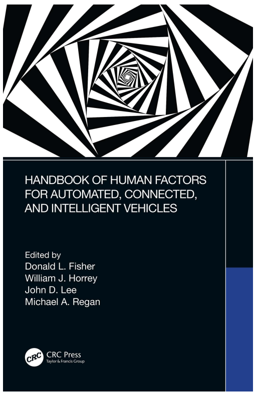

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Automated Vehicle Design for People with Disabilities

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17 Automated Vehicle Design for People with Disabilities

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Independent

CONTENTS

KEY POINTS

- Level 4/5 vehicles may remove the requirement of a driver's license, potentially allowing people with certain disabilities to travel in passenger vehicles independently.
- The principles of universal design should be considered for automated vehicles to potentially enhance the utility for people with disabilities.
- There are standards that exist for Human–Machine Interfaces (HMI) to be accessible to people with certain disabilities.
- Negotiating pick-up and drop-off locations are a factor for automated vehicles to be user friendly for people with disabilities.
- Considerations of how and what to communicate in emergency situations is an additional aspect to consider in enhancing automated vehicle accessibility to people with certain disabilities.

17.1 INTRODUCTION

Currently, to operate a vehicle, one must obtain a driver's license. The specific requirements for obtaining a license vary by jurisdiction. Generally speaking, one must have a certain level of vision acuity, pass a knowledge test, and pass a skills test. Due to these requirements, individuals with certain visual, cognitive, or motor impairments are not able to obtain a driver's license. As a result, they are required to rely on others to travel between locations. This situation creates an additional logistical burden for these individuals. This logistical burden makes it challenging to hold a job, attend medical appointments, and generally participate in commerce and society (Bureau of Transportation Statistics, 2003; World Health Organization, 2016). Fully Automated Vehicles (FAVs), in which a human is not expected to take over lateral (i.e., steering) or longitudinal (i.e., acceleration, speed, and braking) control of the vehicle at any time, have the potential of eliminating the need for a driver's license. For the purposes of this chapter, FAV indicates both SAE Level 4 and 5 (SAE, 2016) vehicles that do not have driver controls.

To be clear, it is likely that some SAE Level 4 and 5 vehicles for private ownership will have driver controls. However, it is unlikely that people with disabilities who cannot obtain a driver's license will be able to operate vehicles with driver controls. Similarly, it also appears that the first SAE Level 4 vehicles will be part of a ride hailing fleet rather than available for purchase (Walker, 2019). As such, this chapter focuses on the design of SAE Level 4 and 5 vehicles that do not have driver controls.

This chapter describes some considerations in developing FAVs to enhance the possibility that people with disabilities may be able to take advantage of the technology. Before discussing the specifics of vehicle design as it relates to people with disabilities, an overview of disabilities can be helpful (see also, this Handbook, Chapter 10). There are two distinct philosophical views of disabilities: the medical model and the social model (Family Voices, 2015). These philosophies may affect individuals with disabilities and the design of vehicles.

17.2 MEDICAL MODEL OF DISABILITIES

The medical model views individuals with disabilities as being defined by a deficiency that needs to be fixed by a medical or other specialized professional. The medical model defines the disability in relation to how biological function is different from normal. Per the medical model, a person's vision would be defined in terms of numerous dimensions, including (1) visual acuity in each eye and (2) size of visual field (which can be measured both horizontally and vertically as well as binocular or monocular for each eye). There are a plethora of other visual impairments (e.g., several versions of color blindness, etc.), but to obtain a driver's license, the above two are typically the primary considerations (Huggett, 2009).

17.3 SOCIAL MODEL OF DISABILITIES

Conversely, the social model takes the viewpoint that a disability is one of many neutral differences that make up an individual. In other words, a disability is no different from height, gender, handedness, or ethnicity. More specifically, within the social model, an individual's inability to perform a task is not a result of the disability, but rather an interaction of a certain set of characteristics and the world. The World Health Organization (2016) defines a disability as "the interaction between individuals with a health condition (e.g., cerebral palsy, Down syndrome, and depression) and personal and environmental factors (e.g., negative attitudes, inaccessible transportation and public buildings, and limited social supports)." That is, the world has certain barriers that make performing certain tasks difficult for some people and not for others.

