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Accessible Personal Transportation for People with Disabilities Using Autonomous Vehicles

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IE 490/BME 495: Grand Challenges in Accessibility
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Title:	**Overview**
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The objective of this paper was to explore the potential of emerging technology of autonomous vehicles in accessible transportation and incorporate these findings a standardized transportation solution that readily accommodates future travelers with disabilities based on careful study on current trends in accessible transportation and interviews and surveys that were conducted as a part of this effort. The suggested solution and design principles associated with it took in account, the popular opinions of people with disabilities as well as various experts in the field of accessible transportation. The presented solution is based on emerging technology that is being actively pursued by the automotive industry and research institutions and seriously being considered through current and pending state legislation as a viable product in the near future. This paper explores the legal, technical and safety obstacles that lay in the path to making this a reality.

The most relevant aspects of our inquiries and proposed solutions have been presented as hypotheses in Section 1, and their validity has been supported by evidence discussed in the following Sections. These hypotheses were mainly tested through literature review, available statistics information, interviews with industry leaders and experts in the field of accessible transportation, and surveying potential end-users with disabilities. Recommendations are also made on how to deal with the anticipated challenges in bringing accessibility to autonomous transportation and ensuring that the future of transportation is accessible to all.

SECTION 1

Title: **Background**

Authors: Levin Ozay

The primary concern is that currently, people with disabilities cannot find adequate personal transportation options for their needs. This paper focusses on the main issues with current transportation systems and the potential solutions that autonomous vehicles (AVs) can present in the area. To this end, the paper discusses a number of different hypotheses reflecting the need for novel transportation options as well as features that would be required in a personal vehicle with independence and accessibility in mind. The four hypotheses are as follows:

1. People with disabilities require fully autonomous on-demand personal transportation.
2. To provide AV access to all, it is best to utilize a personal vehicle model that from the ground-up incorporates accessible design principles.
3. There should be legal recommendations for those traveling in self-driving vehicles.
4. Two-way communication with the AV incorporating accessible user interfaces is critical for optimal strategic decision-making with a vehicle designed to accommodate most passengers with or without disabilities.

The **first** hypothesis was developed on the basis that the transportation needs of people with disabilities are not being met by the options that are currently afforded to them. In order to prove this hypothesis, statistics on current travel characteristics of users with disabilities and interviews with them are needed. This topic is important as it is required to determine how best to improve current transportation options and the sort of reception that AVs will receive amongst the disabled community. This topic is dependent upon a number of variables including the cost of AV travel compared to other common options on the market such as relying solely upon commercial transportation and/or retrofitted accessible personal vehicles. This is explored through the cost analysis of the transportation elements and the feasibility of manufacturing of accessible AVs.

The **second** hypothesis intends to prove that it would be better to require that AVs for personal or commercial transport would be built using universal design standards incorporated from initial concept. The purpose of this section discusses the advantages of AVs designed with accessibility in mind over the current practice of modifying existing models of vehicles to make them accessible. The section also aims to highlight how such a vehicle would be designed and with what features in mind.

The **third** hypothesis aims to assess what legal considerations are in place and how they potentially affect persons with disabilities from having access to autonomous transportation. Additionally, what laws that would need to be enacted to ensure that AVs can become more readily accepted for passengers with disabilities. The section also aims to analyze the potential implications of such laws and the safeguards that would have to be put in place to ensure the safety of passengers in AVs, including persons with mobility or sensory disabilities and those with impairments related to judgement, understanding, or memory. The goal is to ensure that legal restrictions are identified and new laws recommended.

The **fourth** hypothesis discusses the interaction that users can have with the AV and the aspects of universal design that help to provide an efficient, safe, and enjoyable experience for all passengers. Several types of various disabilities are considered and the issues that might be posed with inputting commands and receiving feedback from the AV. Through research and design principles, the hypothesis hopes to prove that there are designs that can accommodate all users and yet appear seamless and intuitive to passengers without disabilities. Thus, is becomes important to consider what such a design might function like and how the common principles of universal design should be applied.

The authors explore these hypotheses in the following four sections; respectively, in order to address key factors ensuring the use of autonomous transportation by people with disabilities.

SECTION 2

Title: **People with disabilities require fully autonomous on-demand personal transportation**

Authors: Levin Ozay

2.1 Current Transportation Situation

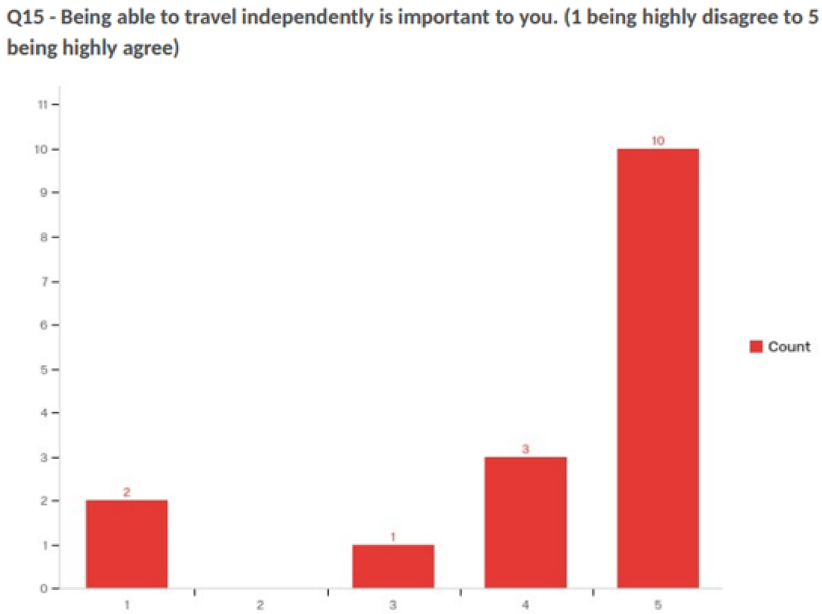
The focus of this section is to discuss the current need that people with disabilities have for an automated and accessible mode of transportation. This prevents a large proportion of the population from being able to reliably work jobs, reach their healthcare providers on time, and pursue their own independent leisure activities. The contention that AVs may ideally situated to fill this gap is supported by data gathered by us through an online survey, personal interviews with experts and individuals with disabilities, and a review of the literature including a report through the Ruderman Family Foundation (Claypool, Bin-Nun, Gerlach; 2017).

In the US, approximately 15 million individuals do not have adequate access to transport with people with disabilities representing 6 million of these. As a result, 3.5 million people in the USA never leave their homes, with more than half of these being individuals with disabilities (BTS, n.d.). Those most likely not to leave their homes are individuals with severe mobility impairments including due to spinal cord injury (SCI), cerebral palsy, multiple sclerosis, and muscular dystrophy; and those with cognitive impairments, such as traumatic brain injury (TBI) and Alzheimer's disease. However, over half a million individuals without severe mobility impairments are still hesitant to leave their homes on account of the difficulty with standard modes of transportation. This has led to increased unemployment for people with disabilities, at 12.9% as opposed to the nationwide average of 8.7%. (BTS, n.d.). Lack of transportation also likely contributes to various other issues, such as failing to make regular medical visits, social stigmatization and alienation, poverty, increased likelihood of homelessness and institutionalization.

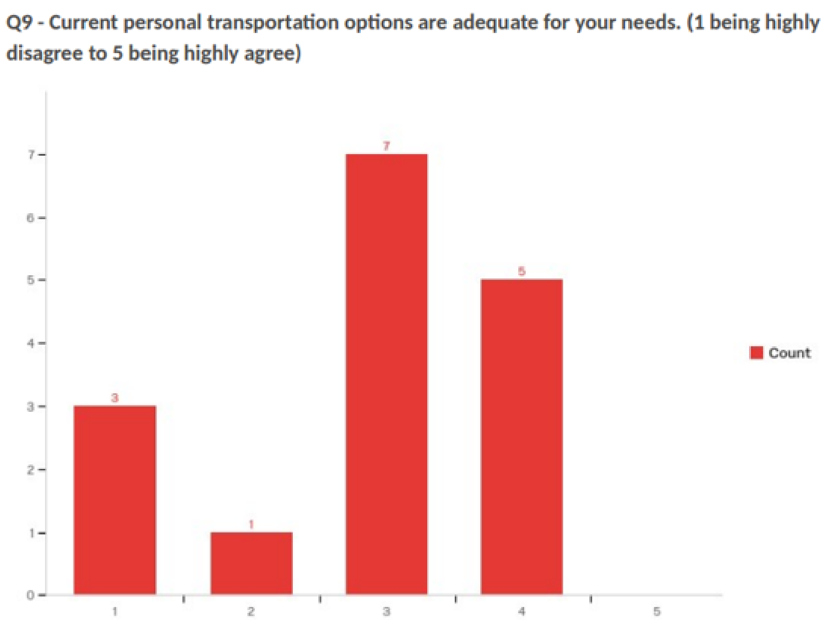
Using personal transportation is one the most critical issue for persons with disabilities. When going to work for instance, only 66% of disabled individuals drive whereas 85% of nondisabled individuals drive. When going to school only 21% of disabled students ride as passengers in personal vehicles compared to 36% of nondisabled students. (L., n.d.). This is primarily due to the difficulty many individuals with disabilities have in entering personal vehicles. More accessible personal vehicles could improve the rate at which people with disabilities use their personal transportation for both work and school. When going to the doctor, the vast majority of people with disabilities use personal transportation as either the driver or passenger whereas only 2-3% will take the bus (BTS., n.d.). Therefore, personal transportation is integral to making health appointments on time. An improved system of personal transportation would help individuals with disabilities to make their appointments more often.

