified in safely driving and assisting people with disabilities. UberAssist is similar and is designed to accommodate those who need only assistance but not accessible vehicles, such as blind customers, or those with less complex mobility needs or aids.

For both taxis and other demand-responsive (ride-hailed and paratransit) vehicle fleets, the problem is often numbers of available accessible vehicles. These vehicles are more expensive and harder to maintain, and therefore less common in fleets. There are fewer wheelchair-accessible cars in both sourced and taxi fleets, which increases wait times for those with accessibility needs.

This contrasts with ride hailing for the general public, which was designed to increase convenience and reduce wait times for hails. There is therefore a gap in service quality between those with disabilities who need accessible vehicles and everyone else. (Or alternatively a gap in service quality when it comes to availability of drivers who are qualified to provide access assistance.)

Transit agencies are contracting with shared ride services to provide paratransit services required under the ADA. As a result, ride-hailing services become less like taxi services and more like paratransit. Under these contracts, ride-hailing services must provide accessible vehicles and driver assistance (Steinfeld). Furthermore, some agencies leverage shared-ride services as a "non-ADA" alternative for ADA customers to reduce the ADA paratransit demand and hence to potentially reduce the total cost. (Rodman).

Equal access to service can be a challenge. Equivalent service for individuals with disabilities is required where there is federal funding. This can mean response times, fares, driver qualifications and other elements. Some transit agencies provide accessible vehicles to taxi companies in order to ensure equal access. Both Uber and Lyft, for example, provide accessible service in some cities but not all, and service levels may not be equivalent. Eligibility for drivers is also different with TNCs as with ADA Paratransit, and training for drivers of accessible vehicles probably is not as comprehensive with TNCs. For TNCs, older modified accessible vehicles must have a National Mobility Equipment Dealers Association (NMEDA) label and a vehicle age limit (Rodman).

Unique Design Considerations for Automated Vehicles

SAE International Standard J3016 classifies and defines six levels of driving automation, which span from “no automation” to “full automation.” NHTSA’s Federal Automated Vehicles Policy (FAVP) (2016) and ADS 2.0 Guidance (2017) adopted SAE Levels of Automation, explained further in SAEJ2016, define vehicle automation features. L*evel 1 and 2 automation includes “driver assistance” and “partial driving automation” features such as lane centering, emergency brake assist and adaptive cruise control (ACC) and require that the human driver constantly monitor the driving environment, intervening as necessary to maintain safe operation of the vehicle (SAE J3016). Level 3-5 are referred to by SAE J3016 as Automated Driving Systems (ADS)-equipped vehicles and can monitor the driving environment in certain situations, relieving the human driver from doing so. Level 3 features require a human to perform the fallback of the dynamic driving task, while Level 4-5 features rely on the ADS in such circumstances. Level 4 features are limited to certain Operational Design Domains (ODDs), such as geo-fenced areas or time of day usage, while Level 5 features have no ODD restrictions*.

In contrast, fully automated vehicles have a single automated vehicle system that performs under all conditions (“Federal Automated Vehicles Policy”).

- SAE Level 0 *No Automation:* Zero autonomy; the driver performs all driving tasks.
- SAE Level 1 *Driver Assistance:* Vehicle is controlled by the driver, but some driving assist features may be included in the vehicle design.
- SAE Level 2 *Partial Automation:* Vehicle has combined automated functions, like acceleration and steering, but the driver must remain engaged with the driving task and monitor the environment at all times.
- SAE Level 3 *Conditional Automation:* Driver is a necessity but is not required to monitor the environment. The driver must be ready to take control of the vehicle at all times, with notice.
- SAE Level 4: *High Automation*: The vehicle is capable of performing all driving functions under certain conditions. The driver may have the option to control the vehicle.
- SAE Level 5: *Full Automation:* The vehicle is capable of performing all driving functions under all conditions. The driver may have the option to control the vehicle.

SAE Levels 4 and 5 automated vehicles do not require the human operator to execute the fallback performance of the dynamic driving task. Only when this requirement is eliminated does the ability to drive become irrelevant to independent use of vehicles. Thus, this paper focuses on automated vehicle systems in ranges of Levels 4 and 5, or what is also informally understood as “highly automated” vehicles.

Critically, the FAVP describes need for emergency procedures, which would likely need to be tailored to address the needs of people with disabilities. Specifically, it states that “Manufacturers and other entities should have a documented process for transitioning to a minimal risk condition when a problem is encountered. Highly Automated Vehicles operating on the road should be capable of detecting that their Highly Automated Vehicle systems have malfunctioned, are operating in a degraded state, or are operating outside of their Operational Design Domain (ODD). A Highly Automated Vehicle must be capable of informing the human driver or passenger in a way that enables them either to regain proper control of the vehicle or allows the Highly Automated Vehicle system to return to a minimal risk condition independently and automatically." Again, how users with disabilities could interact with systems in the case of emergency is a topic that has not been fully explored by the researchers and automotive designers.

Interfaces that enable human-machine interaction to allow exchange of information in an unambiguous manner between a highly automated vehicle and passenger have not been fully considered in SAE's taxonomy. SAE international, however, has begun the process of exploring requirements and technology within the SAE On-Road Automated Driving (ORAD) Committee.

Not addressed significantly in the Federal Automated Vehicle Policy are problems related to assistance with ingress, egress and securement. In transit systems, often drivers are responsible for securing wheelchair users. If the driver is removed in automated systems, there is likely no one who can secure the wheelchair in vehicle or troubleshoot ingress/egress or any problems that may develop en route. Furthermore, certain types of paratransit often may require a driver to shepherd and escort the rider beyond the vehicle, extending potentially door-to-door (Steinfeld).

Disability can be viewed as a socially constructed phenomenon that results from barriers that are present in the environment (Cook & Polgar, 2015). This view locates disability within the automated vehicle system, and its inability to accommodate, rather than within the person who is able or unable to perform certain tasks.