For example, height has been a disqualifying characteristic for numerous activities. That is, one's height could be a barrier to certain jobs. In fact, two astronauts were retired from space flight because of their height when the United States retired the space shuttles. The Russian Soyuz was designed differently than the space shuttles, and Scott E. Parazynski (6 feet 2 inch) and Wendy Lawrence (5 feet 3 inch) were deemed too tall and too short to safely fly within the Soyuz capsule (NYT, 1995). Yet, no one considers their height disabilities; rather, it is recognized that the design of the Soyuz placed a barrier on their ability to fly in space.

Currently, the requirements to obtain a driver's license are a barrier to people with certain visual, motor, and cognitive disabilities to traveling without relying on others (Chapman, 2018). FAVs have the potential of removing the barrier of a driver's license and allowing for greater mobility. However, this is true only if the FAV is accessible to these individuals. It should be noted that what is accessible to one person with a given disability is not necessarily accessible to another individual with the same disability. The social model better explains this variability than the medical model. In particular, there are two aspects of the social model that support this understanding, which are ignored by the medical model: (1) the nature of the task and (2) individual differences.

17.3.1 Nature of the Task

As stated above, the World Health Organization (2016) defines a disability as "the interaction between individuals with a health condition (e.g., cerebral palsy, Down syndrome, and depression) and personal and environmental factors (e.g., negative attitudes, inaccessible transportation and public buildings, and limited social supports)." This definition emphasizes the importance of both the nature of the task and the specific medical diagnosis to the experience of the disability. Given the almost infinite number of medical diagnoses and tasks as well as the always-evolving nature of work and technology, there has not been an attempt to provide an exhaustive classification of disabilities. The classification schema for the Paralympics (International Paralympic Committee, n.d.) is a useful example of how much work would be required. There are two steps to classification: (1) impairment eligibility and (2) sport class classification.

For the Paralympics, there are ten different categories of impairment including impaired muscle power (e.g., paralysis), impaired passive range of movement, limb deficiency (e.g., amputees), leg length differences, short stature, hypertonia, ataxia, athetosis, and visual impairment. However, what defines an impairment depends on the sport. For example, the maximum height to be considered, short stature or the maximum amount of muscle power to be considered impaired, is different among the different sports (e.g., athletics, swimming, ...).

After a para-athlete is deemed eligible to compete in a specific sport, a classification panel determines what sport class the individual will compete in. These sport classes have been created to ensure that the events are competitive. Para-athletics (i.e., track and field) has the most number of sport classes at 52. This rather large number is because of the variety of activities. These sport classes may divide individuals based on the different levels of impairments (e.g., single versus double amputee for certain field events or races) or could combine different impairments (e.g., paralysis and amputation in wheelchair racing) into one sport class. In summary, what is an impairment depends on the sport in which one wants to compete.

This is all to say categorization of disabilities can be problematic if the to-be-performed tasks are not considered. For this reason, the universal design principles presented in Section 17.4 do not mention specific disabilities, but rather speak to the goals to be accomplished with the system design. Furthermore, this is what motivated the task analysis demonstrating the differences between traditional vehicles and FAVs that are presented in Section 17.5.

17.3.2 INDIVIDUAL DIFFERENCES

The second important design consideration highlighted by the social model is individual differences. That is, two individuals who have the same medical diagnosis may have different methods of interacting with the world and, as such, encounter different barriers. For example, an individual who is legally blind from birth has a very different experience than an individual who loses his/her sight suddenly as an adult. The individual who is blind from birth does not know anything other than interacting with the world without vision. The individual who loses his/her sight suddenly as an adult may go through a period of grief over the loss of sight. After this period, the person can usually learn strategies and continuously work to improve these strategies. Both of these individuals have a very different experience compared with an individual who loses vision over a period of years. The person who loses his/her sight gradually over the years is continuously learning new strategies to adapt to the worsening vision. As such, although these three individuals may ultimately have the same visual acuity, they interact with the world in very different ways. When conducting research with users with disabilities, the researchers should consider the important between-subjects variability of people with the same disabilities.

17.3.3 Summary of the Social Model

In summary, the medical model categorizes people based on their diagnosis, which does not fully account for the impact of individual differences in accomplishing tasks. In the social model, there is no one method of categorizing people with disabilities. The emphasis of the social model is on the interaction of an individual with the environment. That is, there are individual differences that may prevent some of us from accomplishing certain tasks. Thus, the social model is an excellent starting place for discussions of universal design (Vautier, 2014).

17.4 UNIVERSAL DESIGN

Universal design, at its simplest, is the utilization of the standard human factors approach to design in which people with disabilities are included in the user population. Earlier chapters have discussed the special design considerations for the interface to automated, connected, and intelligent vehicles (Chapter 15) and design considerations that need to be taken into account when the driver's fitness is impaired (e.g., the driver is distracted or impaired) (Chapter 16). The focus has been for the most part on the design of interface for vehicles with driver controls (SAE Levels 0–3). Here, the discussion focuses on the universal design of vehicles that do not have driver controls (SAE Levels 4–5).

