IMPROVING MOBILITY OF PEOPLE WITH DISABILITIES: THE POTENTIAL OF AUTONOMOUS VEHICLE TRANSPORTATION SERVICE AND THE ROLE OF THE BUILT ENVIRONMENT

A Dissertation

by

JINUK HWANG

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Chair of Committee,	Wei Li
Committee Members,	Chanam Lee
	Laura Stough
	Katherine Turnbull
Head of Department,	Shannon S. Van Zandt

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ABSTRACT

This dissertation research examines whether autonomous vehicles (AVs) have the potential to become a viable transportation option to improve mobility for people with disabilities. In this study, I focus on two disability types, including physical disabilities (i.e., difficulty in walking or climbing stairs) and visual impairments (i.e., difficulty seeing while wearing glasses or blind). The study areas include Austin and Houston, Texas, USA.

This study uses mixed-methods of focus groups and surveys to explore people with disabilities' mobility issues and their perceptions of the potential of autonomous vehicle transportation (AVT) services that help improve mobility. Through the analyses of focus group and survey data, it was found that the current public transportation services and neighborhood built environments still caused mobility issues for those with disabilities. Furthermore, the results showed that people with disabilities highly expected AVT to resolve their mobility issues despite several concerns regarding the accessibility and safety of AVs. The findings also suggested that people with disabilities' expectations for AVT might be due to the frustrations that came from mobility issues.

Built upon these findings, this study examines the probability of AVT being chosen as a viable transportation option among people with disabilities and what factors influence their choice. To explain both observable factors and unobservable psychological factors, this study employs a hybrid choice model (HCM) using stated preference data collected by the survey. The model results showed that some people with disabilities still worried about the absence of a human assistant when they chose AVT. In addition, the results corroborated that a high preference for AVT among people with disabilities were associated with their negative attitudes toward public transportation services and built environments. That is, the results corroborated the expectations of people with disabilities that AVT would resolve their mobility issues. Nevertheless, since people with disabilities' mobility issues are complex and intertwined in several ways across different domains, such as transportation systems and built environments, AV technology alone would hardly resolve all. Therefore, even in the era of AVs, to improve people with disabilities' mobility, it will be important to develop more targeted strategies through the multidisciplinary approach.

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1. INTRODUCTION

1.1. Autonomous Vehicles and People with Disabilities

Automation technologies are becoming popular in various sectors, such as transportation, logistics, military, mining, and delivery service (Bajpai, 2017). One of the cutting edge technologies is an autonomous vehicle (AV) that is able to drive by itself, allowing one to ride a car without any needs to operate a vehicle.[1] Many countries and companies around the world have been willing to invest in commercializing AVs. From 2012 to 2016, the CityMobil2 project demonstrated Automated Road Transport Systems using fully automated vehicles in several European cities (Community Research and Development Information Service, 2016). In the U.S., Google began a self-driving car project in 2009 (current Waymo), and one person who was blind rode in a fully self-driving car on public roads in Austin, Texas in 2015. Tesla advertised in 2017 that their passenger cars are capable of providing a “full self-driving” mode. Transportation Network Companies (TNC), such as Uber and Lyft are also aggressively investing in AV technology development in several U.S. cities.

The advance of AV technology is expected to bring significant and broad impacts especially to transportation-disadvantaged populations who have not been

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[1] While vehicle automation has different levels from “no driving automation” to “full driving automation” (SAE International, 2018), autonomous vehicles (AVs) in this study refers to the highest level of automation (full automation) that enables performing all driving functions under all conditions (U.S. Department of Transportation, 2018).

benefited from the use of personal vehicles. Many scholars anticipate that AVs would be able to remove the mobility barriers of people who are currently non-drivers or underserved by existing transit systems due to age, income, and health or mental conditions (Claypool et al., 2017; Harper et al., 2016; Kröger et al., 2018).[2] Among those transportation-disadvantaged populations, individuals with disabilities are considered as some of the main beneficiaries when AVs become available. This is because AVs are expected to enable people with disabilities to ride and travel on their own as the vehicle will not require driving skills, which sometimes need physical and sensory abilities.

One of the important keys to the success of AVs is user acceptance and insights (Axsen & Sovacool, 2019; Nordhoff et al., 2018). The likelihood of market penetration and the promising impacts of the technology could be analyzed and understood through the studies of potential users. Many studies have investigated users' preferences (e.g., willingness-to-pay) and concerns regarding AVs from drivers' perspectives focusing on the impacts of the transfer of vehicle control to machines (Bansal & Kockelman, 2017; Haboucha et al., 2017; König & Neumayr, 2017; Kyriakidis et al., 2015; Liljamo et al., 2018). However, despite the potential of AVs to have profound impacts on people with disabilities' mobility, little is known about their opinions regarding AVs, which might vary from existing studies addressing the general public's perceptions and acceptance.

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[2] In urban transportation, the term *mobility* means "the ability to move between different activity sites (e.g., from home to grocery store)" (Hanson, 2004).

People with disabilities could have different expectations, concerns, and needs as a non-driver and as a person with limited mobility options compared to those without disabilities. Therefore, prior to the AV commercialization, it is important to explore people with disabilities' opinions and to incorporate their feedback into the technology development process.

1.2. Autonomous Vehicles Transportation Services

According to the American Community Survey, there are significant disparities in income level between people with and without disabilities: in 2017, the U.S. median income for people without disabilities was over $32,924, whereas that for people with disabilities was $22,274 (U.S. Census Bureau, 2018b). When considering the proportion of low-income populations among people with disabilities, public transit service using AVs should be a viable alternative for disability communities. As the same as other fields, AVs in public transit services are expected to transform diverse aspects of service operations in terms of service type, efficiency, employment pool, liability, and so on. Given the expectation that AVs can enable transit agencies to provide efficient services while maintaining financial sustainability, many transit agencies have conducted pilot projects using AV shuttles to assess potential performances (American Public Transportation Authority, 2019). For example, the Regional Transportation Commission of Southern Nevada (RTC), a transit provider in Las Vegas, conducted a pilot project using a self-driving shuttle in the Las Vegas Innovation District from 2017 to 2018. In

2018, Valley Metro, a regional transit agency in the Phoenix metropolitan areas, announced a technology partnership with Waymo to develop a new mobility transportation service using AVs. The Metropolitan Transit Authority of Harris County (Metro) in Houston, Texas also approved the implementation of AV pilot project that cooperates with Texas Southern University in 2019.

Especially for ADA paratransit service, AVs have the potential to decrease operating costs if vehicle automation can replace human drivers thereby lowering labor costs.[3] An expensive operating cost of paratransit service has laid a serious financial burden on many transit agencies. The average cost of paratransit services is over three times higher than a fixed-route bus or rail services (U.S. Government Accountability Office, 2012). However, compared to the huge interests of transit agencies in the application of AV technology to public transit services, there have been scarce discussions regarding autonomous vehicle transportation (AVT) services for people with disabilities. Even considering that most AV projects are still in the pilot stage, the lack of policies and guidelines related to accessibility can be a concern for people with disabilities. Therefore, it is necessary to examine how transit agencies are preparing AVT services for people with disabilities and what could be an appropriate shape of services.

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[3] ADA paratransit service is required by the Americans with Disabilities Act (ADA) of 1990 to provide complementary service for people with disabilities who cannot use the fixed-route service.