Different disabilities also influence people's ability to use personal transportation. Persons that are blind or visually impaired (BVI) currently have no way to drive themselves around and independently travel. As such, these are some of the users who are most likely to stay at home and reduce their chances of seeking employment and education and accessing healthcare regularly. These were also the users with the most issues with current transportation options as not being able to drive greatly inhibits their freedom of movement. As such, AVs would have the most potential for improving quality of life in this market.

Users with mobility impairments asked for accessibility features that are easier to add to a car. They also preferred the concept of an AV that did not need further modification to the driving mechanism since it would drive the user around automatically.



A.



B.

Figure 1: Survey of responses of persons with disabilities for need for independent personal transportation (A) and adequacy of current personal transportation options (B).

In a survey that we conducted further iterated on the need for additional transportation options for users with disabilities. The majority of respondents agreed that they feel independent travel was incredibly important to them (Fig. 1A). The survey responses also showed that people with disabilities had issues with their personal transportation. None of the respondents answered that they were fully satisfied with their personal vehicle and overall improvements could be made (Fig. 1B). However, are AVs or self-driving cars the ideal solution for providing people with disabilities with improved modes of transportation? Survey respondents clearly showed a willingness to purchase a self-driving cars (Fig. 2). This data also demonstrates the comfort level of users with emergent technology, whereas individual conversations with nondisabled and elderly users of indicated more reluctance in wanting an AV. Thus, persons with disabilities would likely be early adopters of AV due to the great need for independent personal transportation.

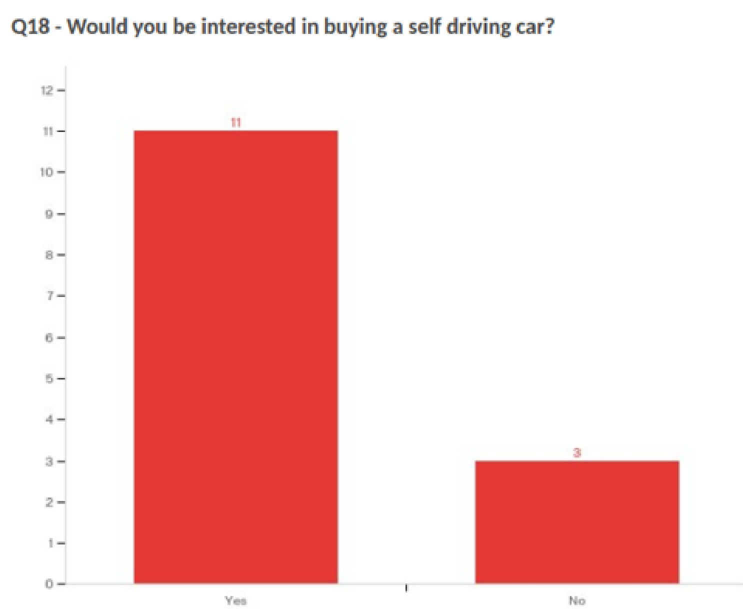


Figure 2: Survey responses on the interest in purchasing a self-driving vehicle.

2.2 Cost Analysis

Current options for accessible personal transportation are becoming more available to persons with disabilities; however, accessible vehicles are much more expensive than what owners without disabilities must pay for a similar vehicle model. Individuals with disabilities typically have to bear additional costs, either by modifying existing vehicles or buying specialty accessible vehicles. A standard van may be cost around $30,000 whereas modifying this van to be accessible for someone with a disability would be expected to cost an additional $10,000 to $50,000 depending on the modification. A high-end modification would include a vehicle with a lowered floor and a ramp or lift for wheelchair users (NHTSA,). Comparatively there are some vehicle options such as the MV-1™, designed specifically with accessibility in mind. The base model of this vehicle costs $40,000 whereas the top model with all possible upgrades costs $50,000 (MV-1.us, 2016). Though the MV-1™ is purpose-built for people with disabilities, especially those using a wheelchair, the relatively small production runs of the MV-1™ and high factory set up and retooling costs makes the cost comparable to a modified van (Fig. 3). The cheapest vehicle accessible to wheelchair users they could find is the Kenguru™, which costs only $25,000 (Mason, L., n.d.). The drawback of this vehicle is that it fits only one driver in a wheelchair and no passengers, thus lacking the same degree of practicality as other accessible vehicles. Modified vehicles have long dominated the accessible vehicle market due to the fact that purpose-built accessible vehicles do not have the volume to push prices down. A personal vehicle manufacturing industry estimate that were given to us by experts is that in order to get the cost An AV designed especially to be accessible would need to cost below $40,000 to satisfy most people. In order to get a vehicle down to these proposed prices, a volume of around 10,000 vehicles would have to be produced and sold in order to bring costs down to an acceptable level.

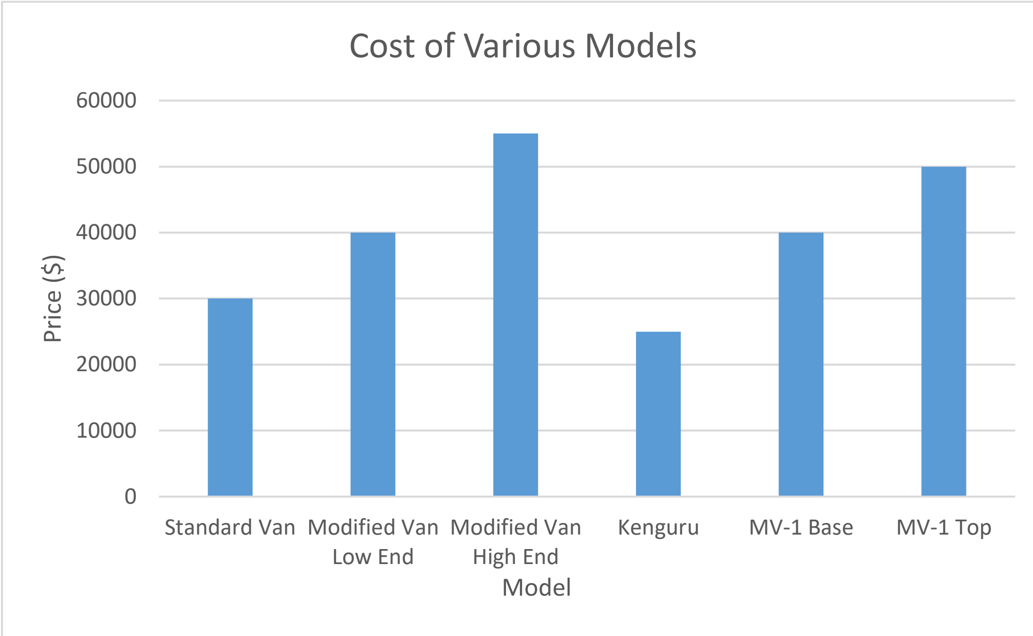


Figure 3: Comparison costs of various currently available accessible vehicles (in $).

SECTION 3

<u>Title:</u> **Technical standards for designing an accessible vehicle for personal use**

<u>Authors:</u> Sashank Allu | Anjali Malik

This section aims to evaluate our hypothesis that universal design principles should be used as a minimum design standard for autonomous vehicles (AVs). This position applies to both vehicles for personal use and public transportation, including taxi or ridership services, and best support the objectives defined in the previous sections. This section incorporates a few design suggestions to better elucidate the direction and philosophy behind our recommendations. One of the previous sections has looked at this from a cost and viability perspective. This section, however, looks at it from technical feasibility and safety perspectives. We also take this opportunity to discuss a few safety concerns pertaining to accessible transportation and how they could be addressed in the proposed AV design concept.

Wheelchair users and riders with mobility issues pose serious challenges that require a lot of accommodations or modifications to current vehicles. In this section, most of our discussion revolves around making a vehicle wheelchair accessible. Disabilities that do not impair mobility chiefly require changes in the way the rider with a disability interacts with the vehicle's control interface. User Interface design is discussed more fully in Section 5.