There is evidence that universal design can result in designs that enhance the usability for nearly everyone. The classic example of such benefit is the curb cut-out. In 1990 with the passage of the Americans with Disabilities Act, curb cut-outs came into wide usage within the United States. However, as early as 1945, the city of Kalamazoo, MI had installed curb cut-outs for injured veterans coming home from World War II (Brown, 1999). As more people experienced curb cut-outs, their utility to the general public increased. Curb cut-outs make sidewalks easier for people with luggage or strollers (i.e., prams). In fact, in Australia, they are sometimes referred to as pram ramps. This example illustrates how something designed for people with disability was beneficial to the general public. Another example is the typewriter, which was invented in the early 1800s to help a blind noble woman write legible letters to her friends (Niven, 2012). These are just two examples. The interested reader is encouraged to review other case studies compiled by Niven (2012) and the National Disability Authority (2014) of universal designs that had benefits beyond those for persons with disabilities.

The universal design process encourages product and system designers to involve people with a variety of disabilities and experiences in all stages of the design process. To maximize the gain from the involvement of people with disabilities, it is best to focus on the interactions that are unique to the system being built rather than on general interactions. To that end, North Carolina State University (NCSU), funded by the National Institute for Disability & Rehabilitation (NIDR) under the U.S. Department of Education, developed seven principles of Universal Design in 1997 (Connell et al., 1997). These principles are as follows:

1. Equitable use,
2. Flexibility in use,
3. Simple & intuitive use,
4. Perceptible information,
5. Tolerance for error,
6. Low physical effort, and
7. Size and shape for approach and use.

The next sections describe these principles in brief. Interested readers are encouraged to review the original documents. In the original publications, Connell et al. (1997), describe several guidelines to be used in the design process for each principle. What is presented next is merely a paraphrase of each principle and the associated design guidelines. In addition, an example of a design choice to illustrate a potential implementation of the principle is provided for some of the principles.

17.4.1 Equitable Use

What is meant by *equitable use* is that the design should be appealing, safe, and secure for as many people as possible, regardless of abilities. Ideally, the means with which the user interacts with the technology is identical for all users, but when that is not possible equivalent means should be provided. If it is not possible to have one design for all, the equivalent means provided should be most appealing and least stigmatizing to utilize. For example, instead of having a label stating "settings for the visually impaired" it may be better to have labels like "screen magnifier" "select color scheme," and "change contrast."

17.4.2 Flexibility in Use

What is meant by *flexibility in use* is that the design does not force the user to perform actions in one way. Rather, the design is accommodating to the widest user base, by considering a wide range of abilities or preferences. The design helps the user make accurate and precise responses where required. A user can perform tasks with either the right or the left hand. The design does not force the user to interact faster or slower than s/he prefers. The technology presents multiple ways of interacting with it. Ideally, these multiple methods of interaction utilize different control methods (e.g., voice and keyboard) or sensory modalities (e.g., auditory and visual).

17.4.3 Simple & Intuitive Use

Systems that support *simple and intuitive use* are more likely to be comprehended by anyone regardless of their past experience, current knowledge, ability to concentrate on the task, or language skills. In the words of Steve Krug (2000) "Don't make me think!" Towards this end, information should be arranged consistently and in accordance with its importance. Prompts and feedback should be designed to maximize effectiveness for the user throughout his or her interaction with the technology. The interface should promote an accurate mental model of the technology without unnecessary complexity (see also, this Handbook, Chapter 3). In the words of the French novelist, Antoine de Saint-Exupery, "A designer knows he has achieved perfection not when there is nothing left to add, but when there is nothing left to take away."