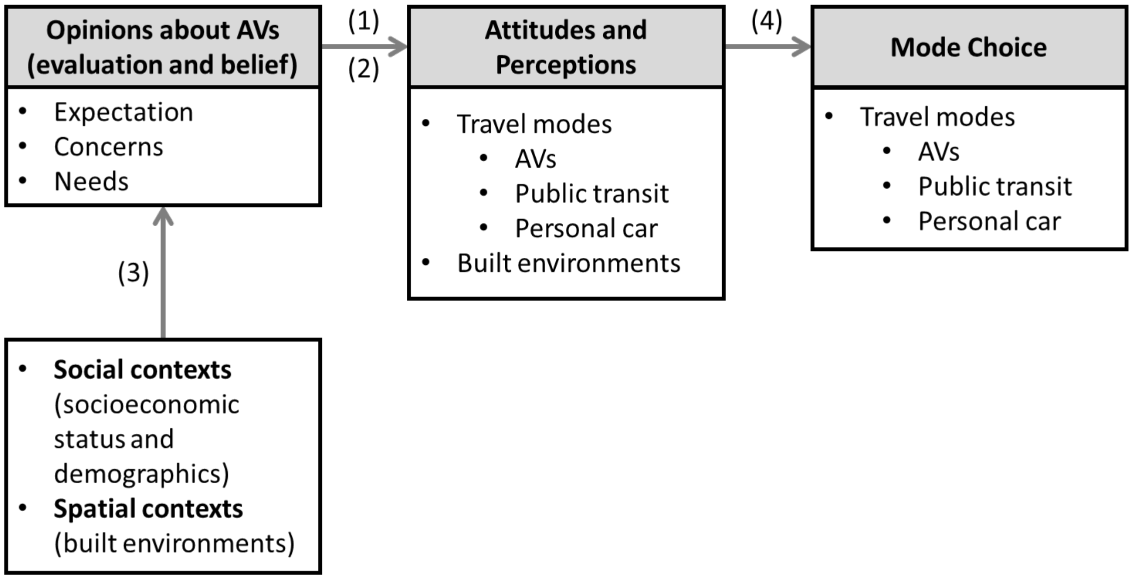
1.3. The Role of the Built Environment in Improving Mobility for People with Disabilities

Along with the lack of an available transportation option, inaccessible built environments are one of the most critical issues that affect the mobility of people with disabilities. While there has been a significant improvement in the accessibility of public transit systems after ADA enacted, people with disabilities still report challenges related to environmental accessibility. Although most transit vehicles are equipped with accessibility-aids, a large number of transit stops and stations are not easily accessible for individuals with disabilities (Bureau of Transportation Statistics, 2017). In 2015, the National Council on Disability (NCD) stated that inaccessible built environments as obstacles to people with disabilities using public transportation services (NCD, 2015). For example, too steep ramps, inoperable lifts, and inappropriate platform levels could cause boarding problems. Inclusive features in built environments (e.g., sidewalks, pedestrian amenities, crosswalks, and curb cuts) can play an essential role in ensuring accessibility to public transit (Clarke et al., 2009; Jansuwan et al., 2013).

The prevalence of AVs will be a transformational event in urban planning and design just like the advent of automobiles in the early 20th century. Many researchers and planners suggest the potential of AVs to change the urban form and land uses. Some studies expected that, when shared autonomous vehicles (SAVs) allow riders to drop off without any parking considerations, almost every parking demand would be eliminated since AVs can still drive themselves on the streets to find another riders (Zhang et al., 2015; Zhang & Guhathakurta, 2017). The underlying meaning of the reduced parking demand is that such changes provide planners and policymakers with opportunities to transform the current parking space into more productive uses, such as residential and commercial developments or parks and plazas for social and physical activities (Crute et al., 2018). Also accurate driving skills that AVs can perform will redesign road infrastructure, such as rights-of-way usage, access management, signage and signalization, and pedestrian and bicycle infrastructure (Crute et al., 2018). For example, more efficient driving systems, such as platooning, could make current road widths narrower since the system allows the vehicles to travel close together. However, it has been rarely paid sufficient attention to how we prepare the built environment in the era of AVs for all people. For instance, to ensure efficient traffic flow, some scholars have suggested designated areas for AV pick-up and drop-off (Chapin et al., 2016; Crute et al., 2018). While such areas must be safe and accessible to people with disabilities, only a handful of researchers have raised discourse on the issue. Therefore, empirical research studies should be conducted to examine people with disabilities' opinions about mobility improvements and their needs regarding the vehicles and built environment to prepare the era of AVs.

1.4. Overview of the Dissertation

The primary goals of the dissertation are (1) to investigate the potential of AVs to improve people with disabilities' mobility and (2) to examine the adequate landscape of neighborhood built environments for people with disabilities in an era of AVs. The dissertation consists of the three parts to achieve these goals. In the first part, this study conducts a series of focus groups to gather information about people with disabilities' mobility issues. Through focus groups, this study also explores the potential of AVs from the perspectives of people with disabilities and public transit professionals. In the second part, this study develops survey instruments based on the results of the first part to identify the factors associated with people with disabilities' attitudes and perceptions toward AVs. Finally, the third part of this dissertation develops people with disabilities' travel mode choice modeling considering AVT to estimate the impacts of the determinants identified in the previous parts. Figure 1.1 illustrates the conceptual framework of the dissertation.



(1): Part 1 – Exploratory study on the potential of AVT to improve people with disabilities' mobility
(2): Part 2 – Identification of the factors associated with people with disabilities' perceptions and attitudes toward travel modes considering AVs
(3) and (4): Part 3 – Development of statistical models to estimate the impacts of the determinants on people with disabilities' mode choice

Figure 1.1 Conceptual framework of the dissertation study

2. A FOCUS GROUP STUDY ON THE POTENTIAL OF AUTONOMOUS VEHICLES AS A VIABLE TRANSPORTATION OPTION: PERSPECTIVES FROM PEOPLE WITH DISABILITIES AND PUBLIC TRANSIT AGENCIES[*]

Some people with disabilities have limited functional mobility and restricted transportation options. According to a 2002 national survey of the U.S. Department of Transportation (USDOT), the top two challenges people with disabilities had regarding transportation were having limited or no access to public transportation, and not having a personal vehicle (Bureau of Transportation Statistics, 2003). A 2017 survey of the U.S. Census Bureau revealed that about 25.5 million Americans aged 5 and older self-reported travel-limiting disabilities (Brumbaugh, 2018). The same survey reported that people with disabilities, regardless of age, made fewer trips and used personal vehicles less frequently than people without disabilities (Brumbaugh, 2018). These statistics illustrate mobility challenges that people with disabilities experience.

The Americans with Disabilities Act of 1990 (ADA) is a U.S. federal law prohibiting discrimination based on disability. The ADA mandates that all public entities operating a fixed-route transit system provide a complementary and comparable ADA paratransit, which generally operates door-to-door services responding to individual

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[*] Reprinted with permission from "A Focus Group Study on the Potential of Autonomous Vehicles as a Viable Transportation Option: Perspectives from People with Disabilities and Public Transit Agencies" by Jinuk Hwang, Wei Li, Laura Stough, Chanam Lee, & Katherine Turnbull, 2020. *Transportation Research Part F: Traffic Psychology and Behaviour*, 70, 260-274, Copyright 2020 by Elsevier.

riders' demands (U.S. Government Accountability Office, 2012). The demands for paratransit services are expected to increase continuously as the population over 65 years will reach 20 percent of the nation's population by 2030 (Kaufman et al., 2016). For transit agencies, the growth in paratransit demand is critical, given expensive operating costs (Balog, 1997; U.S. Government Accountability Office, 2012). Thus, developing transformative strategies to meet growing needs, while still maintaining financial sustainability, is a priority for governments, transit agencies, and researchers.

The emergence of autonomous vehicle (AV) technology is expected to bring significant changes to transportation modes worldwide. From 2012 to 2016, the CityMobil2 project demonstrated Automated Road Transport Systems using fully automated vehicles in several European cities (Community Research and Development Information Service, 2016). In the U.S., Google began a self-driving car project in 2009, and one person who was blind rode in a fully self-driving car on public roads in Austin, Texas in 2015. Tesla also advertised in 2016 that their passenger cars are capable of providing a "full self-driving" mode (The Tesla Team, 2016).