With this in mind, an "accessible automated vehicle" can be defined as one that enables persons with disabilities to independently (i) get in and out of the vehicle (ingress/egress); (ii) use occupant and mobility aid restraint systems; and (iii) communicate with and operate the vehicle. Designing an automated vehicle that physically supports tasks (i) and (ii) is anticipated to be a major challenge. The need to make the human-machine interface (HMI) component of automated vehicles accessible, as stated in NHTSA's FAVP, is anticipated to be a relatively uncomplicated effort as it does not require a new technology.

Accessible Human Machine Interfaces for Automated Vehicles

Accessible interfaces both inside and outside the vehicle need further development. There may be new opportunities for assistive devices to be integrated into vehicles through mobile devices and peripherals. However, mobile devices themselves must become more accessible and better able to address wayfinding and other challenges beyond the interior of the vehicle.

Within the vehicle, a great deal of good work has been done in the last several years on the development of pairing platforms, such as Apple's CarPlay, Google's Android Auto, and the Car Connectivity Consortium's MirrorLink. Besides pairing, apps have been developed to support remote control of vehicles, such as OnStar Remote Link (General Motors), Uconnect (Fiat Chrysler) and other apps, which allow mobile devices to unlock car doors, start or stop the engine, and control interior climate and lighting.

The practice of "pairing" mobile devices to vehicles is becoming more common in newer vehicles. Pairing mobile devices integrates services from the phone into the vehicle, such as multimedia infotainment, hands-free calling, navigation/weather/traffic and other services. Pairing, in particular, may reduce temptation of drivers to handle their phones while driving, which increases the risk of driver distraction that may result in crashes.

Mobile device pairing and remote link may also provide a platform for future integration of assistive technologies that support people with disabilities. As mentioned earlier, vehicle head unit integration of hearing aids using Bluetooth is one potential improvement. Other integrations could be input/output devices such as Braille readers or keyboards for passengers. There is a particularly big push for Voice Command Systems in cars to reduce driver distraction risks using Google Voice or Apple Siri, and such command interfaces would benefit drivers or passengers with sensory or mobility limitations.

Outside of the vehicle, there are more challenges to providing accessibility through wayfinding. The tech industry has been especially active in expanding accessibility, especially in mobile device interfaces. Ride hailing would likely never have been as successful without the development of mobile computing platforms such as iPhone iOS and Android. Even with ride-hailing services, one of the critical problems are related to wayfinding – navigating to precise pickup points.

For the blind and those who are mobility impaired, wayfinding around obstacles to pick up zones, parking spots, transit stops, and other accessible vehicle ingress/egress points is absolutely critical. New tools and devices are becoming more available to those with disabilities, particularly for blind and low-vision users. Wayfinding might be supported further through relatively mature technologies that support virtual reality and location services. The National Federation of the Blind's Nearby Explorer "Geobeam" and compass features now enable the user to point toward any feature in the environment and receive feedback (e.g. points of interest), including turn-by-turn walking navigation.

The next generation of wayfinding might be supported by artificial intelligence, such as Google Lens, which acts as a visual search engine that allows the user to point a mobile device camera to query objects in the built environment. There are also new proximity services technologies. New Infrared, wireless or vision-based sensors in mobile devices allow an individual to point sensor at a sign or other tagged object to interrogate it. Sensors then read information about the sign and provide orientation (e.g. "talking signage" or GPS coordinates) using barcodes. Low Power Bluetooth Beaconing may also provide wayfinding and signage. Apple iBeacon allows OS apps the ability to determine their proximity to iBeacon-enabled hardware using Bluetooth Low Energy proximity sensing. Apps support wayfinding and major map-makers such as HERE are developing maps of indoor venues. There is also high-power Vehicle-to-Everything (V2X) Communications: Honda, in cooperation with a consortium of other automakers developing cooperative crash avoidance systems, developed Intelligent Transportation Services (ITS) /Dedicated Short Range Communications (DSRC) Vehicle-to-Pedestrian (V2P) communications that support pedestrian safety apps by providing proximity alerts between cars and users with mobile devices.

Overall, mobile devices and vehicle head units may be hubs for assistive technology integration. Both major mobile device platforms, iOS and Android, have application programming interfaces for accessible features that can be used by third-party application developers. For example, VoiceOver in iOS supports the visually impaired by providing a screen reading interface. Uber's app leverages screen reading interfaces and has wireless Braille display compatibility to enable riders who are blind to use the app. iOS accessibility also includes software telephone teletype (TTY) and interfaces for Bluetooth hearing aids. For people with limited manual dexterity or without hands, for whom touch screens may be inaccessible, a "switch control" can allow sequence navigation using alternative Bluetooth enabled input accessories.

Future multi-modal input technologies may reduce barriers to accessibility. Efforts to integrate a hands-free (voice command/auditory) overlay will allow access to apps that would otherwise require visual-manual interactions. Such tools can help tell users how to use a system, where to locate features, how to orient oneself, etc. (Crawford). Gesture-based interfaces also may be emergent using "front-facing" cameras of devices. Gestures would allow some people with disabilities to interface with systems and select or reject options. As the number of different human-machine input interfaces grows—first keyboard, then mouse, touchpad, touchscreen, voice command and finally gesture—the utility and accessibility of these devices will most likely grow. Wearable devices, such as watches or health sensors, may deepen innovation in this domain.

For mobile devices now, however, some challenges remain. There is no requirement for third-party apps to be accessible, though Apple has encouraged accessibility in the development of standard interfaces, and leading transportation app services, such as Uber and Lyft, have leveraged the embedded accessibility features or introduced some of their own.