17.4.4 PERCEPTIBLE INFORMATION

Systems that are designed in accordance with the principle of *perceptible information* recognize the different sensory capabilities amongst the population. In addition, the presentation of information considers the ambient conditions (e.g., background noise, sun glare) in which the system will be used. Adequate contrast between presented information and its surroundings should be offered, particularly when the information is essential. Just as in the flexibility of use principle, the technology should be able to present information via multi-modal interfaces (i.e., verbal, pictorial, tactile). In addition, interface elements should be designed such that they can be described in multiple ways that do not require a specific, single sensory modality. For example, a good instruction and design could be, "push the green square labeled go, which is the rightmost button in the top row." In response, a person with normal sight may look for the green button or the button labeled "'Go." Whereas a person with a visual impairment might feel for an array of buttons and then for the top right button within that array. Essential words or symbols should be legible to the widest audience within the context of use. Information shall be perceptible by people using assistive devices for sensory impairments. To elucidate, here are three examples: (1) Many accessibility devices such as portable braille displays can connect via standard methods to enable access to otherwise inaccessible user interfaces; (2) People with hearing impairments sometimes need things repeated verbatim—if an instruction is not repeated verbatim it can lead to even more confusion; (3) The ability to adjust contrast, brightness, color scheme, or font size/type is helpful to individuals with visual difficulties.

17.4.5 TOLERANCE FOR ERROR

The next principle is *tolerance for error.* The system's design should reduce the likelihood of the user making a mistake. If a mistake is made, the design should further minimize the negative consequences of that mistake. This is accomplished in part by ensuring that the elements that are most easily activated or controlled are the most commonly used elements. In addition, those controls that could potentially have negative results if activated accidently should be located remotely or shielded. A classic example of such a control is a fire alarm, which often has a two-step process to ensure that it is not accidently activated. The design should reduce the likelihood of automatic or unconscious actions in tasks that require alertness. In addition, there should be warnings an fail-safe features for hazards and errors.

17.4.6 Low Physical Effort

The principle of *low physical effort* means that the user can interact with the system without exerting a great deal of strength or energy. Moreover, the user should not be required to contort him/herself, and the design should not require excessive repetitive motions or actions.

17.4.7 Size and Space for Approach and/or Use

The final principle is *size and space for approach and/or use*. This means that the design should consider a variety of body sizes, postures, and mobility levels, as well as abilities to see, reach, and manipulate controls. Visual obstructions between the user and the interface should be minimized. There should be consideration for different hand sizes and different grip strengths. Finally, the design should ideally allow people to use assistive devices (e.g., such as pointers, artificial limbs) when interacting with the technology.

17.4.8 Universal Design Summary

These seven principles were developed in order to provide information and guidance regarding the breadth of disabilities and how to accommodate them (Connell et al., 1997). They do not supplant the need to conduct iterative design research with persons with disabilities. However, if these universal design principles are considered prior to the involvement of people with disabilities, the designer may be able to focus his/her attention on more technology-specific challenges.

17.5 HOW HUMANS WILL INTERACT WITH FAVs

The addition of automation does not always remove tasks from the human, but often changes the tasks that the human performs (Grier, 2015; this Handbook, Chapter 8). The following two sections describe the differences in task flow when using a non-FAV in 2018 and a hypothesized or potential task flow for an FAV in the future. For the purpose of this comparison, both vehicles are personally owned and the owner is traveling alone with only hand-carried personal items. Furthermore, the trip is routine in that there are no malfunctions or crashes. As FAVs are not yet commercially available, the task flow for the FAV is hypothetical. The goal of this comparison is to show the differences in actions that potentially need to be considered when designing FAVs.

17.5.1 Non-FAV Task Flow

For the purposes of this comparison, let us describe the interactions a human has with a vehicle without automation (i.e., SAE Level 0). The human likely travels to where s/he parked the vehicle. The human gains access to the vehicle by unlocking/opening the doors. The human then enters the vehicle. The human or the vehicle may or may not adjust seats and mirrors. The human fastens the seat belt. The human starts the engine. The human disengages the parking brake, if it was set. The human shifts the vehicle out of the park and into the appropriate gear. The human monitors the environment while maintaining lateral and longitudinal control of the vehicle. The human also is in charge of wayfinding with or without assistance from Global Positioning System (GPS) navigation. The human identifies a parking space near his/her destination and parks the vehicle. After the vehicle is parked, the human gathers his/her personal items and exits the vehicle. The human then closes/locks the doors of the vehicle and travels from the vehicle to his/her destination.

17.5.2 FAV Task Flow

The task flow for FAVs is not likely to be a simple reassignment of the monitoring of the driving environment, navigation, and lateral and longitudinal control from the human to the vehicle. FAVs may potentially have a very different task flow. As FAVs are still being designed and are not yet commercially available the task flow that is presented here is merely hypothetical and not a statement of fact. First, the human and vehicle negotiate where and when the pick-up will occur.