3.1 Technical Challenges Involved in Vehicle Modification

Wheelchair users often have a choice in types of accessible vehicles for personal use: a sedan that they can transfer from their wheelchair to the car seat or entering into the vehicle while remaining in their wheelchair, such as minivans with lowered floors and ramps or full-size vans with wheelchair lifts. Sedans typically require individuals to have a significant amount of upper limb strength to make the seat transfer, which makes them inaccessible to a lot of wheelchair users. Hence, we do not categorize them as being completely wheelchair-accessible. Today's technology and manufacturing methods allow many more types of personal-use vehicles to be completely wheelchair-accessible, including vans, minivans, pickup trucks, and sport utility vehicles (SUVs), to be modified to make it wheelchair accessible (Fig. 4).

The availability of technology itself is not usually the problem. The challenge lies in packing all the heavy modifications into a vehicle so that passengers are obstructed as little as possible without compromising vehicle performance significantly while keeping costs as low as possible is the challenge. Therefore, this challenge poses a restraint on the types of vehicles that are commercially available that can be efficiently modified to accommodate persons with disabilities. Almost all the modifications on a wheelchair-accessible vehicle are done post-market. This situation creates a low-volume/high-cost economic model to bring to market wheelchair-accessible vehicles, which presses the responsibility of modification to the end-user and often state or federal government agencies to cover their high costs. Figure 5below shows a unique example of a commercially available pre-modified accessible vehicle for personal use, MV-1. It is rare in its kind as it is specifically designed from ground up to be accessible for people with disabilities, and transcends ADA accessibility guidelines.

Figure 5: Mobility Ventures 2016 MV-1 is a fitting example of a commercially available modified accessible vehicle for personal use. It comes in varied models, all with included standard in-floor ramp, spacious flat floor, and power door package.

Typically, a personally-owned wheelchair accessible vehicle has the following modifications:

1. A ramp or a wheelchair lift that allows the rider in a wheelchair to enter the car without transferring.
2. A lowered floor or raised top to provide extra headroom and other modifications to allow for it. Ideally, useable interior height must be 56 inches or more.
3. A wheelchair restraint system to tie down a wheelchair to the vehicle. This includes a tie-down system for the wheelchair as well as safety restraint belts for the person.
4. Seating arrangement to allow for necessary maneuvering space for the rider in a wheelchair.
5. Optionally, some vehicles have specialized controls to allow a driver with disabilities safely operate the vehicle.

3.2 Universal Design Principles for an Ideal Autonomous Vehicle

AV designs that comply with minimal universal or ADA standards would serve the greatest number of users to capture the largest market potential. AVs that happen to be wheelchair accessible without sacrificing convenience to able-bodied passengers and come at a price like any other vehicle in the same class would be the most ideal autonomous vehicle. Having all autonomous vehicles, especially those manufactured for public or private passenger transportation, universally designed to be wheelchair accessible would be equivalent to current standards of designing public buildings or places of business to be accessible. By applying this philosophy to autonomous transportation, ensuring the AVs vehicles are accessible to all segments of society including persons with disabilities would not be revolutionary but practical. It would also ensure that riders with disabilities would be early adopters of autonomous transportation.

A universal design for all AVs would have the potential to become a high-volume production car while requiring no major structural changes while incorporating enough modularity to make post-market modifications cheaper and easier. This is very important because it ties the high revenue from a high-volume production vehicle popular in a large market to a much wider consumer base, including riders with mobility impairments to eliminate the current low-volume post-market conversion of wheelchair accessible vehicles. Additionally, by adopting universal design principles would lead to greater efficiency and usability for all riders as possible to improve the entire process of autonomous transportation, including entry and egress, route planning, and other user interface procedures. Automation and intelligent systems in the car should allow for the rider in a wheelchair to be independent for the entire ride. This is especially important because, if the vehicle is used as a taxi, there would be no driver to assist the rider.

3.3 Recommended Features

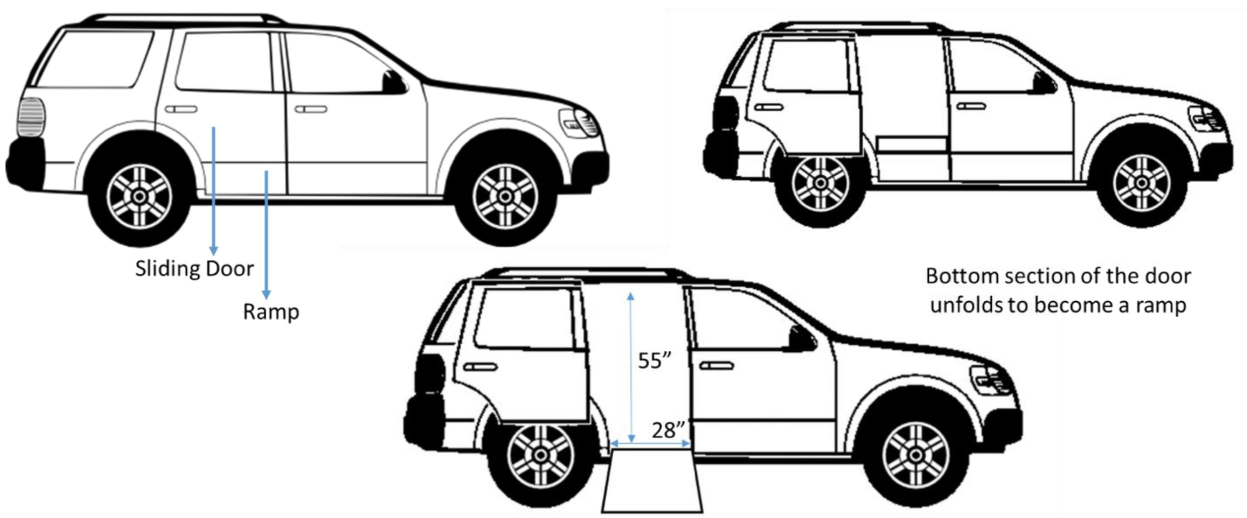


Figure 6: Depiction of a SUV-like vehicle equipped with lowered floor, wide doorway, and ramp. The ramp could be part of the sliding door that unfolds and falls out.

In Figure 6 are recommended structural features that are essential in a universal design for an ideal AV chassis.

- An SUV- or minivan-like chassis with a lowered floor conversion was chosen by its proven ability to go in to high-volume production while providing enough interior floor-to-ceiling height for many wheelchair users.
- A side entry design provides multiple seating configurations for one or more wheelchair users in front or middle seating rows. Rear entry vehicles provide less seating options and limit the wheelchair user to be in the middle or rear seating rows.
- A ramp installed to a lowered floor vehicle provides quick entry/egress for wheelchair users and is easier to manually operate, if broken, than wheelchair lifts.
- Using a fold-out ramp instead of an in-floor ramp keeps the floor low and would be cheaper to retrofit if not standard.

Figure 7 shows schemes for reconfigurable seats that accommodate a wheelchair-using rider by being able to automatically fold existing seats in the front and middle rows. The wheelchair user may be able to stay in their wheelchair or transfer to one of the existing vehicle seats depending on passenger preference. Being able to compact seats does not sacrifice maximum occupancy when there is no wheelchair user. This would be well-suited for a vehicle meant to run as a taxi. The wheelchair user can only be a passenger and not a driver in this case.

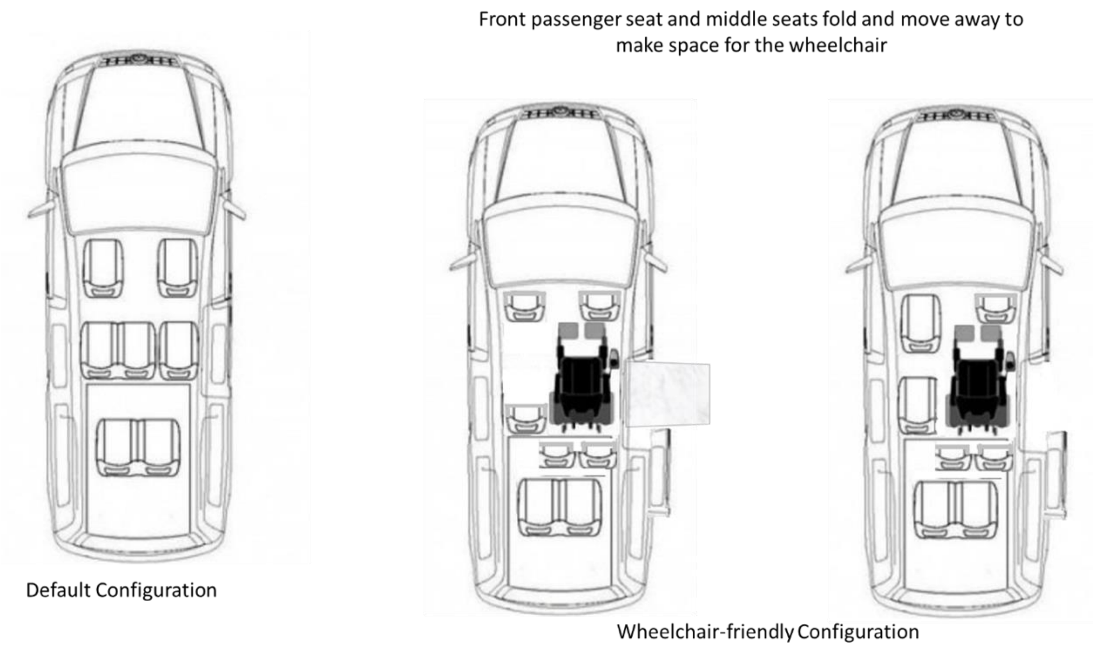


Figure 7: Illustration showing a reconfigurable seating arrangement to accommodate a him wheelchair user in a vehicle designed as a taxi or for ridership services.