An important key to the success of AVs is user acceptance and insights (Axsen & Sovacool, 2019; Nordhoff et al., 2018). Although people with disabilities are expected to be some of the main beneficiaries, little is known about their thoughts regarding AVs, which could vary from existing studies addressing the general publics' perceptions and acceptance of AVs. For example, many studies investigated preferences (e.g., willingness-to-pay) and concerns about AVs from the perspectives of drivers with a focus on a transfer of vehicle control to machines (Bansal & Kockelman, 2017; Haboucha et al., 2017; König & Neumayr, 2017; Kyriakidis et al., 2015; Liljamo et al., 2018); but people with disabilities might have different perceptions, needs, and concerns as a non-driver and as they have limited mobility options compared to people without disabilities. Moreover, the perspective of transit agencies, the most probable service providers of autonomous vehicle transportation (AVT) services, has also been overlooked.

Given the expected impacts of AVT on people with disabilities and transit systems, this study discusses mobility issues and challenges among people with disabilities and explores the potential of AVT to serve this population to improve mobility. This study focuses on people with visual impairments and people with physical disabilities (i.e., having severe difficulty walking or climbing stairs). According to recent research, when compared to other types of disabilities, these two groups have more barriers to using public transit services, such as difficulties in using mobility-aids (e.g., wheelchair or scooter), traveling with service animals, or receiving inadequate services from drivers (Bezyak et al., 2017). In the following sections, previous studies related to mobility issues among people with disabilities and the potential impacts of AVs are reviewed, followed by the methodology and the findings of this study. The concluding remarks offer initial insights on shaping AVT strategies and policies relevant to improving mobility for those populations.

2.1. Literature Review

2.1.1. Mobility Issues among People with Disabilities

In urban transportation, mobility supports an individuals' ability to carry out daily activities. However, people with disabilities often face obstacles that restrict their mobility (Stough & Mayhorn, 2013). Limited mobility can be a critical barrier to accessing health-care services, physical and social activities, and job opportunities (Blais & El-Geneidy, 2014; Bowe, 1979; S. Kim & Ulfarsson, 2013; Lubin & Deka, 2012; Montarzino et al., 2007). These obstacles may include physical and psychological constraints, limited available transportation modes, and environmental barriers (Blais & El-Geneidy, 2014; Lubin & Deka, 2012).

In many U.S. cities, an individual's mobility relies greatly on automobiles, with the possible exception of central areas in large cities (Donaghy et al., 2004). The dominance of personal vehicles has posed serious mobility challenges to people who cannot drive because of their health conditions, sensory impairments, cognitive limitations, or diminished driving skills. Thus, most non-drivers, including some people with disabilities, must rely on family members or friends for rides unless other modes of transportation, such as public transit, are available. A 2017 USDOT travel survey found that 38.9 percent of people with disabilities traveled as passengers on personal vehicle trips (Brumbaugh, 2018).

As a viable alternative to a private car, public transit can support the independence of people with disabilities. In many cases, however, it has been not easy or not available for people with disabilities to use public transit services. Several studies indicate discriminatory attitudes by other passengers and drivers hamper the use of public transit by people with disabilities (Bezyak et al., 2017; Chan et al., 2009; Gallagher et al., 2011). According to a 2017 nationwide study, around 27 percent of people with disabilities encountered inappropriate attitudes by drivers, 14 percent experienced drivers' refusal to stop while using fixed-route transit, and 30 percent reported drivers' attitudes as a barrier to using paratransit (Bezyak et al., 2017).

Another barrier is the lack of available transportation services. In the U.S., public transit is often unavailable for some people with disabilities. USDOT reported in 2017 that only 3.7 percent of people with disabilities used local public transit and paratransit, while 84 percent traveled in a private vehicle as a driver or passenger (Brumbaugh, 2018). One reason could be a lack of available transit service in areas where they lived: according to the National Health Interview Survey on Disability, one-third of Americans with disabilities reported that no public transit was available in their area (Rosenbloom, 2007).

Despite the improvements in the accessibility of transit systems, people with disabilities have continued to report challenges related to environmental accessibility. Although most transit vehicles are equipped with accessibility-aids, a large number of transit stops and stations are not easily accessible for individuals with disabilities (Bureau of Transportation Statistics, 2017). In 2015, the National Council on Disability (NCD) stated that inaccessible built environments as obstacles to people with disabilities using public transportation services (NCD, 2015). For example, too steep ramps, inoperable lifts, and inappropriate platform levels could cause boarding problems. Inclusive features in built environments (e.g., sidewalks, pedestrian amenities, crosswalks, and curb cuts) can play an essential role in ensuring accessibility to public transit (Clarke et al., 2009; Jansuwan et al., 2013).

2.1.2. Potential Impacts of AVs on People with Disabilities

While many studies have examined the potential impacts of AVs on the mobility of the general public, scant attention has been paid to its effect on people with disabilities. A few studies merely shared an anticipation that current non-drivers, such as people with disabilities, seniors, and teenagers, could travel as much as drivers (Harper et al., 2016; Kröger et al., 2018). Despite the limited empirical investigation on this topic, the disability community could be a large beneficiary when AVs are integrated into transportation systems. Claypool et al. (2017) claimed that AVs would allow around 2 million individuals with disabilities to access new employment opportunities. They also expected a $19 billion reduction in healthcare expenditures if AVs ensured patients' medical appointments by providing transportation services. They further highlighted potential benefits of AVs to people with disabilities to include increased opportunities to participate in social activities in their communities.

AV systems have potential benefits not only to riders with disabilities, but also to pedestrians with disabilities. In the U.S., an average of 102 people were killed per day in motor vehicle crashes in 2016 (NHTSA, 2018b). One research study reported that 94 percent of crashes were caused by human driver errors including drivers' distraction, speeding, and misinterpreting others' actions (NHTSA, 2018a). People with disabilities may be more vulnerable on the road when their physical and cognitive functions limit reaction times (OECD, 1998). Scholars foresee improved safety for pedestrians with disabilities (Owens et al., 2019), because AVs are expected to remove or, at least, mitigate the risk of crashes resulting from human driver errors (Anderson et al., 2014; Hayes, 2011).

Evidence suggests that more empirical studies are needed to better understand the potential of AVs as a viable transportation option to overcome the mobility issues that people with disabilities face. Despite the potential impact of AVs on people with disabilities, few studies have examined how people with disabilities perceive AVs, what they expect and concern, what they need, and how to deliver appropriate services. Such a needed line of studies would establish a knowledgeable foundation to reform planning and policy-making in a new era of AVT. Through focus group discussions, this study first revisits what mobility issues people with disabilities are facing. And more critically, we explore people with disabilities' perceptions of AVs to identify their specific expectations, concerns, and needs. Finally, this study solicits public transit service experts' opinions to provide initial insights on AVT strategies and policies aimed at improving mobility for people with disabilities.

2.2. Methodology

2.2.1. Focus Groups and Content Analysis

The aims of this study are to identify daily mobility issues that people with disabilities face and to explore how people with disabilities and how transit service experts perceive AVT. Several transportation researchers have used focus groups to collect such data (Clifton & Handy, 2003; Huth et al., 2014; Lubin & Feeley, 2016; Naznin et al., 2017). Focus groups are particularly useful for several reasons. First, discussions among participants often generate themes that the researcher has not anticipated (Kitzinger, 2005; Morgan, 1996). Second, when focus groups include participants who have had similar experiences, it is more likely to identify trends and patterns (R. A. Krueger & Casey, 2015). Finally, given their open format and flexible implementation, focus groups can accommodate individual differences and thus be more accessible for people with disabilities (Kroll et al., 2007).