The vehicle may have to travel on its own to that location to arrive at the time negotiated. The human may also have to travel to this location. The human may have to identify the appropriate vehicle. The vehicle doors are opened by either the vehicle or the human. The human then enters the vehicle. The human potentially fastens the seat belts. The human potentially indicates that s/he is ready for the vehicle to begin travel. After the vehicle has begun its trip, it is assumed the vehicle will safely enter traffic. At some point, presumably before indicating s/he is ready for travel, the human indicates his/her travel intentions to the vehicle. These travel intentions could include negotiating the drop-off location and perhaps the purpose of the ride. The purpose of the ride could affect the path taken or the driving style of the vehicle. These intentions may change while in transit. The human may be able to monitor the vehicle's progress along the route and may be alerted when the route or estimated time of arrival is altered significantly. The human also may be alerted when approaching or upon arrival at the negotiated drop-off location. At the negotiated drop-off location, it is assumed that the human exits the vehicle. When exiting is complete, either the human dismisses the vehicle or the vehicle senses that it may depart based on some set of parameters. The vehicle then departs. Meanwhile, it is assumed the human navigates and travels between the drop-off location and his/her destination.

As with all introductions of automation throughout history, there are several differences between these task flows (see Table 17.1 for a summary). One difference that emerges is with regard to what information is passed between the human and the vehicle. It is anticipated that much of the interaction will be using human–machine interfaces (HMI) that are used in other domains (e.g., touchscreens, voice, physical controls like knobs, switches, and buttons, audio displays, and visual displays). Best practices for the design of many HMI to be accessible to people with disabilities are documented elsewhere [see for example Section 508 Amendment to the Rehabilitation Act of 1973 (www.section508.gov) and Web Content Accessibility Guidelines (WCAG) developed by the World Wide Web Consortium (W3C); www.w3.org/standards/webdesign/accessibility)]. The reader is encouraged to examine

TABLE 17.1
Summary of the Differences between the Two Task Flows (i.e., Non-FAVS and Potential FAVs)

Stage	Non-FAVs	Potential FAVs
Pre-Trip	Human travels to where s/he parked vehicle	Human negotiates with vehicle where and when s/he will be picked up.
Trip Initiation	Human starts engine, puts car into appropriate gear, and presses accelerator	Vehicle engine is already started. Human tells the vehicle s/he is ready to begin trip. Vehicle then safely pulls into traffic.
Traveling	Human controls longitudinal and/or lateral control over vehicle, monitors environment, and navigates with or without the aid of GPS.	Human indicates purpose of ride and negotiates drop-off location.[1] Vehicle controls longitudinal and lateral control to meet the human's purpose and arrive at the designated drop-off location. Vehicle has the ability to communicate route and progress to human.
Trip ending	Human parks vehicle, exits vehicle, and makes way to destination.	Vehicle arrives at drop-off location and alerts human. Human exits vehicle. Human indicates the vehicle can depart or vehicle senses it can depart. Human makes way to destination.

[1] This indication could occur at any time before this, but this is the latest stage at which this could occur.

these sources, which can provide more information than this chapter regarding selecting and designing HMIs that are usable by people with disabilities. Based on the hypothesized task flow, HMI is critical to accessibility. Another critical design consideration is related to vehicle entry and exit. Specifically, the human and the vehicle may have to negotiate where this will occur.

17.5.3 NEGOTIATING STOPPING LOCATION FOR PICK-UP & DROP-OFF

In a personally owned non-FAV, the driver (1) makes his/her way to the location the vehicle is parked, (2) drives the vehicle, (3) parks the vehicle somewhere near the destination, and (4) makes his/her way to the destination. With an FAV, the process may potentially be more similar to the process a passenger uses with a taxi or other hired driver. In this situation, the passenger typically negotiates the stopping location with the driver in two phases: (1a) the passenger provides driver/service a place of interest or street address; (1b) as necessary, the passenger provides additional information regarding location (i.e., specific entrance name/description such as airline or store); (2) driver and passenger consider current conditions (e.g., weather, other vehicles, infrastructure) and individual needs (e.g., disability, cargo) to determine the best available stopping location. This process happens easily for most humans today, because of a shared language and knowledge. However, without shared language and knowledge, the process could potentially be challenging. For example, some people with certain disabilities (e.g., communication disabilities) or those who do not speak the same language as the driver might find coordinating a stopping location challenging with a human driver.