Automated vehicles may also need street level geodata to know where accessible pickup and drop-off points can be found (e.g. curb cuts), and this data may be integrated with such apps that dispatch vehicles (ride hailing) or provide wayfinding. There is abundant experience and innovation coming from the tech industry on human-machine interfaces that can inform highly automated vehicle design. Furthermore, as mobile devices are already important in wayfinding for people with disabilities, it is not unrealistic to think that devices themselves may provide a direct passenger interface to vehicles, as they do now to manage payments or even provide rudimentary control of doors or other ancillary systems.

Potential Evolution of Automated Vehicle Systems

There appears to be great industry interest and investment in developing highly and fully automated vehicles. The key developers of automated vehicles (including major automakers, tech giants, and startups) are pursuing technology in the hope of creating a significant market for the automated transportation of passengers or freight. For at least the immediate future, key automated vehicle developers will continue their race to be the first manufacturer of fully automated vehicles.

Participation in such a race will likely result in accessibility gaps, especially for the first iterations of the technologies. As a result, as has happened in the past, some persons with disabilities could be at least temporarily excluded from automated vehicle use. To mitigate the extent and duration of these gaps, it will be important for disability advocacy groups to be actively engaged in the development of requirements, standards and architectures of new vehicles early.

Some legislation being considered by Congress calls for creation of an automated vehicle technical committee that would study issues relating to highly automated vehicles and make recommendations to the Secretary of Transportation on standards. These would include, among many other things, crashworthiness for vehicles with unconventional seating positions, physical accessibility, and human-machine interface accessibility.

If this committee is to be successful, it will have to have identify gaps and establish a research, development and technology agenda and track progress. Furthermore, its charge is far broader than just establishing standards to assure safety and promote public confidence in the technology. Automation must not be applied just to enhance vehicle safety, but must also be applied and integrated across all domains. Automation must be applied to also include the full spectrum of activities beyond the car such as door-to-door planning (and driverless vehicle dispatch), passenger wayfinding to pickup/parking, vehicle ingress, passenger seating, securement and belting, en route troubleshooting, vehicle egress, parking/drop-off and additional wayfinding to destination.

Furthermore, there is still a lot of uncertainty on how automated vehicle technology will evolve and how quickly. There are different approaches to vehicle automation. The SAE International Standard J3016 classifies and defines six levels of driving automation, which span from "no automation" to "full automation" ("Automated Driving"). Even within these automation categories, there are different approaches and an overall great deal of experimentation by a large number and diverse group of companies -- from startups, to tech giants to traditional automobile manufacturers.

Fragmentation in human services transportation also dilutes incentives. According to the Coordinating Council on Access and Mobility (CCAM), specialized transportation services for seniors, persons with disabilities, and the economically disadvantaged are provided through more than 80 federal programs. For local services that are federally funded, this results in fragmented services that are hard to access.

There are some other places where coordination and incentives have been improving, albeit in small ways. For example, there is some movement within the Veterans Administration (VA), which is requiring wheelchairs that the VA purchases meet RESNA standards (Manary). These requirements encourage standardization and may indirectly drive a lot of manufacturers towards compliance.

But market pull also needs to be considered from the perspective of automakers and technology companies. Economics show that automated vehicles will be out of reach to most, at least if contemplated as a personally-owned vehicle. Automated vehicles are anticipated to be one of the most expensive personally-owned light passenger vehicles, especially in the beginning as the technology is still in its infancy from a commercial perspective. According to some, current prototype vehicles would cost $250,000 (LeVine).

Cost would decline over time with economies of scale but would not likely drop in the near future below the current cost of conventional vehicles. For persons with disabilities, any needed aftermarket modifications would result in additional costs. If an automaker is focusing on economies of scale to drive down costs, accessible design may support augmentation of their consumer base to include those who would be excluded in conventional vehicle categories. Accessibility could expand the market for automated vehicles to include individuals who currently cannot obtain an unrestricted license, including those who are blind or low-vision, cognitively impaired, or seniors.

Even though light passenger vehicles are designed upon major platforms and marketed to multiple segments, most automakers target narrower segments and design and enhance further to those segments, integrating marketing and establishing a unique product/service to their target customers. The focus is often on appealing to the owner's desires (for design, power/driving performance, other amenities), a specific utility (cargo/passenger accommodation, etc.), or a combination thereof. A real question is whether a vehicle designed for accessibility can be integrated into this tried and true production and marketing model for personally-owned vehicles.

One unique feature of highly automated vehicles is their appeal not just to drivers/owners, but also to passengers who would judge the utility of these vehicles as much as the drivers. Therefore, a microtransit or other demand-responsive operator would more likely take efforts to design their vehicles and operations to support accessible passenger use more than a light vehicle manufacturer might.

Beyond features, cost is a primary determining factor. Driverless passenger-ferrying fleets of cars, movement away from mobility as a product to one of service, suggest a huge shift in how automobile travel may be perceived -- a way that affects individual decisions related to travel and even where people live and work. According to McKinsey, the consumer break-even point of owning a car versus using shared-use mobility services or transit is about 3,500 miles per year. Currently, however, 90 to 95 percent of U.S. car owners drive more than this per year (McKinsey). Driving cost per mile today is $0.80/mile for a personally-owned vehicle, and $1.50/mile for a shared (hailed) car. By 2030, the costs for an automated system need to be below for an owned car, around $.50/mile (Morgan Stanley).

Opportunities for Universal Design and Accessibility

However, if driverless cars radically reduce the cost per mile of providing the service, then demand responsive passenger carrier fleets may draw in larger numbers from those that are already reasonably served. However, while traveling, passengers may need a comfortable environment that allows them to work, or socialize, but can address other universal needs – safe and comfortable seating, accommodating carry-ons, luggage, car-seats, service animals and small freight. Future automated passenger carriers must accommodate groups of adults, children, caregivers and other individuals traveling together and be inclusive of those with special needs without splitting up or otherwise burdening families and companions (McKinsey). Use-centric design will be important.