Reconfigurable seating is already becoming a popular design option for AV concepts as well as traditional vehicles. Image below shows the interior of a Volkswagen® autonomous car. It is not too difficult to imagine a version of this design that could accommodate a wheelchair (Fig. 8).

Figure 8: A concept design of an interior of an autonomous car by Volkswagen® demonstrating the trend of innovative reconfigurable seating arrangements.

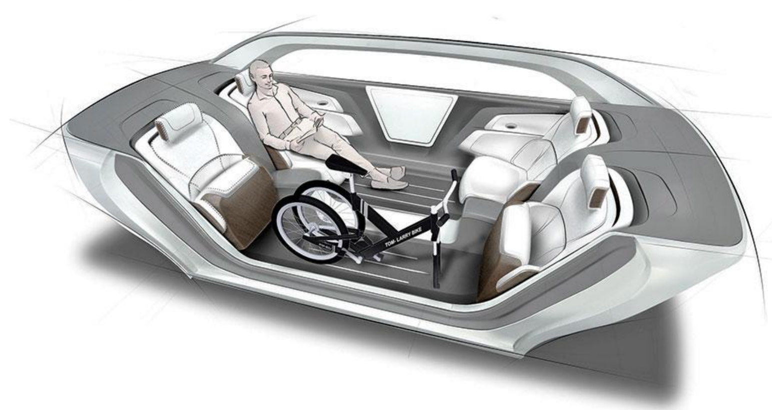


Figure 9 shows schemes for reconfigurable seating that can be folded and/or completely removed if a wheelchair user is expected to be a regular passenger, such as in the use case that the AV is owned by the wheelchair user. The wheelchair user has the option to be in the front or middle rows while sitting in the wheelchair or transferring into a seat. The wheelchair user could also be in the driver seat position.

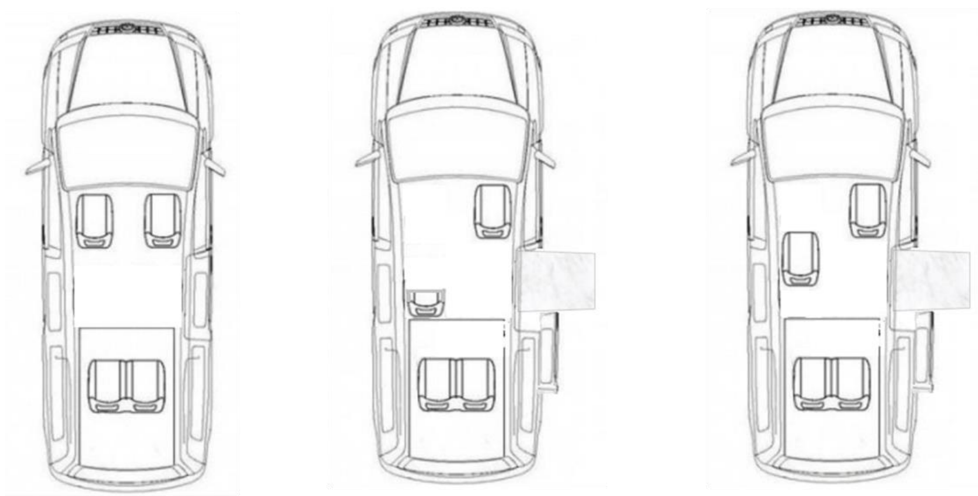


Figure 9: Illustration showing reconfigurable seats to accommodate a wheelchair user as a passenger or a driver for personal use situations.

3.4 Safety Aspects for Travelers with Disabilities

The safe operation of an automobile requires the successful integration of human, vehicle, and environmental factors. A great deal of effort has focused on designing vehicles and roadways to reduce the likelihood of an automobile crash and injury during a crash. People with disabilities can drive safely by making modifications or adding adaptive equipment to their vehicles to meet their specific needs. As assistive technologies improved and become more available, the number of people using adapted vehicles has also increased (NHTSA, 2016). The Rehabilitation Engineering Society of North America (RESNA) Standards Committee on Wheelchairs and Transportation (COWHAT) (RESNA, 2017) and National Highway Traffic

Safety Administration (NHTSA) are some of the organizations that provide guidelines to ensure a safe environment for travelers with disabilities who are drivers as well as passengers. However, accessible transportation comes with its own set of risks on top of the risks an able-bodied traveler faces. Causes of accidents for travelers with disabilities range from malfunctioning or inadequate equipment to health complications due to inaccessibility

To make it easier to get in to the details of different aspects of safety, a crude attempt at classifying the causes of accidents has been made. There might be an overlap of causes or intersection of two classes, but it would help in stressing or highlighting the key causes.

Safety of travelers with disabilities can be discussed under these broad categories.

1. Improper equipment or procedures
2. Sudden Change in the physical condition of a traveler with a disability
3. Emergency due to a traffic incident

3.5 Improper Equipment or Procedures

Mobility Device Users

People using mobility devices constitute a major section of travelers with disabilities. Just over 6.8 million community-resident Americans use assistive devices to help them with mobility. This group comprises of 1.7 million wheelchair or scooter riders and 6.1 million users of other mobility devices, such as canes, crutches, and walkers in order to ambulate (The University of California - Disability Statistics Center, 2013). When people using mobility devices use an accessible vehicle, three different pieces of (often barely compatible) equipment interact with each other – the mobility device, the transfer device and the vehicle (Fig. 10). This serves as a ripe environment for potential failure.

Figure 10: A ramp and lift; respectively, are two of the most common mechanisms used by travelers using wheelchairs to board a vehicle.

Weather conditions like rain or snow could cause the chair to go off one side of the ramp. Undesirable tilt added by the road conditions could result in steeper ramp angles. Hitting the edges of a ramp or the roll-stop of a wheelchair lift could cause the wheelchair to tip or the user to fall off the chair. Unguarded edges are a frequent cause of accidents involving wheelchair lifts. Undulations and bumps are sometimes hard to perceive. They still pose a significant risk Among accidents related to wheelchair lifts alone, the most common ones are of a wheelchair user going off the chair after an impact with the roll-stop or after a steep transition between a vehicle and it's lift platform (Li, Ackerman, & Allu, 2016). Some of these risks also extend to travelers using other mobility devices like scooters and walkers or canes.

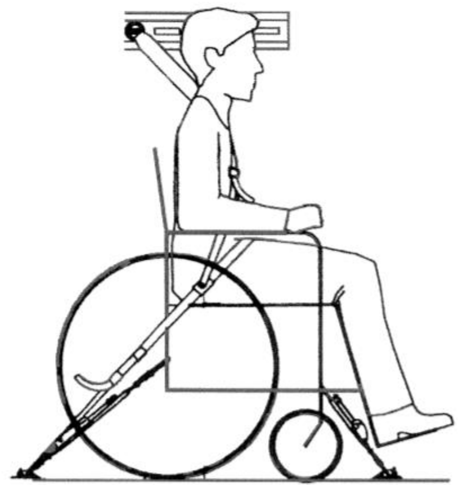


Figure 41: A Typical Wheelchair Restraint System

Figure 11 (Shaw, 2000) shows a typical restraint system used to in buses or cars to hold a wheelchair in place when the vehicle is in motion. There have been reported injuries and even fatalities resulting from improperly or inadequately restrained wheelchairs (Shaw, 2000). Sudden acceleration, deceleration or sharp turns could throw a user off an improperly restrained wheelchair.

In cases of disabled drivers in wheelchairs involved in road accidents, the disabilities or the vehicular modification needed for compensating them are rarely causes for accidents. The disabled drivers, furthermore, do not have an accident or traffic-offence frequency exceeding that of non-disabled drivers (Ysander, 1996).

Vision Impairment and Attention disorders

Vision is inarguably a fundamental component of safe motor vehicle operation. Certain eye conditions and diseases, such as cataract and glaucoma, may elevate crash risk. Test of visual acuity alone (as required by the law) should not be viewed as an effective means of identifying those with vision impairments that elevate crash risk. There is stronger evidence of the critical role of peripheral vision for safe driving. Color vision deficiency by itself is not a threat to good driving performance. Other aspects of visual sensory impairment have high face validity to the driving task (contrast sensitivity, motion perception, eye movements, binocular vision disorders) but have not been sufficiently examined to permit firm conclusions about their roles. Visual attention skills and visual processing speed show great promise as ways to identify high-risk older drivers (Owsley, 1996).