Researchers typically use recording devices to collect focus group data. This data is often supplemented with field notes. The collected data are used to create a complete transcript for the analysis (R. A. Krueger & Casey, 2015). Content analysis is a common research technique for interpreting texts or artifacts (Hesse-Biber & Leavy, 2011; Hsieh & Shannon, 2005; Krippendorff, 2004; Stewart & Shamdasani, 2014). For this study, researchers used a conventional content analysis (CCA) for the coding and data analysis (Hsieh & Shannon, 2005). As CCA extracts information directly from the participants without using predefined categories, the results can yield unique participant perspectives, and it is an appropriate approach for analyzing data in areas that have not previously been investigated (Hsieh & Shannon, 2005). More details about the analytical process of CCA used in this study is described in Section 3.3.

2.2.2. Data Collection

From September 2018 to February 2019, researchers conducted six focus groups (33 participants in total) in Austin, Texas and Houston, Texas, with three different types of participants as follows[1]:

- Group 1) Individuals with physical disabilities: people who have ambulatory difficulties, such as walking or climbing stairs;
- Group 2) Individuals with visual impairments: people who are blind or have serious difficulty seeing even while wearing glasses; and
- Group 3) Transit service experts: public transit service professionals who have appropriate knowledge or experience of ADA paratransit service and/or AVs (e.g., the president/director, project manager, service planner working in paratransit/demand response service department or innovation department).

Each focus group session was comprised of people with similar characteristics to increase the likelihood of shared experiences as well as to foster more comfortable conversation within each group (Hesse-Biber & Leavy, 2011; Morgan, 1996). Therefore,

[1] This study used the U.S. Census' American Community Survey to define each type of disability.

in each city, sessions for each type of disability and transit service expert were conducted separately.

All focus group participants, including both people with disabilities and transit service experts, were recruited through the two local transit agencies providing fixed-route and paratransit/demand-response services in the Austin and Houston areas. The transit agencies contacted their customers or local organizations for people with disabilities via telephone to recruit eligible participants. People with disabilities were recruited if they had any of the listed disabilities, spoke English, and were 18 years old or older, regardless of their use of public transit services. Transit service experts were also recruited from the two local transit agencies based on their titles and roles.

Of a total of 33 participants recruited, 20 were from Houston and 13 from Austin. The Houston group comprised 15 people with disabilities and 5 transit experts, while the Austin group included 8 people with disabilities and 5 transit experts. Table 2.1 summarizes the demographic characteristics of the participants with disabilities.[2]

[2] To maintain anonymity, we opt not to present the personal information of transit service experts in the body of the paper. The interested readers, however, might be able to assume their background through the listed job titles in the definition of transit service experts.

Table 2.1 Demographics of participants with disabilities

Variable	n	%
Disability Type[1]		
Physical	11	45.8
Visual	13	54.2
Age[2]		
35 – 44	3	13.6
45 – 54	12	54.6
55 – 64	3	13.6
65 and above	4	18.2
Gender		
Female	11	47.8
Male	12	52.2
Employment Status[3]		
Employed	13	61.9
Unemployed	2	9.5
Retired	6	28.6
Race		
Black	10	43.5
White	13	56.5
Ethnicity[2]		
Hispanic	5	22.7
Non-Hispanic	17	77.3

[1] One participant had both types of disability. This participant took part in the discussion with a group of people with visual impairments.
[2] One participant did not reveal his/her age and ethnicity.
[3] Two participants did not reveal their employment status.

Two moderators facilitated the focus groups, except for the session of participants with physical disabilities in Austin for which only one moderator was available. Each session lasted around 75–90 minutes. The moderators used semistructured guide questions for all sessions. The guide questions were developed to facilitate the discussion and to allow participants latitude in sharing their ideas (Hesse-Biber & Leavy, 2011). A full list of guide questions can be found in Appendix A and B.

Before the discussion, moderators provided information about the study and obtained consent from the participants using an informed consent form that the Texas A&M University Institutional Review Board had approved. The moderators also explained the concept of the built environment and AVT as defined in this study. Drawing from the definitions used in similar previous research, this study used the following definitions:

- The built environment includes the physical environment (e.g., urban design, land use, and the transportation system) and patterns of human activities within the physical environment (Handy et al., 2002).
- AVT service refers to the on-demand transit service using self-driving cars. AVT is expected to allow users to book the trips through a smartphone or call center instantly. The size of the vehicle could vary depending on the needs. All vehicles would be wheelchair accessible and have securement systems. Also, they are equipped with audio-systems to inform riders of the vehicle's location.

This study has to point out the following two caveats related to the data collection. First, the sample size could be relatively small. Nevertheless, when considering the typical number of focus group participants for each session (i.e., four to eight) (Hesse-Biber & Leavy, 2011), the sample size should be appropriate for this study that aims to gather first evidence of people with disabilities' perceptions of AVT rather than drawing final conclusions. Second, while this study focused on two disability types and was not able to recruit many adult participants with disabilities younger than 35, future studies may include more diverse disability types, ages, and regions to represent all different needs and perceptions.

2.2.3. Data Analysis

The researchers audio recorded and transcribed each session. CCA was used to analyze the data and to identify major themes. This study followed a step-by-step process for CCA as Hsieh and Shannon recommended (Hsieh & Shannon, 2005). The process began by reading the entire transcripts for each session. Then, each script was re-read with a focus on the text that described the phenomena of interest (i.e., people with disabilities' travel pattern, mobility issues, expectations or concerns about AVT, and transit service experts' opinions on AVT). Next, codes were developed based on the texts of interest. Lastly, the developed codes were organized into a hierarchical structure (e.g., theme, category, and sub-category). For the coding process, QDA Miner, a computer-assisted qualitative coding program developed by Provalis Research, was used for this study. The coauthors who had not participated in the focus groups reviewed the developed themes, categories, and subcategories.

2.3. Results

The focus groups provided valuable information about participants with disabilities' travel patterns, mobility issues, and perceptions of AVT. This study reconfirmed the diverse travel needs of people with disabilities to do daily activities, such as attending work or school, participating in social or religious activities, shopping, eating out, and attending medical appointments. Most participants with disabilities relied on public transit services, including both paratransit and fixed-route systems. With the recent growth of the ride-sharing market, some participants with disabilities, especially individuals with visual impairments, also reported that they frequently used a ride-sharing service (e.g., Uber or Lyft) when they needed to travel urgently. While two participants with physical disabilities drove private vehicles, they needed special authorization to drive and had to remodel a vehicle so that it accommodated their mobility aids (e.g., wheelchair or scooter).

Based on the CAA, this study identified people with disabilities' mobility issues related to the use of current public transit services and the quality of neighborhood built environments. The following sections will describe detailed findings about these two themes.

Table 2.2 Focus group findings regarding mobility issues of people with disabilities

Theme	Category	Sub-Category	Explanations or Representative Quotes[1)]
The use of public transit services	Accessibility	• Limited vehicle space	• PHY: "There are only two spaces in the bus [for wheelchair users], and there is always someone blocking one of them."
		• Complex eligibility process[2)]	• Some participants in the disability-groups explained that they have never been registered for using paratransit because they thought that the eligibility process is time-consuming.
	Flexibility	• Reservation requirement[2)]	• Participants in the disability-groups explained that it is difficult to make a trip immediately whenever they want. All paratransit users in the disability-groups noted that they need to make a reservation in advance. • VIS: "If I forget to book a trip, then I won't make the trip."
		• Limited service capacity	• One participant with visual impairments reported that she had to use a private taxi or ask her friends to take her because her destination was out of the service area of paratransit service.
	Efficiency	• Inefficient route and schedule	• PHY: "The way paratransit run is just not efficient and not fast enough for me to work and make meetings. That was one of the reasons why I just never even try to ride." • VIS: "Going to cross the town using fixed-route, it could take an hour or two, depending on where you are going."
	Reliability	• Unreliable service	• Most complains came from the arrival time of the paratransit service. • PHY: "I scheduled for 9:30 pick-up, and I called up then they said I was going to get picked up at 9:45. I called up again; they said 9:47. They said the driver is only a few miles away. [Other participants laughed and then said] That's paratransit."