For designers of FAVs, there will need to be careful consideration of the task flow and HMI for the negotiation of stopping location, as the quality of both are necessary to ensuring shared knowledge and adequate communication between the FAV and the passenger. If asked to describe where a person can expect an FAV to stop, people may say as close as possible to the origin/destination. However, the shortest distance between the origin/destination and the FAV may have barriers that pose challenges to an individual with a disability. For this reason, accessible parking spaces (i.e., parking spaces reserved for individuals with a disability permit) within the United States are required to be located on the shortest *accessible* path to an accessible entrance (United States Access Board, 2016). An accessible path is one that is free of barriers, most notably stairs and curbs, but also poles, trees, and other objects that can reduce the width of the path. The closest parking spaces to the door may not have an accessible path. If there is no acceptable path between the space and the entrance, then the spaces would not be considered accessible spaces. Moreover, if there are several parking spaces on different accessible paths, those that are on the shortest path are the ones that should be designated as accessible parking (United States Access Board, 2016). Collectively, this is not meant to indicate that FAVs should ONLY be able to pick-up and drop-off in accessible parking spaces. Rather, it is meant to illustrate the importance of a barrier-free path between the vehicle and origin/destination when selecting a stopping location (Disability Right Education and Defense Fund, 2018). What constitutes a barrier-free path varies by individual. The following sections describe different potential barriers for different disabilities (summarized in Table 17.2).

TABLE 17.2
Parameters Related to Vehicle Stopping Location Important to People with Disabilities

Distance from curb cut-outs
Distance from (accessible) entrance
Incline of road
Distance from curb
Space needed for lift/ramp
Space needed for wheelchair to approach/exit lift/ramp
Presence of physical obstacles (e.g., poles, vehicles, puddles, etc.)
Side of street of origin/destination
Bike lanes between vehicular traffic and sidewalks

17.5.3.1 People Who Use Wheelchairs

For people in wheelchairs, the accessible path described by the United States Access Board (2016) is the primary concern. Thus, rather than being closest to the main entrance (which may not be accessible), wheelchair users would prefer to be let out of a vehicle near a curb cut-out. All other things being equal, they would prefer this curb cut-out be as close as possible to the nearest accessible entrance. More specifically, the curb cut-out that is the closest to the end of any ramp access to the building. However, if the roadway has an incline, it may be helpful if the user could select a pick-up location that is downhill from their origin and a drop-off location that is uphill from the destination (SAE, 2019).

The above considerations generally apply to all people who use wheelchairs. That said, people who use wheelchairs vary greatly. For the purposes of negotiating drop-off and pick-up locations, people who use wheelchairs can be divided into two groups: (1) those that can transfer themselves between the wheelchair and a vehicle seat without assistance (see Schaupp et al., 2016, for a thorough task analysis of this process) and (2) those that need more assistance. There are several reasons why individuals who can transfer between their wheelchair and a vehicle seat do so. First, it is considered safer for an individual to sit in a vehicle's seat rather than in a wheelchair (Van Roosmalen, Ritchie Orton, & Schneider, 2013). Second, the ability to transfer to a vehicle seat allows an individual greater flexibility in terms of vehicle types they can utilize; not all vehicles can accommodate the seated height of an individual in a wheelchair for entry/exit.

These two groups of individuals have different needs as it relates to stopping location. We will assume these individuals are traveling alone and as such have no assistance. Individuals who remain in their wheelchair require a ramp or wheelchair lift to enter the vehicle. As such, it would be helpful if the stopping location considers the space needed for the ramp/lift (SAE, 2019). Similarly, it would be helpful if the space needed for the wheelchair to get into position to enter/exit the ramp/lift as well as the direction the person is coming from or going to be considered (SAE, 2019). For those that transfer themselves, it would be helpful if the vehicle stopped approximately 1 m away from the curb. This provides sufficient room for the wheelchair at the appropriate height to support transfer (SAE, 2019).

17.5.3.1 Other Mobility Impairments

For individuals with other mobility impairments who do not use wheelchairs (e.g., individuals who have hemiplegia, arthritis, cerebral palsy, and lupus), there are two concerns associated with stopping location: distance and stairs/curbs. These individuals may be limited in the distance that they can walk. That is, they would prefer the vehicle to stop as close to the origin and destination as possible. However, if that location has numerous stairs, they may prefer to be closer to the end of the ramp (SAE, in production). Similarly, they may find it helpful if the vehicle stops near enough to the curb, so that they can step directly on to the sidewalk when exiting the vehicle and directly into the vehicle from the sidewalk (SAE, 2019). For example, if the vehicle stops at a typical 6 to 12 inches from the curb, they may have difficulty trying to negotiate the curb with a small amount of space between themselves and the vehicle. Some individuals may prefer stopping near a curb cut-out depending upon its distance from the ramp or entrance (SAE, 2019).