Hearing Impairment and Deafness

The relationship between hearing loss and accidents is not clear. Hearing plays a role in driving, but elderly drivers with hearing impairments were not at added risk of car accidents (Ivers, Mitchell, & Cumming, 1998).

Elderly

Advancing age is often accompanied by a combination of mobility and sensory impairments. Drivers older than 79 years have a higher accident rate when the rate is measured as a function of exposure, have accidents with more severe and more often fatal consequences, and are more often judged as legally responsible for causing an accident than are younger drivers (Ivers, Mitchell, & Cumming, 1998).

Paralysis and Loss of Skin Sensitivity

Pressure ulcers remain a dominant health problem for persons with spinal cord injury (Byrne & Salzberg, 1996). Sitting restrained in the same position without a chance to relieve pressure on the skin increases the risk of a pressure. It also increases the risk of clots in the lower limbs and other complications like deep vein thrombosis. In cases where the traveler needs to transfer in to a seat from a mobility device, a break in the skin during the process might be the start of a pressure ulcer.

3.6 Sudden Change in the physical condition of a disabled traveler

Sudden illness, usually leading to complete or partial loss of consciousness, is a well-recognized cause of accidents, though not a common cause. The following acute medical conditions are most commonly named as causative factors: coronary thrombosis, epilepsy, cerebral or subarachnoid hemorrhage, cerebral tumor resulting in epileptiform fits, hypoglycemia, laryngeal vertigo or sudden nausea, acute psychiatric states, and vasovagal attacks (Grattan & Jeffcoate, 1968). Many of the above conditions have medications to keep them under control.In the case of diabetes, insulin and other medications used to control the disease may increase the risk of traffic accidents, because the frequency and severity of hypoglycemia are increased among patients with insulin-dependent diabetes being treated intensively.

3.7 Emergency due to a traffic incident

In the event of a collision or fire, a disabled passenger or driver is almost always at a higher risk than an able-bodied one. In general, the wheelchair seated occupant is at greater risk of injury than the vehicle seated occupant (Claire et al., 2003). Based on the research described in this report, wheelchair seated passengers as well as travelers with vision and other physical impairments have much lower chances of navigating the exit or evacuating a vehicle during emergencies

SECTION 4

Title: **Legislation on Autonomous Vehicles**
Authors: Michael Lin

This section of the paper focuses on the current legal restrictions in place to prevent independent travel in self-driving vehicles. According to a study by The Boston Consulting Group partially autonomous vehicles (AV) will be on the roads in large numbers in the coming years. The largest growth will come within the next 20 years with about 12 million projected sales for fully AVs on a global scale (Boston Consulting Group, 2017). This new mass adoption of autonomous vehicles will change the way that 46.3 million Americans with disabilities travel (United Census Bureau, 2017). Both state and federal law entities have begun the process of pushing laws out to not only hold the ethical use of AVs but also ensuring that these vehicles are universally accessible to the American demographic.

4.1 Current Laws in the United States

Each year, state and municipal governments have been addressing the potential impacts of AVs on the roads. Ever since Nevada first authorized the operation of AVs in 2011, the number of states considering legislation related to AVs has increased. A total of 41 states have considered legislation related to AVs since 2012 with about 12 states passing legislation allowing for a high level operation of AVs (National Conference of State Legislatures, 2017). Many of these pieces of legislation refer to a level or tier of autonomous driving on a scale of 0 to 5 (Table 1). The usage of this terminology of autonomous driving was adopted by the National Highway Traffic Safety Administration (NHTSA) in 2016 based on the Society of Automotive Engineers (SAE) International's J3016 document (Reese, 2017).

Table 1: Tier Levels of Autonomous Driving from Reese, H. (January 20, 2016). Updated: Autonomous driving levels 0 to 5: Understanding the differences. In TechRepublic.

Tier 0	The driver controls all aspects of the vehicle: steering, brakes, throttle, and power.

Tier 1	This driver-assistance level means that most functions are still controlled by the driver, but a specific function can be done automatically by the car.
Tier 2	The driver is disengaged from physically operating the vehicle by having his or her hands off the steering wheel AND foot off pedal at the same time.
Tier 3	Drivers are able to completely shift "safety-critical functions" to the vehicle, under certain traffic or environmental conditions.
Tier 4	Level 4 vehicles are designed to perform all safety-critical driving functions and monitor roadway conditions for an entire trip.
Tier 5	This refers to a fully-autonomous system that expects the vehicle's performance to equal that of a human driver, in every driving scenario

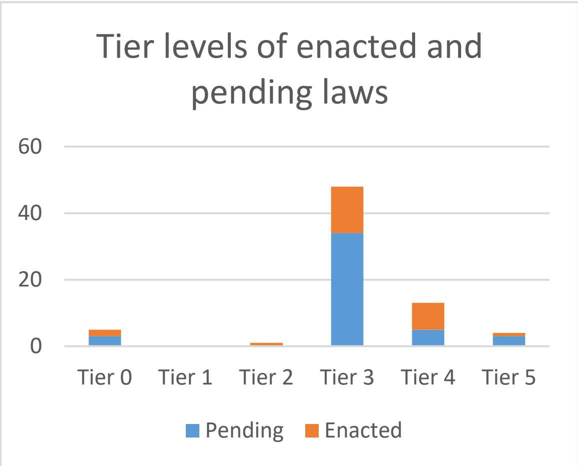


Figure 12: Graphical representation of tier levels of enacted and pending laws.

Many pieces of legislation that is currently in the process of being passed are at the tier 3 level, the level where a driver is able to shift control over to the vehicle and not have to actively monitor the situation on the road (Fig 12). The majority of the Tier 0 and Tier 2 level laws that have been passed are logistical laws that set up a board of members that will in future cases suggest revisions of legislation. Figure 12 shows both the pending and current tier levels of the pieces of legislation that have been considered and passed. Many of the pending laws are level three but in recent year's legislation with tier levels of 4 and 5 have begun to be introduced in states with strong ties to the automotive and technological industries such as: California, Tennessee, Michigan, and Illinois (Michigan Automotive News, 2017). Almost all pieces of legislation that has been adopted or been pushed through with an executive order by the state governor has been in states known to have heavy traffic problems, high levels of research in STEM (science, technological, engineering, mathematics) fields, or invested in the automotive industry (Fig. 13).

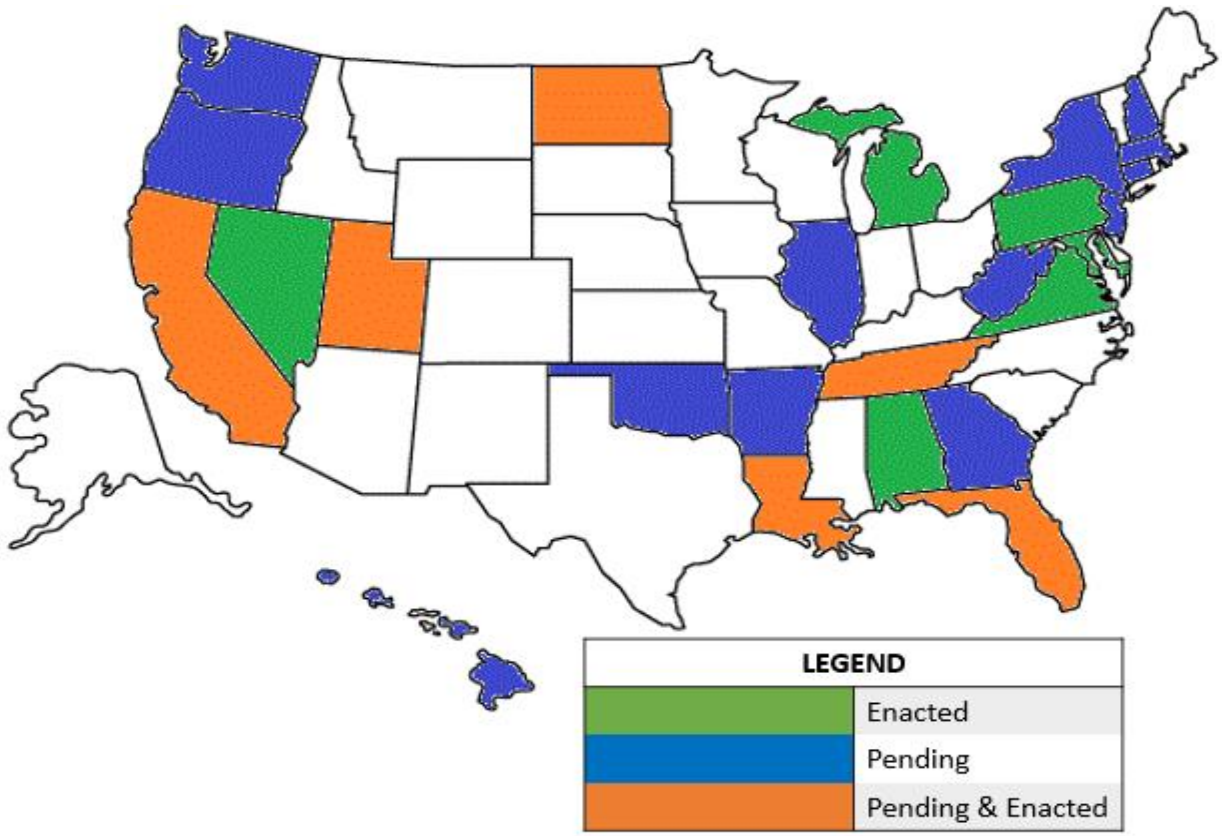


Figure 13: The image shows current states with enacted and pending autonomous vehicle legislation.