[1)] PHY (participants with physical disabilities) and VIS (participants with visual impairments) indicate the group origin of the quotes.
[2)] For paratransit users only.

Table 2.2 Continued

Theme	Category	Sub-Category	Explanations or Representative Quotes[1)]
The use of public transit services	Public Attitude	• Inappropriate or hostile attitude by others	• PHY: "People on the bus don't pay attention to you; even you are in a wheelchair. It's very scary." • PHY: "It's going to take longer for the ramp to go down, drivers have to move people, and you get this feeling when you roll on—everyone at the bus stop is staring at you, like, you are making us late." • PHY: "My home has steps. And I'm in a wheelchair. So, I have to get out of my chair, and I have to lift my chair. One driver just sat there and said, 'I'm going to see how you're going to do it.' I said, 'I'm not your entertainment. Get away from me!'"
Quality of the built environment	Accessibility	• Lack of sidewalks • Lack of curb cuts or ramps • Inaccessible bus stops	• Participants in the disability-groups indicated that they would either fall or could not use the paths if there were no sidewalks and curb cuts/ramps. • PHY: "Once you go over one block, and you find that you are at the end of the sidewalk that has no curb cut. So, you go back all the way around." • VIS: "There are no sidewalks. I'm not a fan of walking along busy roads with ditches."
		• Inaccessible crosswalks	• VIS: "I like accessible pedestrian signals (APS), and unfortunately, we don't have enough of them." • PHY: "You get to a street that you need to hit the crosswalk button, because it doesn't automatically change. But the crosswalk buttons are over in the grass in a whole. And these are very busy streets."
		• Car-dependent land-use patterns	• PHY: "The closest grocery is two miles from my home. So, even if I do get groceries, it's going to be hard to hold the groceries and wheel yourself at the same time. So, it's especially impossible to go shopping."

[1)] PHY (participants with physical disabilities) and VIS (participants with visual impairments) indicate the group origin of the quotes.
[2)] For paratransit users only.

Table 2.2 Continued

Theme	Category	Sub-Category	Explanations or Representative Quotes[1)]
Quality of the built environment	Maintenance	• Poorly maintained sidewalks and bus stops • Obstacles on sidewalks and streets	• PHY: "Part of the sidewalks in my neighborhood has constant one-inch or two-inch holes. It's bad on my back, my injury. I don't have ab and back muscles, so, my spine takes the shock in the lower back. So, I mean, these are the little things no one thinks about." • VIS: "[In] the neighborhood where I live, there are always vehicles parked on the sidewalk. If the cars extend into the main path of the sidewalk, [then this] means I have to get out in the street to just get around it."
	Safety	• Heavy and high-speed traffic	• VIS: "This street is, no matter what time a day it is, it's the heavy traffic time. That is the scariest one. I crossed this only one time by myself successfully, but any other time, all I have to do is looking like I'm trying to cross the street. One time, I was standing there for 20-30 minutes."
		• Lack of streetlights	• VIS: "If it is getting dusk, I have to be very, very careful come and across there, because the cars are coming every which way [and hard to distinguish me]. Now if it has some lights out there, it might be okay."

[1)] PHY (participants with physical disabilities) and VIS (participants with visual impairments) indicate the group origin of the quotes.
[2)] For paratransit users only.

2.3.1. Mobility Issues in the Current Public Transit Services

Table 2.2 presents the focus group findings from the analysis of mobility issues.

2.3.1.1. Accessibility

Most participants with disabilities, especially wheelchair users, explained that the current public transit had limited available space inside the vehicle. While the vehicles themselves are accessible to wheelchair users through a lift or ramp, the interior space available to wheelchair users is limited. Similar challenges are found in paratransit services. In some cases, services that the local transit agencies provide do not accommodate individuals using a mobility scooter. Houston METROLift, for example, has a contract with Yellow Cab to provide subsidized services to customers who take a cab (i.e., METROLift Subsidy Program). However, one participant with physical disabilities noted that she could not take a Yellow Cab because the vehicle did not have enough space for her scooter. Hence, the availability of and access to larger vehicles such as vans appear essential for those using a larger size mobility-aid.

A complex eligibility process for paratransit service was reported to be another barrier to their mobility. Although several participants in the disability-groups acknowledged the advantages of paratransit, such as door-to-door and demand-responsive features, they lamented their restrictive service policy (e.g., time-consuming process and strict criteria for eligibility). Participants with disabilities reported that the limited service areas made it inconvenient to use such services. According to the FTA, the ADA paratransit service must be provided to origins and destinations within 0.75-mile of a bus route (FTA, 2015). One participant with visual impairments stated that he had never tried to be eligible to use the paratransit service even though he is blind because he lives outside the required service area. Also, several participants in the disability-groups complained that the service is only available within the transit agency's service area (usually within the city boundary); thus, if they want to use the service in another city or jurisdiction, they need to complete another process to get eligibility.

2.3.1.2. Flexibility

A difficulty in modifying trip plans was another barrier that discouraged people with disabilities from using public transit, including both the fixed-route and paratransit services. Although people with disabilities have a similar level of travel demand compared to people without disabilities, they could not travel as "spontaneously" as their counterparts do when using public transit services. It was more serious when paratransit services are the only option for participants with disabilities. The inflexibility of paratransit service was a critical drawback for those in urgent or unexpected need of the service. Especially, the policy to require customers to make a reservation at least a day prior to the trip was the most critical barrier that restricts flexible travel of participants with disabilities.

The limited service hours and service areas of fixed-route and paratransit services also were cited as barriers that restrict the flexible travel of participants with disabilities.

For example, FTA recommends the same operating hours and days to both the fixed-route and paratransit systems. As mentioned above, the service area of paratransit service cannot meet customers' travel needs when bus routes do not cover the destination areas. Therefore, if people with disabilities want to ride paratransit services, they should make a trip plan with limited flexibility inherent in operating hours and the available service area. Otherwise, they have no choice but to look for other means of transportation or rely on their acquaintances.

2.3.1.3. Efficiency

Participants with disabilities deplored inefficient public transit routes and schedules that take a long time to reach their destinations. One participant with visual impairments reported that riding a bus to cross the city will take an hour or two, but he had no choice to get to the destination. Besides the fixed-route services, paratransit service also was complained because of its inefficient travel route to pick up other passengers. One participant with physical disabilities stated that she has not used paratransit because the way the current paratransit system runs is not efficient when considering travel time.

Some participants with disabilities reported that one alternative to paratransit was ride-sharing services that transportation network companies (TNC), such as Uber and Lyft, provide. Participants with disabilities used TNC because it is faster, more responsive, and more flexible than public transit. However, TNC was not an alternative for everyone. Some participants with visual impairments were concerned that TNC drivers are not trained to treat people with disabilities. Also, because most TNC vehicles are typical passenger cars, the capacity of the vehicle is insufficient for wheelchair or scooter users. While Uber and Lyft recently began to provide accessibility options for people with disabilities, higher costs and limited service areas remain barriers.

2.3.1.4. Reliability

Several participants with disabilities mentioned unreliable service. Notably, paratransit users claimed that drivers arrive late frequently. They also reported that sometimes they missed an appointment because paratransit did not arrive for a pickup. Some participants in the disability-groups said in a sarcastic tone that they were used to waiting for the late arrival, so they deliberately made reservations an hour earlier than the time they needed the ride. While some participants with disabilities understood that paratransit could be late depending on the traffic situation and due to the ride-sharing feature, others stated that they get fed up with endlessly waiting for the driver.