17.5.3.2 Visual Impairments

For some individuals with visual impairments, moving or potentially moving objects are the barrier that may determine what is an accessible path (SAE, 2019). As such, it may be helpful if the FAV could allow these individuals to choose locations in which they do not have to cross a street or bike lane in transiting from/to the FAV. Similarly, they may prefer to avoid double parking (i.e., stopping next to an already parked vehicle; SAE, 2019).

Brinkley, Posadas, Woodward, and Gilbert (2017) and the Disability Right Education and Defense Fund (2018) specify some individuals with visual impairments have concerns related to their confidence in the vehicle location in relation to themselves for pick-up and in relation to their destination for drop-off. To address these concerns, it may be helpful to offer very specific information about the vehicle location that they can compare to their current location/destination (SAE, 2019). In addition, it may help to alleviate these concerns if the information provided could be used for wayfinding (Disability Right Education and Defense Fund, 2018; SAE, 2019).

In this context, wayfinding is the process of navigating and traveling safely between the vehicle and the origin/destination. This would include the location of the vehicle, the individual's current location (for pick-up) or the destination information (for drop-off), the presence of bike lanes, the presence of vehicles, the presence of infrastructure, etc. In addition, at drop-off this information would include what side of the vehicle is the safest for exiting (e.g., the curbside). With regard to the last of these, curbside is typically standard within a country, but there are exceptions such as one-way streets. For those exceptions, the vehicle could stop with traffic on either side of the vehicle (SAE, 2019). Per the universal design principle of perceptible information (#4, Section 17.4.4), the technology should be able to present the information via multi-modal interfaces (i.e., visual, auditory). Other HMI considerations that align with this universal design principle would be allowing the user to adjust visualization properties (e.g., zoom, color scheme, etc.) (Disability Right Education and Defense Fund, 2018).

17.5.3.3 Final Thoughts on Stopping Locations for Pick-Up and Drop-Off

In the above sections, several considerations associated with the negotiation of location for pick-up and drop-off were discussed (see Table 17.2 for a summary). Preferences regarding these considerations can be presented to the user for each ride, or they could be contained in a user profile similar to accessibility options for other technologies. Either way, it may be helpful for the user to have the ability to make the choices regarding pick-up and drop-off location that are best for him/herself (SAE, 2019).

Negotiating the stopping location is important, but it may not be sufficient. This is because it is possible that the vehicle arrives at the negotiated spot and there is an obstacle inhibiting ingress or egress. For this reason, it may be helpful if there was a way for the vehicle to move slightly or to re-negotiate the space if need be (SAE, 2019).

If neither of these results in a location that is acceptable for the passenger to ingress/egress, it may be helpful if the passenger had the option to request the vehicle wait/circle for an acceptable space to open.

17.5.4 CONSIDERATIONS IN UNUSUAL/EMERGENCY SITUATIONS

Another concern is related to situation awareness in unusual/emergency situations (see also, this Handbook, Chapter 7). Lastly, cabin design considerations will be described. The National Highway Traffic Safety Administration (NHTSA) has suggested that 94% of traffic crashes are caused by human errors (NHTSA, 2015). There are many that believe FAVs will reduce the number of crashes. However, there is still the potential that FAVs will be involved in crashes with wildlife (National Center for Rural Road Safety, 2016), human-driven vehicles (Marshall & Davies, 2018), and detritus that appears suddenly [e.g., rocks thrown; material dislodged from vehicles (e.g., AAA, 2017); rockslides (e.g., Abraham, 2011)]. In addition, riders may experience emergencies while in an FAV. As such, it may be helpful if vehicle- and passenger-initiated emergency procedures were designed into FAVs. To align with universal design principle of equitable use (#1, Section 17.4.1) there should be procedures available for the widest population possible.

For example, if an FAV needs to stop driving for some reason, it may be helpful for some individuals with cognitive or visual impairments if the FAV provides information to support the decision to exit or stay within the vehicle. If the FAV does provide such information, its presentation should ideally align with the universal design principle of perceptible information (#4, Section 17.4.4) (SAE, 2019). If it is safer for the person to exit the vehicle, it may be useful to individuals with visual impairments to have information about the roadway (e.g., number of lanes, speed limit, congestion, location of shoulders, sidewalks, or similar). Furthermore, it may be helpful if the presentation of the information took into consideration those individuals who may have never driven themselves.