Although the current legislation lays a foundation for growth of autonomous vehicles, it still does not capture the required provisions for the disabled population. The Americans with Disability Act (ADA) prohibits discrimination against individuals with disabilities in all areas of public life (jobs, schools, transportation) and all public and private places that serve the general public (ADA National Network, 2017). Although the ADA does require that public transit be accessible to individuals with disability, it does not specifically state anything regarding the autonomous transportation field. It is our recommendation that the current state and federal boards pushing legislation regarding autonomous public and private transit take in consideration of the transportation needs of the 46.3 million individuals with disabilities (United Census Bureau, 2017). By being aware of the basic needs of the disabled community while developing laws and setting a universal standard at a state or federal level, numerous revisions to legislation would be avoided while simultaneously addressing the needs of people with disabilities.

4.2 Ethical Thoughts

As society begins to widely adopt autonomous transportation as a whole there are still several ethical issues that are commonly addressed. Of those the three main ethical questions posed are security, insurance, and programming of the car itself (Stanford law school, 2017). Although pieces of legislation addressing these issues have been passed, these bills only address and solve a part of the problem. The goal of this section is to look at some of the ethical concerns and start a discussion regarding autonomous vehicle transportation particularly related to riders with disabilities.

When looking into the security aspect of AVs there is very little laws outlining how AVs should store and protect the data it collects as it drives. If these vehicles are fully autonomous many are concerned that they would be susceptible to hacking where someone would remotely take over the vehicle. In this scenario there are no protocols outlining how the vehicle should behave (e.g. alert authorities, speed away, remain at the scene, etc.). But giving remote access to a 3rd party could also be seen as a beneficial aspect to this technology. The thought of being able to give control over to someone who can assess the situation and safely guide the vehicle to a safer location can be seen as a large benefit, especially if riders indicate they are having a medical emergency.

Current laws have been proposed to address issues with insurance by stating who would be held accountable in situations when an accident does occur. However, at this point in the industry of AVs not many people are able to predict if the technology will as intended. Whether introducing AVs on the road will lower traffic accidents or cause mega-accidents as cars are networked together and vulnerable to hacking. For now being able to assign responsibility to an entity and hold them accountable is all that is possible until further research is conducted. That being said there are laws that have set up boards in specific states whose primary objective is to interpret the progress in autonomous vehicle technology and revise legislation to appropriately hold parties accountable in certain situations that are brought to the boards' attention.

The largest topic of discussion is the programming of how the vehicle itself should behave in certain situations. Unlike a human, an autonomous vehicle must be programmed to assess situations and make a decision based on a pre-programmed truth. With this in mind, some people have interpreted accidents that result in a death as murder since a programmer had to write an algorithm that results in the death of a person(s). These large scale scenarios should be considered and in some cases are being addressed by state instituted boards that review situations and advises which parties should be held accountable with the full power of the law behind them.

Ultimately, the ethical questions that are posed, for the large part, are able to be addressed by assigning a board of members to follow the progress of autonomous transportation and to revise laws that appropriately upholds the law and order of the state. It seems apparent that in regards to the ethical topic of autonomous transportation the laws regarding this technology will need to be continuously revised in order to properly capture the benefits and mitigate the possible harms that this new technology brings.

SECTION 5

Title: **User Interface Design Principles for Autonomous Vehicles**

Authors: Tarun Prashanth | Ayush Jaiswal

This section focuses on some of the principles that would be needed to design an accessible user interface for personal autonomous vehicles (AVs). This is necessary to allow users of the vehicle to provide and receive information as accurately and clearly as possible in a way tailored to their needs.

5.1 The Need for Universal Design of the User Interface

For AVs to have as large an impact as possible, it is important for manufacturers to incorporate the principles of universal design. The public and private transportation vehicles in the future should be able to address the needs of people with different levels of physical and cognitive abilities. In the past, most public transportation options in the United States did not consider people with disabilities, instead having to make significant changes by retrofitting their vehicles to accommodate people with disabilities in accordance to the American Disabilities Act (Part 37--Transportation Services for Individuals with Disabilities, 2015). To avoid this, it makes sense for manufacturers to factor the needs of as many segments of society as possible when initially designing and producing their vehicles. This would make the potential vehicle, economically viable as it would have a wider market to cater. Previously, it may not have been technologically feasible for companies to do so. Now, with the advancement in self-driving technology, more and more control has started shifting from driver to the in-built system.

5.2 Universal Design and Its Application

One of the ways of accommodating the needs of people with disabilities along with the requirements of regular buyers is to incorporate the principles of Universal Design. The idea is to design a vehicle that accommodates the needs of all of its users, including people with disabilities, as opposed to designing vehicles specifically for a disability. As per the Center for Universal Design at North Carolina State University, universal design is defined as, “The design of products and environments to be usable by all people, to the greatest extent possible, without adaptation or specialized design (The Center for Universal Design, 1997).” There are seven

Principles of Universal Design (Copyright © 1997 NC State University, The Center for Universal Design.):

1. Equitable Use: The design is useful and marketable to people with diverse abilities.

2. Flexibility in Use: The design accommodates a wide range of individual preferences and abilities.

3. Simple and Intuitive Use: Use of the design is easy to understand, regardless of the user's experience, knowledge, language skills, or current concentration level.

4. Perceptible Information: The design communicates necessary information effectively to the user, regardless of ambient conditions or the user's sensory abilities.

5. Tolerance for Error: The design minimizes hazards and the adverse consequences of accidental or unintended actions.

6. Low Physical Effort: The design can be used efficiently and comfortably and with a minimum of fatigue.

7. Size and Space for Approach and Use: Appropriate size and space is provided for approach, reach, manipulation, and use regardless of user's body size, posture, or mobility.

There are many ways to accommodate the needs of people with disabilities with regards to a vehicle's user interface (UI) from the universal design criteria that is presented. Based on the seven Universal Design principles, some examples are described that potentially satisfy each design aspect. In this section, examples of a universally designed UI for AVs are proposed based on the interpretations of the authors of this paper.

The **first** aspect of universal design is equitable use. It states that the design should be useful and marketable to people with diverse abilities. Our suggestion to incorporate this aspect into our interface is to create a touchscreen interface that can change how it interacts based on what people are able to do. For example, for someone who has a mobility or visual impairment who prefers to use the touchscreen based on voice command, the interface will adapt and switch to a voice command system rather than a visual or tactile system. The settings of the screen will adapt as well as the brightness will automatically change based on the drivers' preference. The touchscreen will also contain the option for the car to switch from autonomous mode to non-autonomous mode. While interviewing a diverse range of people, we found that most preferred to have the option of being able to switch between the two modes at any given time. One such design example of this is pressing down on the steering wheel to switch the car into autonomous mode (Brownlee, 2015).

The **second** aspect of universal design is flexibility in use. It defines itself as the capability of accommodating a wide range of individual preferences and abilities. In the context of an AV user interface, flexible use can be the ability to help people with a wide range of disabilities communicate and control the vehicle (Campbell-Dollaghan, 2015). Going back to the point in the previous paragraph, someone with a visual impairment can always switch to a different method of communication such as audio control. The Chevrolet Equinox, is a good example of a vehicle with a voice command system that people can use based on choice in order to communicate with the vehicle (Campbell-Dollaghan, 2015). For people with tactile, mobile, and hearing impairments, there is eye-tracking technology available. This technology makes decisions based on where the user's eyes travel and how they stop or hover over certain objects.

One such company that is working on eye-tracking technology is Tobii (Tobii.com, 2015). For extreme cases where an individual has limited to no control over audio, visual, and tactile actions, one technology that might be useful is gesture recognition technology. Gesture recognition technology is based on the ability to interact with device without needing to make physical contact but without the audio noise problem with speech recognition (Gesturetek about page, 2017). These are all examples of technology that make the user interface flexible. While most of these technologies are not as prominent as the features mentioned in the previous paragraph, and in the cases of the eye-tracking and gesture recognition software, are still in early stages, it is very much possible to build these into an autonomous vehicle.