2.3.1.5. Public Attitude

Compared to participants with visual impairments, participants with physical disabilities tended to express more about the inappropriate or hostile attitudes of the drivers and other passengers that discourage them from using public transit. A possible explanation is that people with physical disabilities are more likely to need assistance when they board and alight; hence, they have more chances to interact with drivers and other passengers. One participant with physical disabilities reported that sometimes bus drivers “just passed by” without picking up a person in a wheelchair. Also, even if wheelchair users got on the bus, the drivers often did not help them “secure” in the seat. During peak hours, especially, persons in wheelchairs felt they were treated as an eyesore on the bus. Some participants with physical disabilities using paratransit also complained about drivers’ “horrible” services. Although a few remembered the kindness that they received from drivers, others reported that drivers were not kind or were unwilling to help them when leaving home or getting on and off the vehicle.

2.3.2. Mobility Issues in the Built Environment

2.3.2.1. Accessibility

Almost all participants in the disability-groups stated that the lack of accessibility was a critical mobility problem in their neighborhoods. Among the many accessibility problems noted, the lack of sidewalks was most frequently mentioned in the disability-groups. The need for such accessibility features is further highlighted in street crossing conditions. Participants with visual impairments lamented that most crosswalks in their neighborhoods do not have accessible pedestrian signal (APS) devices that can alert them by sound. Also, participants with physical disabilities reported that the signal device is sometimes installed in an inaccessible spot where they cannot reach. Without accessible pedestrian paths, people with disabilities are likely to lose other transportation options too. For example, participants with physical disabilities reported that it would be impossible to access a bus stop if it were not equipped with ramps or located too far from home. In a similar vein, some participants with physical disabilities also criticized land-use patterns that encourage car travel, claiming that these patterns did not allow them to get to places with non-motorized modes. One participant with visual impairments stated, “If the built environment were good enough, paratransit would not be necessary for most folks.”

2.3.2.2. Maintenance

Participants with disabilities commonly indicated poorly maintained sidewalks or bus stops prevented users from riding fixed-route services. Especially, participants with disabilities listed several obstacles on sidewalks and streets, including potholes, cracks, parked cars, tree branches, and construction sites. Dirty and messy bus stops also decreased the willingness of participants with disabilities to use a bus. Participants with visual impairments said that they experienced extreme fatigue while trying not to fall or bump into obstacles when they walked on crumbling sidewalks. Even minor or temporary obstacles (e.g., parked cars or tree branches) were potentially hazardous.

2.3.2.3. Safety

Most participants in the disability-groups suggested that heavy traffic volume and high-speed vehicles were two main factors that threatened the safety of the neighborhood. Most, if not all, participants with disabilities shared their concerns about crossing heavy-traffic roads. Especially, participants with visual impairments complained that they have to get through the "busy roads" to get to bus stops or to do daily activities; however, when the crosswalks are not equipped with APS devices, their safety issues worsened. Some wheelchair users reported that it is difficult to be noticed by fast-driving cars because their height is lower when sitting in a wheelchair. Additionally, some participants with disabilities reported that they were scared when traveling at night due to the lack of streetlights.

Table 2.3 Focus group findings regarding perceptions of Autonomous Vehicle Transportation (AVT) services

Theme	Category	Sub-Category	Explanations or Representative Quotes[1)]
Expectations	Freedom of Travel	• Spontaneous travel	• VIS: "AVT can give me the freedom to choose where I want to go. Door-to-door, store-to-store, or area-to-area. I'm not limited." • TSE: "I expect that AVT should allow people not to rely on next-day reservations, so they can plan better."
		• Independent travel	• One participant with physical disabilities who has to always rely on her husband for travel stated that she would "definitely" use AVT because she needs more freedom to travel not relying on her husband.
	Cost-Saving	• Reduced operating cost	• Transit service experts explained that AVT could reduce operating costs while improving service hours, compared to the current systems that pay for human drivers. • TSE: "I would assume that AVs would be more cost effective than having to pay for the personal association with the driver, so I think that it can help control cost." • TSE: "The upfront costs will be pretty high, but five or ten years down the line, I think we're going to see a lot of return on investment."
	Safety	• Safe driving technology • Reduced car accidents	• VIS: "People get tired, but computers never [do]." • PHY: "I think it will decrease my anxiety [as a pedestrian] … I got hit my head on the other day by a guy weren't paying attention when I was on wheelchair. I feel like, it can get to the point where driverless vehicles are way safer than the majority of Americans who don't pay attention to what they're doing while they're driving." • TSE: "I think we would also see much less of a concern over accidents because it just wouldn't happen as much."

[1)] PHY (participants with physical disabilities), VIS (participants with visual impairments), and TSE (transit service experts) indicate the group origin of the quotes.

Table 2.3 Continued

Theme	Category	Sub-Category	Explanations or Representative Quotes[1)]
Concerns	Cost-Saving	• Expensive costs for initial purchasing and maintenance	• Some participants in the disability-groups claimed that they do not expect to enjoy the benefits soon because it will “take a while” to commercialize AVT. • Some transit service experts also doubted the cost-saving effects of AVT because AVTs would require a high level of maintenance and expensive initial purchasing costs.
	Safety	• Absence of human operator	• Participants in the disability-groups explained that trained drivers are necessary for some people with disabilities who cannot get on and off the vehicles by themselves or have to bring luggage. • PHY: “The big thing for people in wheelchairs is that there is nobody to get out and strap them in. That’s not going to work for them.” • PHY: “[What if] the machine is inactive, or we have an accident? [If there is no one] what happens then?” • VIS: “Drivers do a few things for me like getting my luggage properly, holding the door, giving you a direction to the entrance. I don’t think that AVs are going to be able to do those kinds of stuff.” • TSE: “We should never get rid of the traditional service [with human drivers]. The two can complement one another because there is a lot of soft skills that AVs wouldn’t provide.”

[1)] PHY (participants with physical disabilities), VIS (participants with visual impairments), and TSE (transit service experts) indicate the group origin of the quotes.

Table 2.3 Continued

Theme	Category	Sub-Category	Explanations or Representative Quotes[1)]
		• Technological errors	• Some participants in the disability-groups living in apartment complexes insisted that even human drivers often miss their locations, showing concerns about the ability of an AVs to navigate. • PHY: "The machine is not going to make as [correct of a judgment] as a human would." • TSE: "I think it's important how do you respond to the emergency [resulted from mechanical defects] … There has to be an alert system, safety system, and place to identify."
	Accessibility	• Communication between the vehicle and riders	• PHY: "If you couldn't talk to it, like people with speech impairments, that could be a barrier." • VIS: "You don't know where the vehicle really is [if you cannot see]. So, both pick-up and drop-off will be a problem."
		• Lack of accessibility-aids	• One transit service expert explained that most pilot vehicles do not even have seatbelts, adding, "First, we would need to get learning to understand how the vehicles can become ADA-compliant. We can't provide a service without being ADA-compliant."
		• Lack of appropriate built environments	• TSE: "We have a lot of concerns about how we would make sure that the pick-up and drop-off locations are suitable and safe." • TSE: "I think the one biggest thing that has to be done is the wholly developed network systems (5G network) [throughout the city]. That's the key to AVs."

[1)] PHY (participants with physical disabilities), VIS (participants with visual impairments), and TSE (transit service experts) indicate the group origin of the quotes.

Table 2.3 Continued

Theme	Category	Sub-Category	Explanations or Representative Quotes[1)]
	Adverse Effects	• Increase of private vehicles	• VIS: "Even if all shared, we still have the same number of people they want to use one if they didn't have their own car." • TSE: "My concern is that people could have their own vehicles. Some people can't drive their own cars, but if they are able to have their own AVs, they wouldn't need to depend on us to provide transportation."
		• Massive unemployment	• PHY: "What happens to those people, those drivers that we now have. That puts them out of work."
Service Type Preference	Preferred Ride Type	• Single-ride type	• VIS: "If it only picks up one person, that would get us to our destination a lot quicker. It would eliminate some of the multiple pick-ups and add-ons." • PHY: "You are going to one address, not shared, and that would be actually more convenient."
		• Shared-ride type	• VIS: "The vision of AVs is everybody shares. And, if everybody shares, we don't need parking spaces, and there are not many cars on the road, then we can make the lanes smaller that get the cars closer together." • PHY: "It will eliminate some of these drivers on the street because when they see this, they are going to like 'oh, I don't have to drive anymore.' "

[1)] PHY (participants with physical disabilities), VIS (participants with visual impairments), and TSE (transit service experts) indicate the group origin of the quotes.