In other circumstances, a passenger might want to initiate an emergency stop. To align with the universal design principle of equitable use (#1, Section 17.4.1), the design of such a feature should ideally accommodate the widest population possible. In terms of selection of the control device used to initiate an emergency stop, the designer should consider design options that balance the universal design principles of tolerance for error (#5, Section 17.4.5), simple and intuitive use (#3, Section 17.4.3), and size and shape for use (#7, Section 17.4.7). For example, if the HMI for such a feature was a physical button, it would be helpful if it were placed in a location that can be reached by either hand by a person with limited arm mobility while belted, while at the same time helping minimize inadvertent actuation. If the only location is one where it could be inadvertently activated, then one might consider a two-step process or a protective shield over the button.

Persons with disabilities may potentially have concerns regarding how they will be supported in an emergency or unusual situation. Two potential methods to mitigate the needs of people with disabilities in these situations may include the ability to name a contact person and indicate specialized information to first responders. With regard to emergency contact, this could be a person who is notified in unusual circumstances or who may potentially have the ability to monitor the FAV (Disability Right Education and Defense Fund, 2018). Also, these emergency contacts could potentially help to provide additional information to the first responders.

The second method is to allow individuals to voluntarily provide information with the known intent of being shared with a first responder in an emergency. This information could be useful for paramedics or for police. As an example, some people with special needs (e.g., some transplant recipients) have been told that they should only be treated at hospitals with certain specializations. It is important for the first responders to be aware of this information to ensure the person is taken to the appropriate hospital. Similarly, knowledge of disabilities, particularly in terms of communication impairments, autism, and mental health issues, may be useful to emergency responders (Autism Society, n.d.; Center for Development and Disability, n.d.; Perry & Carter-Long, 2016). Some may believe that in terms of these unusual scenarios, we might use the same methods used today. However, we need to consider that individuals today who cannot obtain a driver's license because of a disability are often traveling with other individuals who can communicate this information. In contrast, in an FAV these individuals may be alone. There have been incidents where individuals with disabilities were injured, because first responders were unaware of their special needs (Perry & Carter-Long, 2016).

17.5.5 Cabin Design Considerations

The last category to be discussed within this chapter are considerations related to cabin design. Previously, the needs of wheelchair users as it relates to stopping location were discussed. The population was divided into two groups: those who remain in their wheelchairs; and those who transfer to the vehicle seat. Those who remain in their wheelchairs may benefit from securements for the wheelchair as well as chest restraints (Disability Right Education and Defense Fund, 2018; Bertocci, Hobson, & Digges, 2000). Standards exist for the design of vehicles to accommodate persons who remain in their wheelchairs (SAE, 1999a; b; c). Some individuals can transfer to a vehicle seat but cannot get their wheelchair/scooter into the vehicle without assistance. These individuals may currently use devices such as chair lifts to accomplish this (Disability Right Education and Defense Fund, 2018). Those individuals who can transfer themselves and their wheelchair may need a space within the cabin that allows them to keep the wheelchair within arm's reach throughout the journey (Disability Right Education and Defense Fund, 2018). Such a space may be useful for canes and walkers as well. Similarly, a wide variety of individuals rely on service/support animals, and space for these animals should be considered in the design. Lastly, the design of the cabin should consider the task analysis of the wheelchair to vehicle transfer process completed by Schaupp et al., 2016.

17.6 CONCLUSION

FAVs have the potential of making travel easier for people with disabilities (Chang & Gouse, 2017; see also, this Handbook, Chapter 10). However, designers of FAVs should consider a wide variety of disabilities (at the intersection of medical condition and task) and find solutions within the various constraints (Chang & Gouse, 2017). To that end, this chapter presented the framework of universal design and how it could potentially be applied to FAVs. The primary tenet of the universal design framework is that the designers of technology should consider people with disabilities as part of the user group just as the designers would consider other individual differences. Four areas related to FAVs were discussed in this chapter: HMI, on- and off-boarding, emergency situations, and cabin design. With regard to the first, there are numerous design standards created for other technologies that may potentially be leveraged to make the HMI within an FAV accessible to people with disabilities (also see Chapters 15 and 16 in this Handbook). Second, the on- and off-boarding process is one aspect that is potentially unique to FAVs. As such, considerations for various classes of disabilities related to this process were presented. Third, considerations for the development of responses to emergencies were discussed. Fourth the cabin should consider the needs of those who use wheelchairs, assistive mobility devices such as canes or walkers, and service animals. Finally, designers of FAVs are encouraged to consider disabilities as just another class of individual differences like height, nationality, gender, or handedness.

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