Without investment in user-centric design, it is generally understood that the user must adapt to the machine and learn how to use it correctly and responsibly. Auto manufacturing is steeped in an engineering and production culture that can at times sacrifice user needs for other considerations. However, a universal design approach – although rarely applied in the automotive sector – would be a significant step towards the development and commercialization of an automated vehicle that would be accessible to large segments of the population, including people with disabilities.

Universal design is the design of products and environments to be usable by all people, to the greatest extent possible. Universal design principles, first used in the automotive sector in Japan in the 2000s, are still not widely applied. The first examples of a concerted effort to incorporate universal design was Toyota's development of the Raum and Porte models in Japan. Toyota used multiple user scenarios throughout the design process and created "ergo-" and situation suitability indices, as well as a spiral development process that enhances the universal design qualities of its vehicles. The ergo index scores 180 items in six areas based on ergonomics, taking into account differences in build and physical ability.

The experience of Toyota is telling. The Toyota Raum was marketed as a "universal vehicle" that was designed to accommodate for older adults and people with disabilities. (This is similar to the MV-1 in the United States, which is marketed exclusively to people with disabilities and public or private taxi/paratransit operators.) In contrast to the Raum, Toyota's second-generation universal vehicle, the Porte, was promoted as a lifestyle car for everyone. The Toyota Porte was a tall hatchback, featuring a sliding door on the pavement side. Because the vehicle lacked a transmission tunnel, the driver could also get in and out using the sliding door. The front passenger seat was mounted on rails and could both swivel and flip forward to ease access to the rear seats, among other features. The "multi-modal" aspects of the car were its main appeal to consumers. Accessibility was described as just another feature in its design, which included improved access for passengers and cargo ingress, egress, and storage.

Standards for mobility aids are generally driven by the healthcare sector, not by the auto industry, which may explain some (but not all) of the difficulties regarding vehicle/mobility aid interfaces. According to Dr. Manary, for example, there is generally not enough functional anthropometry to guide design of the interior of vehicles or the ingress/egress functions. The lack of quality performance standards for how various pieces of mobility aids and vehicle equipment come together is a likely result. However, even where there are standards, there are challenges. Ideally, standards should be performance-based with iterations of guidelines that include testing. However, lack of iteration has resulted in problems being discovered only after guidelines are published (Manary).

A lot of design freedom is lost to requirements for safety, particularly crashworthiness (crumple zones) and occupant protection (e.g. seating, securement, and airbags). Ultimately, should driving automation and crash prevention systems be deployed to a sufficient scale and effectiveness in the next two or three decades (and should driving become safer overall as a result), vehicle designers and consumers may find themselves more willing to trade larger, heavier, less fuel efficient, but more crashworthy vehicles (e.ge vehicles with structure and weight to absorb the energy of a crash to protect the occupants) for smaller, lighter, more energy-efficient ones.

Some design freedom may be lost due to privacy requirements, but there may be opportunities to both protect the privacy of people with disabilities and provide them with equipment and services they need based upon their unique circumstances. For the disability community, the tabulation of privacy gains and losses differs from that of other communities. How people balance tensions between utility and potential loss of privacy greatly depends on context—for example, how a mobility service might be used and who is using it, among other considerations. According to research, when older adults must choose among privacy, safety, independence, or mobility, they may be most willing to give up privacy protections (Anita Melander-Wikman). Some people with disabilities may wish to make similar tradeoffs. Information collection, use, or disclosure of data, however, may be more revealing for people with disabilities than those without disabilities (Future of Privacy Forum). Proper privacy controls and practice must be considered before deploying any new in-vehicle assistive technology.

Over the very long term, vehicle engineers may also be able to revisit the issues of occupant protection, ingress/egress, securement, and seating that so much complicate usability and accessibility. The auto industry may examine unconventional seating designs such as carriage configurations that would require omni-directional crash testing. Conventional vehicle crash standards evaluate frontal and side directional impact, but anthropomorphic test devices [e.g. crash test dummies] are not designed for omnidirectional use. Carriage seating or other alternative seating and occupant protection arrangements that may benefit people with disabilities may also struggle to achieve certification under current federal standards, which has been identified by NHTSA as a challenge (NHTSA). It is further worth noting, however, that there may be a lot of room for design creativity for ingress/egress and securement in the future. When you take the steering wheel out of a vehicle and make it driverless, for instance, there may be more flexibility from a physical design perspective for these elements (Steinfeld). Long-term efforts by NHTSA to re-interpret or even revise federal motor vehicle safety standards may go a long way in removing barriers to innovation in these domains. USDOT, as part of the update to its Automated Vehicle Policy (AV 3.0), has begun this process working with the Virginia Tech Transportation Institute to look at FMVSS.

The federally funded study entitled *Accessible Transportation Technologies Research Initiative (ATTRI): State of the Practice Scan*, conducted by the Robotics Institute at Carnegie Mellon University and the Federal Highway Administration, describes some of the most promising technologies and identifies critical gaps (Giampapa). A definitive research agenda that describes specific architecture and standardization efforts that are either ongoing or to be developed would be the logical next step. This agenda would need to be broad and include design considerations for automotive technology, information technology, assistive technology, and even building and road design and traffic management standards.

The National Mobility Equipment Dealers Association (NMEDA) identified at least three pathways, or a combination of paths, which automated vehicle could be made more accessible – as a starting point for future design. The first is full integration of accessibility from the factory floor-- that Original Equipment Manufacturers (OEM) "…prioritize accessible design and only manufacture AVs [automated vehicles] that can be accessed and used by all people, including wheelchair and mobility device users." A second path is the other book-end and largely reflects the status quo– "OEM manufacture certified vehicles that are then altered specifically by independent mobility vehicle manufacturers or mobility equipment dealers to accommodate people with disabilities."