2.3.3. Perceptions of Autonomous Vehicle Transportation (AVT) Service

Table 2.3 summarizes the major themes and categories derived from the analysis regarding all participants'—including people with disabilities and transit service experts—perceptions of AVT. The results include two major themes of expectations and concerns, with 3 or 4 categories extracted for each theme. Additional discussions around the ride type preference (single versus shared service) are also included in the third theme.

2.3.3.1. Freedom of Travel

The most frequently stated expectation by participants with disabilities was that AVT would increase the flexibility of travel. They expressed excitement regarding the possibility of riding AVT whenever they want. Also, participants with disabilities expected AVT to expand the capacity of transportation service in terms of operating hours and service areas, as this expansion would not require as much labor costs as it does currently.

Transit service experts echoed the sentiment that AVT would have a profound impact on the mobility of people with disabilities. They highlighted the potential for AVT to provide a "real sense of independence," if AVT would be on-demand service not requiring customers to make a reservation in advance. Some experts agreed that transit agencies could expand operating hours. Such expectations coincide with those that participants with disabilities made. Taken together, all groups agreed that AVT could provide "freedom of travel" and "independent life."

2.3.3.2. Cost-Saving

Cost-saving was also mentioned as among the most promising benefits of AVT. Some participants with disabilities expected that it would be possible for transit agencies or TNCs to provide cheaper AVT services because of reduced labor costs. According to the participants with disabilities, travel cost was a primary factor that they consider when they have options to choose the mode of transportation, and they looked forward to adding AVT as an affordable travel option. Some transit service experts also expected that AVT would improve the cost efficiency of paratransit service. They predicted that technological advances, such as improved electric-battery efficiency and mass production, would eventually allow long-term cost-savings for AVT.

Nonetheless, doubts about the possibility of realization made participants with disabilities cynical about the cost-saving effects of AVT. Transit service experts also agreed that the deployment of AVs and the cost-saving effects would take a long time. Some experts were concerned about the affordability of AVT services for people with disabilities. They listed several challenges needed to overcome before providing "efficient" AVT services, such as costs for converting to electric vehicles, developing optimized scheduling algorithms, and establishing appropriate infrastructure to accommodate AVs.

2.3.3.3. Safety

Several participants with disabilities and transit service experts expected that AVT could drive safer than human drivers. Also, they forecasted that AVT would decrease concerns about being hit by cars. Despite optimistic expectations for safer driving technology of AVs, some participants with disabilities expressed concerns. Most concerns came from the absence of human operators. Some participants with disabilities argued that the lack of human operators could be a “disaster.” One concern regarding the absence of a human operator was the fear of fellow passengers. Several participants with disabilities expressed that it would be “scary” if they travel with unknown passengers without professional operators. Furthermore, participants with disabilities had doubts about the ability of AVs to cope with emergencies, for example, in the case a vehicle stopped working or first aid was needed.

The possibility of mechanical defects was another reason why participants with disabilities expressed reluctance. Some expressed their fundamental “fear” of machines. In specific, the inaccurate Global Positional System (GPS) signals were most frequently mentioned predictable barrier to using AVT by both people with disabilities and transit experts. One transit service expert reported that one challenge in their AV shuttle pilot project was the trees along the streets, which blocked GPS signals.

2.3.3.4. Accessibility

Accessibility was mentioned as a serious problem that AVTs should address before commercialization. Many participants with disabilities and transit service experts were concerned about communications between humans and vehicles. They explained that the use of AVs would be problematic for people who have problems with seeing, hearing, speaking, and understanding, as it is often difficult for people with such characteristics to interact with vehicles. Participants with disabilities also argued that policy-makers should not "generalize" different types and levels of disabilities when they consider accessibility. One participant with physical disabilities explained that AVT must have diverse service models to meet the different levels of needs and conditions among people with disabilities. Transit service experts were also aware that AV should be equipped with diverse accessibility-aids to serve people with disabilities. They gave priority to ADA-compliant devices, such as wheelchair ramps or lifts and securement-aids. Also, participants in all groups indicated that neighborhood built environments should be accessible to accommodate AVs. Most participants with disabilities were concerned about the accessibility of the pick-up and drop-off areas.

2.3.3.5. Adverse Effects

Some participants with disabilities exhibited negative views about AVs because they believe private AVs could worsen traffic congestion as more people would travel. Also, they argued that AVs would "eliminate" many jobs related to driving. These participants reported that they felt “emotional” or “moral” reasons for not using AVT because many public transit drivers will lose their jobs. Also, participants with disabilities claimed that human operators will still be needed in the vehicle, even if the vehicle can drive itself, because of safety concerns, such as traveling with strangers and emergency during travel. However, this issue was controversial as others felt that the advent of AVT is inevitable. One participant with physical disabilities stated, “The sewing machine also put people out of work. I mean, that’s just moving forward,” and another participant in the same group added, “Do you remember the elevator? We don’t have an operator any longer.”

2.3.3.6. Service Type Preference

Various opinions existed among participants with disabilities as to whether AVT would be better served as a single-ride service or as a ride-sharing service. Some participants with disabilities and transit service experts expected that AVT would provide a more efficient route and faster service, compared with current paratransit systems, if it were a single-ride service. Others claimed that AVT would mitigate congestion and reduce operating costs only if it were shared. Most transit experts also considered various types of services because it would be necessary to meet the different needs and capabilities of people with disabilities. From the service provider’s perspective, transit experts anticipated that AVT could be a complementary mobility option rather than a complete solution for all people with disabilities. Also, many transit experts predicted that transit agencies would keep the traditional paratransit with human drivers because these drivers add a "sense of comfort" and an "assurance." Furthermore, some transit service experts suggested that AVT would change the roles of current drivers, instead of removing them, by having more focus on customer service. This could mean, as transit experts reported, an expanded employment opportunity as transit agencies would not need to require "driving″ skills for the drivers.

2.4. Discussion and Conclusions

Our results reconfirm the mobility issues examined in previous studies and that people with disabilities enthusiastically expect AVs to improve their mobility. Also, the results show that transit service experts expressed their overall supportive views on the potential of AVT to improve people with disabilities' mobility. Such expectations are partly due to their hope to resolve lingering problems with public transit services. However, our findings also identify participants with disabilities' concerns and anxieties about AVT. Most participants with disabilities are concerned about whether AVT is accessible to all people. Moreover, the remaining issues in neighborhood built environments add further doubts to participants with disabilities about the effectiveness of AVT to improve their mobility. For example, inaccessible and/or poorly-maintained built environments would offset the benefits even though AVT can expand mobility options.

Expectations and concerns of people with disabilities regarding AVT have rarely been addressed in previous studies. Despite concerns and uncertainties, policy-makers and planners should prepare targeted strategies to ensure that all people can take full advantages of AVT. To borrow a phrase from one of the transit service experts, “People with disabilities should not be left out of the opportunities that AVT would provide.” Accessibility for people of all ages and abilities should be considered from the early stages of technological development. Supportive built environments should be synergized with technology deployment, to better leverage the potential of AVT to improve mobility for people with disabilities.

The findings from the focus groups of people with disabilities and transit service experts lead to the following three reflections for policy-makers and planners. First, ensuring the accessibility and safety of AVT, second, promoting cooperative relationships among stakeholders, and third, mitigating users’ anxiety toward AVT via education and outreach programs.