The **third** aspect of universal design is simple and intuitive use. This is when then the user interface is easy to understand regardless of the user's experience, language, knowledge, or concentration level. Most vehicle user interfaces are already programmed to have a diverse array of languages that can be specified to the users' preference. As for knowledge, one can look at the example of the Toyota Prius where the energy flow can be very detailed, so much so that it is broken down for each component. However, it is not necessary for everyone to know what is going on in that diagram and it can easily be switched to a different screen.

Designing for intuition may lead to innovative 'smart' features in an AV. Artificial intelligence (AI) can be used to anticipate drivers' actions. For example, if a driver's concentration level it is adversely affecting driving performance. AI coupled with a UI that detects facial features, eye gaze, and other driver behaviors could automatically alert or even take control when the driver feels tired or when not in a good condition to drive. This ability could make the driving experience more safe and comfortable. However, such a feature raises several ethical issues including encouraging driving even if the driver is impaired.

The **fourth** aspect is perceptible information which is defined as "The design communicates necessary information effectively to the user, regardless of ambient conditions or the user's sensory abilities." There is some level of overlap with the first principle due to nature of user interface. For a truly universal experience the UI should be able to relay the same information in multiple ways. Illustrated in Table 2 below are the types of physical abilities and means of giving and receiving information to and from the user interface (Pitts, Seipel, Duerstock, n.d).

Table 2: Various types of physical abilities and how it impacts their approach of giving and receiving information through and accessible UI (Pitts, Seipel, Duerstock, n.d).

Type of Impairment	Information Input			Information Output		
	Visual	Verbal	Tactile	Visual	Auditory	Tactile
No disability	Applicable	Applicable	Applicable	Applicable	Applicable	Applicable
Visual	Not Applicable	Applicable	Applicable	Not Applicable	Applicable	Applicable
Hearing	Applicable	Not Applicable	Applicable	Applicable	Not Applicable	Applicable
Speech	Applicable	Not Applicable	Applicable	Applicable	Applicable	Applicable
Upper Extremity Mobility	Applicable	Applicable	Not Applicable	Applicable	Applicable	Not Applicable
Visual and Hearing	Not Applicable	Not Applicable	Applicable	Not Applicable	Not Applicable	Applicable
Visual and Speech	Not Applicable	Not Applicable	Applicable	Not Applicable	Applicable	Applicable
Visual and Upper Extremity Mobility	Not Applicable	Applicable	Not Applicable	Not Applicable	Applicable	Not Applicable
Hearing and Speech	Applicable	Not Applicable	Applicable	Applicable	Not Applicable	Applicable
Hearing and Upper Extremity Mobility	Applicable	Not Applicable	Not Applicable	Applicable	Not Applicable	Not Applicable
Speech and Upper Extremity Mobility	Applicable	Not Applicable	Not Applicable	Applicable	Applicable	Not Applicable
Visual, Hearing, and Speech	Not Applicable	Not Applicable	Applicable	Not Applicable	Not Applicable	Applicable
Hearing, Speech, and Upper Extremity Mobility	Applicable	Not Applicable	Not Applicable	Applicable	Not Applicable	Not Applicable

(grey)	Applicable
(white)	Not Applicable

Table 3 lists potential devices and features that would allow different users with disabilities to enter and receive information through the AV interface. We suggest including all the features as part of the system and letting the user choose their preferred features to activate or disable.

Table 3: Different approaches that could be integrated into a UI that enables drivers to enter and receive information through multiple modalities.

	Input	Output
Visual	➢ Eye-Tracking ➢ Gesture Recognition	➢ On-Screen Display ➢ Screen Magnifier ➢ Color Correction ➢ Large Text
Verbal/Auditory	➢ Voice Recognition ➢ Intelligent Personal Assistant ➢ Wired/Wireless Connection to Microphones	➢ External Speaker ➢ Verbal/Audio Feedback ➢ Screen Reader ➢ Wired/Wireless Connection to Headphones ➢ Hearing Aid Compatibility
Tactile	➢ Capacitive Touchscreen ➢ Switch Access ➢ Physical Buttons/Keyboard ➢ Wired/Wireless Connected Mobile Device	➢ Wireless Braille Reader/Mobile Device

The **fifth** principle is tolerance for error which aims to minimize the consequences of unintended actions. Similar to using any other application or software, there is potential for the user to make unintended errors. One way to achieve this would be to confirm a decision chosen by the user and relaying the actions taken by the system back to the user. The UI would also need to allow the user to undo their action in light of new information.

The **sixth** principle is low physical effort. As we expect most if the information to be conveyed verbally or using a capacitive touch screen, the physical effort needed to use the interface should be minimal. Although, it can be a challenging task for those with upper extremity mobility disability as the interface of the screen may be out of reach, as stated earlier, a remote mobile device that can wirelessly connect to the system should be able to alleviate this problem.

The **seventh** principle is the size and space for approach and use. As the screen for the UI can be a standalone system, it can be as large as 17 inches as opposed to the generally available size of tablets. This would allow the UI display to show larger text screens for users with low vision. Larger displays also provide enough border regions around action buttons to prevent accidental activation by users that lack fine motor control or have tremors in upper extremity. Connection with a remote personal smartphone or tablet can also be used to achieve the goals of this principle.

5.3 Principles of Heuristic Evaluation

Although Principles of Universal Design are more generally applicable to wide range of applications, these same principles can be applied specifically to user interfaces through the 10 Usability Heuristics for User Interface Design by Jakob Nielsen ("Nielsen Norman Group", 1995). Most of these principles do overlap with Universal Design but Heuristic Principles are more focused towards a User Interface. These are:

1. Visibility of system status: Users should be informed through appropriate feedback. For instance, the path from point A to point B should be displayed on a dashboard.

2. Match between system and the real world: The system should try to mimic the language used by the general population.

3. User control and freedom: The user should be able to undo and redo without having to go through a time-consuming procedure.

4. Consistency and standards: The different platforms that are used should have similar meaning for the same words or actions. This would be useful if the user prefers to use a vehicle using a subscription model.

5. Error prevention: The design of the system should be such to prevent errors for happening in the first place.

6. Recognition rather than recall: Actions that are needed to operate the system should be more intuitive than having the user to learn and remember it.

7. Flexibility and efficiency or use: Through continuous use of the system, it should be able to speed up the interaction for expert users.

8. Aesthetic and minimalist design: Only the information and details that the user needs to know, should be displayed. This would minimize any level of cognitive overload.

9. Help users recognize, diagnose, and recover from errors: Error messages should indicate the problem and suggest a solution in a simplified manner.

10. Help and documentation: Information should be documented and easily searchable and displayed with a list of definite steps regarding user’s task.

SECTION 6

Title: **Recommendations**

Authors: All

- It is essential that manufacturers engage users in the design process and see the need for a universally designed autonomous vehicle (AV) that is built accessible from the ground up.
- AV design should provide a complete independent travel experience for as many riders with disabilities as possible. Automation and intelligent systems may ensure greater independence.
- A standard universally designed AV would lower the cost for people with disabilities so they would not need to make many modifications, which would help with the adoption of this type of vehicle while simultaneously allowing it to be used in the public transportation sector.
- A SUV-type chassis with the capability of easy installation of a side entry ramp would be the type of AV design that has the most potential to go into high-volume production.
- State and federal standards for AVs must be inclusion of the disability population when designing new public and private forms of autonomous transportation.
- Amend the Americans with Disability Act (ADA) to specifically outline standards to be incorporated in all autonomous transportation designs on a national level.
- Include advocates for people with disabilities on State or Federal Boards that will review AV technology and legislation.
- Strive to achieve higher tier levels (tiers 4 and 5) of autonomous transportation across the country in order to create a bigger impact on the lives of people with disabilities.
- The user interface for autonomous vehicles should accommodate users regardless of ability and skill level so that it can easily be changed based on preference.
- Specific assistive technology for eye-tracking, gesture-recognition, and voice command can and should be incorporated into the user interface so that communication with the AV is accessible, reliable, and efficient.

- Further research should be conducted to develop an "Auto-pilot" feature that considers emergency situations when input from the passengers fail, such as someone falling asleep during a long drive or being incapacitated.

SECTION 7

Title: **Methodology**

Authors: Anjali Malik | Tarun Prashanth

Due to nature of the topics of this paper, we needed to investigate considerations of legal, technological, design as well as social aspects of using autonomous private transportation by people with disabilities. Thus, research for this paper involved our team to interact with human participants through use of survey procedures, interview procedures or observation of public behavior. For this study, an expedited, exempt Purdue IRB protocol was approved. Prior to the submission, all members of our investigatory team were CITI certified or recertified in order to conduct the human subjects research.