As not all universally-designed products will necessarily be user centered, not all user-centric products will be universal. NMEDA, however, suggested an alternative pathway that is perhaps a combination of user-centric and universal design. It suggests automakers "…design and make available OEM-built automated vehicles that can generally accommodate people with disabilities (to a greater extent than vehicles produced today), but these designs will also allow for additional post-OEM vehicle alterations to accommodate specific disabilities or circumstances. (NMEDA)

Some OEMs have focused on the user experience, or UX. UX engineering must systematically recognize and document "exclusions," which are defined as functions excluded for individuals based upon their abilities. Exclusions are defined as a mismatch between human capabilities and vehicle functions, with the burden placed upon the individual – but it should be the responsibility of the design or designer. Exclusions can be permanent or situational/temporary (Lorenz).

Designs for vehicles must also feature flexibility, as they are expensive assets to alter and retrofit. Cars are always the result of physical and digital design, and accessible solutions also often straddle physical and digital domains. Digital solutions are often easily modified through iterative software design and modification within a single generation of hardware. Physical accessibility elements are harder, though not impossible to change through iterative design - but solutions are necessary to easily make changes within a given generation or production line of vehicles. Not every problem can be solved in the first generation of design. Another worthy goal would be to create trackable key performance indicators (KPIs) over multiple generations of vehicles so that accessibility can be measured and success documented over time (Lorenz).

Cautionary Tales in Design for Accessibility and Service

The closest example of the challenges that auto and tech companies may face in the near future might be the "Taxi of Tomorrow" effort that New York City undertook in the 2000's. Despite having made headway in improving passenger usability, safety and accessibility, the effort left some gaps, and was hamstrung by changing technology and market realities before its end in 2018.

The *Design Trust for Public Space* created the *Taxi 07* project, which sought to reimagine the taxi one decade out. This international competition called for a purpose-built vehicle with superior safety and environmental standards, reduced vehicle and lifestyle costs, enhanced ride quality, improved durability, and accessibility. In response, the New York City Taxi & Limousine Commission (TLC) launched the "Taxi of Tomorrow" competition in 2008 to create an iconic new, purpose-built taxi in partnership with a major auto manufacturer. The ambition of the Taxi of Tomorrow program was to replace the discontinued Ford Crown Victoria – a vehicle that constituted nearly 90 percent of the city's taxi fleet at the time, with a new vehicle that was manufactured primarily for use as a taxi, rather than retro-fitted passenger vehicle.

The Taxi of Tomorrow would obviously address safety and accessibility. Up until that time, vehicles used as taxicabs - such as the Crown Victoria - were not designed and manufactured to meet federal safety standards in their taxi configuration. (Particularly, the presence of a partition installed after the vehicle is manufactured and crash-tested creates an increased risk of head and face injuries) (NY Taxi Cab and Limousine Commission). As for design, basics such as Official Taxicab Vehicle (OTV) included sliding doors that were easier to open; Hearing Loops to facilitate communication between the driver and those passengers with compatible hearing aids; and entry and exit steps with grab handles and a completely flat floor.

After receipt of seven proposals from a variety of manufacturers, and a year-long detailed evaluation process, the city selected the NV200 to be the exclusive taxicab vehicle. The NV200 is a light compact cargo/combi van developed by Nissan, classified as a “leisure activity vehicle” or LAV. The NV200 taxicabs would be known as Official Taxicab Vehicle (OTV) or the Accessible Official Taxicab Vehicle (AOTV), which met different standards related to wheelchair aids. Braun partnered with Nissan to provide the NV200 AOTV, which included a rear ramp for wheelchair ingress/egress and integrated restraint system for securing wheelchairs.

Lack of clear performance requirements or indices may have inhibited further incremental improvements and innovation in design but also ran afoul of the law. Rather than incorporating specifications from that the NV200 model into the rules to provide opportunities for other suppliers to meet the requirements, as the TLC had done in the past, the rules specified the required make and model. This overall specification ran afoul of some courts, which claimed the commission overstepped its rulemaking authority. Accessibility was also a problematic issue. AOTV users complained that wheelchair passengers were forced to enter the taxi from the rear, which unintentionally exposed them to traffic.

But for people with disabilities, the problems went further as the overall numbers of accessible taxis may have limited access to timely service. Approximately 600,000 people per day ride in medallion taxicabs regulated by the TLC in New York City. In the 13,000-strong fleet, only 200-300 of New York’s taxis were wheelchair accessible. Instead of facing more legal challenges over ADA requirements, New York committed that half of all taxis would be wheelchair accessible by 2020 - though it is uncertain whether enough vehicles may be retired, or enough new taxis could be produced to meet this deadline (Casey). Today, 2,671 NV200s taxis are on the streets according to the TLC, each costing about $39,000. The wheelchair accessible version of NV200 is $50,000 (Blint-Welsh).

In the summer of 2018, the Taxi and Limousine Commission reversed the Taxi of Tomorrow requirement, expanding the option for drivers beyond the Nissan NV200 to other vehicles -- nearly 30 in all, including a number of more fuel-efficient models. The TLC stated the main purpose of the rule change was to give drivers more choices, but the decision comes at a time when the yellow taxi industry has been challenged with the rise of ride-hailing apps like Uber and Lyft. New York’s city council also froze the number of licenses available to for-hire vehicles for up to one year, effectively capping the number of ride-hail cars on the road, currently around 100,000. (About two-thirds of those vehicles are associated with Uber, though the city’s “for-hire” category also includes Lyft, Gett, Juno, car services, and black car operators.) During the one-year freeze, the city will commission a study on how best to regulate these services, although new permits for wheelchair-accessible for-hire vehicles will still be available. (Blint-Welsh)

Next Steps for the Industry and the Disability Community

Unfortunately, original design related to usability and accessibility has been incremental and secondary as industry works out technical challenges to self-driving systems, safety regulation, manufacturing, and mobility service models. Just as the Taxi of Tomorrow effort represented an improvement over the previous generation of for-hire vehicles, it was also vulnerable to changing technology, shifting mobility models and growing expectations from carriers, drivers and travelers. On the heels of that effort, many of the major automated vehicle platform and service providers are making decisions that may lock them into designs and service models into the coming decade. These decisions will impact accessibility a great deal.

For firms that are moving forward with automation, the next several years will be critical. GM, Toyota, Ford, Uber, Waymo, Aurora and a sizable number of other firms and startups have pushed forward with plans to deploy automated and shared mobility systems in the 2020s. IHS Markit predicts that in 2040, there will be 33 million driverless vehicles sold globally, which will represent 26percent of all vehicles sold that year.

Some incremental steps are being made, as automakers and tech companies are choosing vehicle platforms or their autonomous systems with which mobility equipment dealers and suppliers are familiar. Waymo, for example, ordered 62,000 Chrysler Pacificas in 2018. Waymo says the hybrid Chrysler Pacifica minivan is “the perfect platform for ride-hailing” because it’s safe and has “power-sliding doors and roomy, versatile interiors that can accommodate large groups.” The high-voltage battery can also power the vehicle sensors and computing equipment (Laris). At least one company, Revability, is now manufacturing the first hybrid-electric Chrysler Pacifica wheelchair van, equipped with a rear ramp and four-wheel drive. There are three different conversions available for the side entry Chrysler Pacifica from Braun Ability and VMI (MV Mobility Works). Waymo is also working on development of an accessible mobile app with wayfinding audio cues for visually impaired travelers, braille labels, and visual displays for the deaf and hearing impaired (Waymo Safety Report).

Toyota, besides being on the forefront of universal design for the last decade, also announced a partnership with Uber in 2018 that they have collaborated to market autonomous ride-sharing as a mobility service at scale. The initial "Autono-MaaS" (autonomous-mobility as a service) fleet will be based on Toyota's Sienna Minivan platform, which supports the auto-access seat – the automated seat that lifts mobility impaired passengers into the passenger cabin. For wheelchair users, there are also seven different conversions available for the Toyota Sienna (MV Mobility Works). Toyota also has its own wayfinding technology: its BLAID is a wearable gadget that helps the visually impaired and vision-debilitated explore in indoor spaces. BLAID is worn around the shoulders and is outfitted with cameras that recognize the wearer’s environment and convey data through speakers and vibration engines (Toyota).

No major technology or automotive companies have thought about differentiation related to accessibility, but some have suggested designs to support multiple conveyance or logistics roles. Ford, for example, will design and build its own fleet specifically to carry paying passengers and make deliveries, sometimes at the same time. One executive described it as a mix of minivan, van and truck, “with comfort features of sedans,” he said. The company has yet to unveil its creation, slated for production in 2021 (Laris).

There are niches that might emerge beyond light passenger vehicles that are the domain of the large automakers, such as “Low Speed” or “Neighborhood Electric Vehicles.” A low-speed vehicle (LSV) is a federally approved street-legal vehicle classification that came into existence in 1998 under Federal Motor Vehicle Safety Standard 500 (FMVSS 500). Low-speed vehicles are deployed in low-density built environments such as campuses or gated communities where distances are beyond walkable and travel demand along routes might still be significant. LSVs are exempt from most federal safety standards that apply to motor vehicles and are not required to meet any criteria for vehicle crashworthiness. Many of these systems are designed for individual use, but passenger transit use is often limited to off-public road settings, such as universities, campuses, airports and closed communities where they are separated or have little interaction with conventional vehicle traffic. (TTI)

Low-speed automated shuttles such as Local Motors (Olli), Easymile (EZ10) and Navya (Arma) have heightened profiles, operating as demonstrations or functionally in controlled environments. Local Motors, with its partner IBM, emphasized accessibility in not just equipment but also the service design of their system. For example, Olli’s shuttle includes a retractable wheelchair ramp, software that can process sign language, and displays inside offering simplified information and reminders for people with cognitive disabilities like memory loss (Rubin). Some have thought about designing automation around serving older adults close to their homes, such as Voyage, Optimus Ride, and May, which operate in retirement communities and other geographically confined, managed environments where speed is restricted, but where access (and accessibility) to transportation is a pressing need (Coren).

However, low-speed vehicles are subject to other restrictions, such as weight, that may limit their utility as passenger or freight carriers. For conventional vehicles, both traditional and non-traditional automotive manufacturers have developed prototype platforms and passenger interiors that provide flexibility but must meet equivalent levels of safety. For example, General Motors plans by 2019 to produce self-driving cars that lack traditional controls like steering wheels and pedals. They also seek to provide features that will accommodate hearing and visually impaired individuals “so they can experience our self-driving vehicle services through their mobile app and in-vehicle tablets, and communications with our remote operators.” (GM Safety Report)

Long-range concepts are also being touted. Other radical concepts include Zoox’s symmetrical car that can drive in any direction, with four passengers siting around the edges (e.g. “social or ‘omnidirectional’ seating”) facing each other as if around a dining table (Vance). The Toyota “e-Palette” and concepts such as modular automated systems (interchangeable pods that attach to a rolling skateboard-like chassis, which houses automated driving system and the electric power train) can be traded to support multiple configurations such as freight, conventional passenger, or transit. Toyota plans to run the e-Palette alongside other mobility solutions during the 2020 Olympic and Paralympic Games in Tokyo (Hawkins).

Ultimately, there is an opportunity for industry to develop a usable, accessible design for automated vehicles, ones that capture the public’s imagination, pleases riders, carriers and transportation enthusiasts alike, and most importantly accommodates people with disabilities. It is no easy feat, but a universal and accessible design can be developed to rival the iconic vehicles of yore, such as the New York Marathon Checker A series cab, or the London Black Cab. Establishing design culture and requirements to focus on usability and accessibility are important pursuits in the early days of the technology.