For the scope of our human subjects research, it was determined that the criteria for human subjects would include that all must be above the age of 18, and the participants must either have some form of disability, or have significant relevant experience with people who do, implying, that the subject must provide goods or services to people with disabilities. Further, it was expected that all subjects will have some stake in the outcome of this study.

Methods of this study entailed conducting surveys and interviews via varied means. Surveys were collaboratively designed by the team such that they were easy to understand, applicable to most of the subjects, can be completed in up to 30 minutes, and without the need to reveal significant personal details. The online survey was created common for the subjects and consisted of several questions with multiple choice options, scaling, short answers, and one word responses. The survey was conducted using Purdue Qualtrics. First, we compiled the appropriate questions to query survey users. Once the questions were finalized, they were uploaded onto Purdue Qualtrics and posted in a multitude of locations. The survey was sent to all people that were interviewed and was also posted on a sub-Reddit page that specifically addressed the disabled community. Furthermore, distribution of surveys in communities was done through our contacts in relevant centers, organizations, companies, and Purdue campus. As the survey was relatively long, there were twenty-one responses in total to the survey. The Qualtrics dashboard automatically generated graphs in real time as more responses were completed. These graphs could be customized to ones preferences.

Additionally, we conducted interviews with eleven subjects in person as well as through audio calls. The interviewees were contacted through emails or calls, some of whom were our previous contacts and others that we were introduced through the web or general knowledge. If interested, interviewees were either invited to meet in person or converse through phone. In contrast with the surveys, our team designed multiple sets of interview layouts for different interviewees, who varied in their occupations, knowledge and experience with disability. With interviews, it gave us an opportunity to specifically tailor the questions, take longer, and gather more detailed responses from the subjects.

We wish to specifically thank Dr. Justin Seipel, Phil Bell from BraunAbility, and Kevin Crawford from AbiliTrax for their invaluable expertise.

SECTION 8

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SECTION 9

Title: **Appendix**

Authors: All

9.1 Survey Questions

Link to survey can be found here: https://www.surveymonkey.com/r/7KQK83V

Disabled Driver/ Passenger Survey

Basic Info

* 1. How old are you (years)?

- ◯ 18-24
- ◯ 25-34
- ◯ 35-44
- ◯ 45-54
- ◯ 55-64
- ◯ 65-74
- ◯ 75-84
- ◯ 85 or above

* 2. What is the nature of your disability? (Check all that apply)

- ☐ Paralysis/ Weakness in muscles
- ☐ Visial Impairment or blindness
- ☐ Auditory Impairment/ Deafness
- ☐ Other (please specify)
- ☐ Cognitive Impairment
- ☐ Intellectual Impairment

* 3. What assistive technology devices you use? (check all that apply)

- ☐ Manual Wheelchair
- ☐ Power wheelchair
- ☐ Scooter
- ☐ Other (please specify)
- ☐ walker/crutches
- ☐ service animal
- ☐ white cane
- ☐ Hearing aids
- ☐ Braille reader
- ☐ Transfer board

4. How many hours a week do you spend travelling or commuting?

5. Do you currently have a Driver's license?

◯ Yes ◯ No

6. Do you own a personal vehicle?

◯ Yes ◯ No

Disabled Driver/ Passenger Survey

Owners of Personal Vehicles

7. What is the model and make of your vehicle?

8. What kind of modifications do you use in your personal vehicle? (check all that apply)

- [ ] None
- [ ] Hand Controls for Gas and Brake
- [ ] Zero Effort Steering
- [ ] Spinner Knobs or pins for the steering wheel
- [ ] Wheelchair Lock
- [ ] Transfer Seat
- [ ] Extra or Special Mirrors
- [ ] Other (please specify)

* 9. What was the total approximate cost of your vehicle at the time of purchase? (USD)

10. If the vehicle was subsidized or partially funded by an organization,

What is the name of the organization?

How much was the funding/ subsidy?

11. Are there other features or modifications you wish you had on your vehicle?

Disabled Driver/ Passenger Survey

Ride Sharing

* 12. Have you ever used a bus service, taxi or ride sharing service?

◯ Yes ◯ No

13. List the taxi or ride-sharing services you have used so far.

☐ Uber ☐ Lyft

☐ Curb

☐ Other (please specify)

14. How often do you use a public bus service?

15. How often do you use a taxi or ride sharing service?

16. How would you describe your overall level of convenience of using these services?

	Never Used This Service	Extremely Convenient	Very Convenient	Okay	Needs Improvement but usable	Extremely Inconvenient/ Very Hard to use	Unusable
Taxi	◯	◯	◯	◯	◯	◯	◯
Uber, Lyft and other Ride Sharing Services	◯	◯	◯	◯	◯	◯	◯
Local Bus Service	◯	◯	◯	◯	◯	◯	◯
Amtrak	◯	◯	◯	◯	◯	◯	◯

Please comment on any other Public or commercial services that you have used.

17. How do you think on demand or public transportation services could be improved?

Disabled Driver/ Passenger Survey

General

18. How true are the following statements for you?

	Highly Disagree	Disagree	Neither Agree Nor Disagree	Agree	Highly agree
Current paratransit options are adequate for your needs.	○	○	○	○	○
Current personal transportation options are adequate for your needs.	○	○	○	○	○
You are happy with current public transportation sevices? (Ex. buses, …)	○	○	○	○	○
You are happy with ride sharing services.	○	○	○	○	○
You feel safe with current transportation options.	○	○	○	○	○
You trust a GPS system in bringing you to your desired destination.	○	○	○	○	○
Timeliness of transportation is important.	○	○	○	○	○
Comfort of transportation is important.	○	○	○	○	○
Being able to travel independently is important.	○	○	○	○	○
You are able to use applications on tablets/smartphones with ease.	○	○	○	○	○
Aesthetic appeal is important when purchasing your personal transportation vehicle.	○	○	○	○	○

Disabled Driver/ Passenger Survey

Autonomous Vehicles

Imagine an autonomous and universally accessible vehicle is available to drive you and can be summoned on a short notice any time of the day.

19. Would you be interested in using such a self-driving car?

- ◯ Yes
- ◯ No

Please specify reasons or stipulations for your answer above.

20. Which would you prefer if given the choice?

- ◯ Owning a self-driving personal vehicle
- ◯ Summoning a self-driving vehicle whenever needed (like a taxi)

21. How much would you be willing to spend for an accessible autonomous car in comparison to a regular car in the same class?

- ◯ Same as a regular car in the same class
- ◯ $ 10,000 more
- ◯ $5000 more
- ◯ $ 20,000 more
- ◯ Other (please specify)

22. How safe would you feel in a self-driving car? (on a scale of 1-5, 5 being the safest)

1 5

23. What would make you want to use such a car more? Please describe and list features or conditions that would make you choose this over a regular car.

9.2 Interview Questions

Interviews Questions for Service Providers

1. How long have you been involved with transportation for people with disabilities?

2. What are the most common places to get to which you find people with disabilities using your services?

3. What is the nature of the service you provide? How does it add value to the travel chain of a person with disability?

4. What are the most common types of disabilities you encounter?

5. What aspects of the transportation service you provide would you like to improve? Prioritize them.

6. Explain the process you had to go through when you acquired your driver's license.

7. What sort of training did you go through to specifically deal with travelers with disabilities or their needs? Was it enough? How would you change your training if you could?

8. What is the approximate cost incurred by your clients with disabilities in using your services? How does it compare to the cost incurred by your clients without disabilities?

9. Do you have any safety concerns with your service and the way it is utilized? What safety procedures do you follow to ensure no accidents?

Say, there was an option for you to own or rent or summon on short notice, an autonomous accessible vehicle:

5. What would you want or expect from such a vehicle?

6. Would you feel safe riding alone? If not, what would it take?

7. What level of control would you expect in case you want to manually override the drive?

8. How would this affect your service or product? How would you change to adapt to this new product?

9. How comfortable would you be with autonomous vehicle being involved in your service?

10. Will a shift towards autonomy be favorable to your business model? (For a for profit organization only)

11. How much more than a vehicle of similar class would you be willing to pay for the autonomous vehicle described?

Interview Questions for Disabled Drivers

1. How do you get around now? Where do you usually need to go?

2. How often do you use personal, commercial (Uber, taxi, etc.) and public transportation? Comment on the convenience of each.

3. What aspects of each of the above means of transportation would you like to improve? Prioritize them.

4. Explain the process you had to go through when you acquired your driver's license.

5. Do you set aside a budget for your transportation needs? If yes, then what is the approximate cost?

6. Do you have any safety concerns with your current options?

Say, there was an option for you to own or rent or summon on short notice, an autonomous accessible vehicle:

5. What would you want or expect from such a vehicle?

6. Would you feel safe riding alone? If not, what would it take?

7. What level of control would you expect in case you want to manually override the drive.

8. How would you want to interact with the autonomous vehicle?

9. How comfortable would you be with autonomous vehicle?