So far, with the possible exception of Local Motors Low Speed Olli, no automated vehicle manufacturer has emphasized a unique, complete, ground-up design to support accessibility in the manner envisioned by the National Mobility Equipment Dealers Association – one that combines universal design but still enables interfaces to address more specific user needs. NMEDA's sentiments reflect their members' experience: "automated vehicle "…usage by people with disabilities must be thoroughly considered during the [Original Equipment Manufacturers] [Automated Vehicle] design state, accommodation of people with disabilities cannot be relegated to an aftermarket afterthought" (NMEDA). The risk is that like the current marketplace for light passenger cars and vans, accessibility for automated vehicles will be niche, costly and relegated to the aftermarket. If accessibility equipment does not benefit from much larger economies of scale in development and production that are implied by a large-scale transition to fleet-based, shared-use mobility, then costs of accessibility are not likely to drop.

A recent report from the Analysis Group suggests that current "travel-limited" population of the U.S. constitutes a large and growing market. (Travel limited is defined as any traveler where disabilities limits travel options) Yet despite this, the report remarks, "no automobile manufacturers currently mass-produce an accessible vehicle" and many transportation-as-a-service ("TaaS") providers do not yet provide widespread availability of accessible vehicles for hire, although this is beginning to change. (Analysis Group)

The report estimates up to 15.4 million vehicle owning households are "travel-limited" and up to 6.3 million are wheelchair users. In reference to just wheelchair conversions, the numbers show double digit growth. Wheelchair users grew 50 percent between 2010 and 2014, with estimates that users could total 12 million. The report also estimates that for transit, more than two million accessible vehicles would be needed for ridesharing fleets (Analysis Group). At two million, the market just for ridesharing alone may be significant for manufacturers, especially given higher-duty cycles and fleet turnover for taxis and ridesharing. To put the demand for two million ridesharing accessible vehicles in perspective, the top five bestselling cars totaled only 1.8 million in the United States in 2018, excluding trucks (Car and Driver).

The implications of the combination of new mobility models and automation technology are dramatic, and the stakes of getting accessibility wrong are high. Uber declared in a blogpost that "transportation can be as reliable as running water," (Uber). In this metaphor, "reliability," however, is only one metric for productivity in water infrastructure – the equally important one being "access."

The *We Will Ride Campaign* has called on the auto manufacturers to address not just reliability but access. Comprised of the National Council on Independent Living, Disability Rights Education and Defense Fund, United Spinal Association, and Paralyzed Veterans of America as founding members, *We Will Ride* declares the time is now: "We have the opportunity now to incorporate accessibility into the design of autonomous vehicles from the very beginning. Self-driving cars have offered us a rare opportunity to completely revolutionize auto design. Let's take advantage of this blank slate and consider accessibility from the very first design phase" (We Will Ride).

Conclusion

Nearly one in five people in the United States have a disability and one-third of U.S. residents do not drive – a demographic impossible for auto and tech industry to ignore from both market and regulatory perspectives. Establishing a comprehensive research and standards roadmap could help the automakers, the medical device and assistive technology sectors, and the consumer electronics industry work together to advance automotive accessibility in general, incorporating lessons from nearly three decades of accessible transportation.

Over-reaching promises and marketing hype present a real risk – such distractions may serve to obviate the necessity for design and production of a future automated vehicle that is both affordable and accessible. Ultimately, achieving accessibility in automated vehicles will take a concerted effort to document the needs and requirements for accessibility and engage industry partners in a collaborative and iterative way. Furthermore, the effort to develop a fully automated vehicle suggests an industry break from past vehicle architectures, designs, and engineering practices. It is therefore important to strike while the iron is hot.

The ultimate aim of creating accessible, autonomous, passenger vehicles is to enable all people, regardless of disability, to travel independently - and for those with disabilities to access mobility without the need for expensive retrofitting or the use of special, separate transportation services. Currently, many people with significant disabilities drive their own vehicles, often with adaptations that may be expensive or difficult to obtain, while others travel as passengers, often because they cannot or are not permitted to drive. Even when traveling as a passenger in a private vehicle or on public transportation, some people with disabilities currently need the help of another person. That person might, for example, help the individual with disabilities enter or leave a vehicle, sit safely within the vehicle, secure any accompanying mobility devices, identify the correct transit stop (in the case of microtransit) for transfers, or find the way to/from the vehicle. A truly accessible automated vehicle would reduce the need for that type of assistance. For a future driverless vehicle to be fully accessible, automation of operation does not apply just to the driving task, but also to how the vehicle is dispatched, how it parks or docks, how it manages passengers entering and exiting, and how it secures passengers in seating.

Standards development organizations appear to want to address specific needs. For assistive technology, the Rehabilitation Engineering and Assistive Technology Society of North America Standards Committee on Wheelchairs and Transportation covers wheelchairs, vehicle seating, and restraints. For vehicle technology, the Society of Automotive Engineers (SAE) has, in the past, developed standards for conventional vehicle driving controls (e.g. steering, etc.) for drivers with disabilities. Specifically, for automated vehicles, SAE has established an Automated Driving System Dedicated Vehicles User Issues for Persons with Disabilities Task Force as a part of its On-Road Automated Driving (ORAD) Committee. Other organizations that may play a role include the International Standards Organization and the U.S. National Academies of Sciences, Engineering, and Medicine's Transportation Research Board.

The ORAD Committee recently began development of the SAE J3131 reference architecture, which describes a shared framework and language for addressing the basic system functions and functional interfaces for an automated driving system. The reference architecture describes the application interfaces that will promote the interoperability of automated driving systems/subsystems from different suppliers, minimizing the integration effort and helping to ensure the extensibility and flexibility of these systems for future applications. In the future, some of these efforts may address accessibility requirements and assistive technology application interfaces.

Yet despite this effort, there are real risks that industry will widen the accessibility gap with new vehicle technology, not close it. Automated vehicles tested to date have relied upon existing conventional vehicle designs and platforms, with automated driving systems retrofitted. History has shown that retrofitting accessibility features onto conventional vehicles is expensive and complicated and can sometimes compromise occupant protection and passenger safety for the sake of usability.

There is a question as to whether even some of the major developers of automated vehicle technology will consider a wholesale redesign of their vehicles to support accessibility, following the example of Toyota in its embrace of universal design over a decade ago in Japan. Ignoring the demographics of disability and aging in the United States, however, would be a tremendous lost opportunity for the auto and tech industries. It would also be a lost opportunity for transit agencies, as standardization of accessible vehicles would likely lower the cost of ADA paratransit services, which might in turn free up scarce resources that could be used improve the quality or expand the quantity of service for all of their constituents.

For relatively little investment in upfront design, automated vehicle manufacturers or service operators have the opportunity to substantially expand the demand for transportation by accommodating people with disabilities, older adults, and others who have otherwise limited access to mobility. Clearing a path for people with disabilities can clear the path for everyone.

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Appendix

Interviews:

- [Mar 30, 2017] Miriam A. Manary, Senior Research Associate, Biosciences Group, University of Michigan Transportation Research Institute (UMTRI)
- [April 6, 2017] Aaron Steinfeld, Associate Research Professor & scientist at the Carnegie Mellon Robotics Institute, Carnegie Mellon University
- [April 6, 2017] Edward Steinfeld, Professor & Director of the Center for Inclusive Design and Environmental Access, University at Buffalo
- [April 13, 2017] Henry Claypool, Policy Director, Community Living Policy Center, University of California, San Francisco (UCSF)
- [April 17, 2017] Carl Ringgold, Technical Assistance Center Program Manager, Rural and Targeted Programs, Federal Transit Administration (FTA)
- [April 17, 2017] Rik Opstelten, Mobility Innovation Program Analyst, United States Department of Transportation
- [April 18, 2017] Charlie Crawford, Executive Director, American Council of the Blind
- [April 19, 2017] John G. Paré, Jr., Executive Director of Advocacy and Policy, National Federation for the Blind
- [May 3, 2017] Mohammed Yousuf, Research Transportation Specialist, Federal Highway Administration
- [May 4, 2017] Zainab Alkebsi, Policy Counsel, National Association of the Deaf (NAD)

Meetings:

Title: "Fully Accessible and Automated Vehicles Charrette"
Date: January 11, 2017
Location: Renaissance Hotel - 999 9th St NW, Washington, DC 20001
Participants with comments that were directly or indirectly included in this paper include:

- Steve Bayless (Intelligent Transportation Society of America)
- Henry Claypool (Community Living Policy Center, University of California, San Francisco)
- Barrie Kirk (Canadian Automated Vehicles Centre of Excellence)
- Lindsay Elin (Uber)
- Jade Nobles (Toyota Motor North America)
- Juliet Rothenberg (Waymo, Google)

- Aaron Steinfeld (Robotics Institute, Carnegie Mellon University)
- John Tschida, (National Institute on Disability, Independent Living, and Rehabilitation Research)
- Mohammed Yousuf (Federal Highway Administration)

Title: "The Future of Autonomous Vehicles and the Disability Community"
Date: November 10, 2016
Hosted by: The National Institute on Disability, Independent Living and Rehabilitation Research (NIDILRR) & ITS America

Recording: an uncut meeting recording can be found here: http://itsa.adobeconnect.com/p2xc7ze1bon

Participants include:

- Carlos Alban (Intelligent Transportation Society of America)
- Zainab Alkebsi (National Association of the Deaf)
- Debra Alvarez (AARP, Inc.)
- Robert Bartolotta (New Editions Consulting, Inc.)
- Steve Bayless (Intelligent Transportation Society of America)
- Kelly Buckland (National Council on Independent Living)
- Hilary Cain (Toyota)
- Annie Chang (Intelligent Transportation Society of America)
- Henry Claypool (Community Living Policy Center, UCSF)
- Al Cook (University of Alberta)
- Charlie Crawford (American Council of the Blind)
- Sara Davidson (Intelligent Transportation Society of America)
- Virginia Dize (National Association of Area Agencies on Aging)
- J. Dobres (Massachusetts Institute of Technology (MIT)
- Lindsay Elin (Uber)
- Malcolm Glenn (Uber)
- Joey Goldman (Nelson\Nygaard)
- Justin Holmes (Zipcar)
- Jill Ingrassia (AAA)

- George Ivanov (Google)
- Michael Justis (University of Jacksonville/TASI)
- T. Kent Keyser (United Spinal Association)
- Barrie Kirk (Canadian Automated Vehicles Centre of Excellence, CAVCOE)
- Chan Lieu (Venable LLP)
- Miriam A. Manary (UMTRI, University of Michigan)
- Ross Meglathery (VetsFirst)
- John Michel (MV Transit)
- John G. Paré, Jr. (National Federation for the Blind)
- Jan Polgar (Western University Canada)
- Mark Richert (American Foundation for the Blind)
- Robert Rudney (New Editions Consulting, Inc.)
- Nicolas Saunier (Montreal Polytechnique University)
- Anna Schneider (Volkswagen North America)
- Lawrence Schneider (University of Michigan)
- Clyde Terry (National Council on Disability)
- Robin Toliver (New Editions Consulting, Inc.)
- Daniel Trigub (lyft)
- John Tschida (National Institute on Disability, Independent Living and Rehabilitation Research, NIDILRR)
- Devon Wardlaw (Lyft Federal)
- Brian Worth (Uber)
- Mohammed Yousuf (USDOT)

About the Intelligent Transportation Society of America

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