2.4.1. Ensure Accessibility and Safety for All People

For people with disabilities, AVs are emerging as a transformational travel mode with a promise of providing freedom of travel and independent travel. However, if service providers do not consider accessibility across different types of disabilities, the expected benefits would be available only for a few groups. While this study focused on individuals with visual or mobility limitations, accessibility for individuals with cognitive or health-related disabilities should also be considered. Policy-makers should remember that, as shown in this focus group study, people with disabilities have different levels of capabilities. To meet their diverse needs, service types should also be diverse and flexible in terms of vehicle size, design, and communication-aids. Universal design should be a required element for people with disabilities to ensure their access to and independent use of AVs (Ferati et al., 2018; National Center for Mobility Management, 2018; Sundararajan et al., 2019). Such universal design principles should also be applied to the urban planning process to allow people with disabilities to benefit from AVT fully. For example, to ensure efficient traffic flow, some scholars have suggested designated areas for AV pick-up and drop-off (Chapin et al., 2016; Crute et al., 2018). However, such areas also must be safe and accessible to people with disabilities. As participants with disabilities pointed out, barrier-free sidewalks, access ramps or curb cuts, and APS should be considered requirements, not optional amenities.

In addition to accessibility, ensuring safety also is important to increase the reliability of AVT. Since the majority of concerns regarding safety came from the absence of human operators during the travel, service providers may need to prepare several options for customers who may request human assistant or observer. Although the possibility of mechanical defects also was mentioned as the factor that brings the anxiety of AVs, this issue might be resolved as the technology improved and appropriate built environments/infrastructure (e.g., Bluetooth devices along the roads or certain points that can replace or supplement GPS devices) provided.

2.4.2. Promote Cooperative Relationships among Transit Agencies, Local Authorities, and Industries

Given the wide range of influences that AVT will bring, agenda-setting should not be considered for public transit alone: multi-sectoral cooperation should be required (Fraedrich et al., 2018). Currently, many transit agencies cooperate with one another or with other entities, including local governments, non-profits, and private sectors, to serve riders with special needs. Such cooperation should be enhanced through more discussions between various sectors because accessible AVT would be available when developed technology, appropriate built environments and infrastructure, and diverse service options are well-prepared for people with disabilities. For example, local authorities would be required to incorporate technologies needed for the operation of AVT into the infrastructure (e.g., vehicle-to-infrastructure connection) to supplement inaccurate GPS wayfinding systems. Also, private sectors, including TNCs and local taxi companies, should be cooperative partners rather than competitors to serve people with disabilities to provide flexible and reliable services for people with disabilities.

The picture of the city with AVT will depend on how various sectors cooperate. To avoid the adverse effects of AVs, such as the flood of private AVs, many sectors, including state DOTs, transit agencies, local authorities, planning organizations, and industries, need to develop clear and detailed plans to take advantage of AVT. Some transit service experts stated that the lack of consistent policy guidelines would be one of the serious challenges in undertaking the projects. Thus, more research and projects may need to be conducted to enable anticipating and developing a more effective plan for AVT (Fagnant & Kockelman, 2015).

2.4.3. Provide Education, Training, and Outreach Programs

Various education and outreach programs may mitigate anxiety towards AVT. Principles and programs developed by relevant Non-Governmental Organizations provide reference materials for decision-makers and stakeholders to achieve desirable outcomes in the transition period of AVs (Litman, 2018). Several concerns about AVT, including safety and technical issues, could be relieved when the public understands what the technology entails and how that technology can serve their needs safely and reliably. In this regard, efforts like pilot projects that engage the public would be helpful.

Also, various training programs should be developed for both passengers and drivers of public transit. For passengers, travel training, which is similar to programs that many transit agencies currently provide for people with disabilities, should be provided during a period of transition to AVT to relieve the expressed anxieties and concerns. In addition, continuous and regular training programs may also need to be prepared for additional individuals who may need the service as their health, sensory, or mobility conditions change. Vocational training should be developed for current transit drivers, thus allowing them to transfer to other roles. Instead of driving, these roles could include customer services, security, and vehicle control and maintenance.

The reflections from the findings of this study provide initial insights on shaping AVT strategies and policies relevant to improving mobility for people with disabilities. Future research should consider investigating other types and severity of disabilities as well; hence AVT has to anticipate the need for diverse strategies in order to provide appropriate and inclusive services for people with disabilities.

3. PEOPLE WITH DISABILITIES' PERCEPTIONS OF AUTONOMOUS VEHICLES AS A VIABLE TRANSPORTATION OPTION TO IMPROVE MOBILITY: AN EXPLORATORY STUDY USING MIXED METHODS

Since the invention of internal-combustion vehicles, driving has dramatically improved human mobility by allowing people to move faster and farther. However, people who cannot drive may have been left out of the benefits of automobiles. Due to the automobile-dependent development patterns in many U.S. cities, people who cannot use a personal vehicle suffer from limited ability to travel (Donaghy et al., 2004). This is especially true of people with disabilities. With limited access to personal vehicles, they are forced to rely on public transportation or caregivers.

Public transportation in the U.S., however, has not been well used by people with disabilities. According to the U.S. Department of Transportation (USDOT), only 3.7% of people with disabilities used local public transit services in 2017, while 84% traveled by a personal vehicle as a driver or passenger (Brumbaugh, 2018). One national survey suggested a possible reason for the high dependency on personal vehicles is the limited availability of public transit services. The survey found that one-third of Americans with disabilities had no public transit options in their neighborhoods (Rosenbloom, 2007).

People with physical or mental disabilities may be unable to access certain transportation modes. In 2017, USDOT revealed that about 25.5 million Americans, aged five and older, reported that they have travel-limiting disabilities, and they made fewer trips than people without disabilities (Brumbaugh, 2018). Previous studies reported that impaired mobility is one of the most serious obstacles for people with disabilities, limiting their access to healthcare services, physical and social activities, and job opportunities (Blais & El-Geneidy, 2014; Bowe, 1979; Kenyon et al., 2002; Kim & Ulfarsson, 2013; Lubin & Deka, 2012; Montarzino et al., 2007).

In the near future, autonomous vehicle (AV) technologies are expected to improve people with disabilities' mobility. Individuals who cannot drive, due to their disabilities or age, would be able to take full advantage of automobiles when driving skills are no longer necessary (Alessandrini et al., 2015; Anderson et al., 2014). Hence, when AVs are available on the road, people with disabilities could be among the largest beneficiaries.

Several studies offer evidence supporting the benefits of AVs to the social and economic environment of people with disabilities. For instance, a study undertaken by Claypool et al. (2017) suggests that around two million people with disabilities in the U.S. could access new employment opportunities through AVs. In addition, they expect that AVs would prevent patients from missing their medical appointments due to limited transportation, which could reduce wasted healthcare expenditures by as much as $19 billion. Other researchers also predict that people with disabilities and other non-drivers would have more freedom to travel when AVs become available (Fagnant & Kockelman, 2015; Harper et al., 2016; Kröger et al., 2018).

In terms of the safety of all road users, AVs are expected to eliminate, or at least mitigate, the risk of crashes due to human errors (Anderson et al., 2014; Hayes, 2011). In the U.S., on average, one pedestrian was killed in a car crash every 1.5 hours in 2016 (NHTSA, 2018b). Although all pedestrians are vulnerable to motor vehicles, people with disabilities require special considerations (e.g., different requirements for infrastructure, such as detectable warning surface, curb cuts, accessible pedestrian signals) to ensure their safety (Czech, 2017; OECD, 1998). Since most car crashes are caused by human drivers' errors (NHTSA, 2018a), the capability of AVs to drive without human errors could mitigate the risk of crashes. According to one study that used game theory to analyze the interactions between pedestrians and AVs, pedestrians could feel safer when they share the streets with AVs because people may believe that the vehicles would be more careful than human drivers in recognizing pedestrians (Millard-Ball, 2018). People with disabilities, especially those who use a wheelchair, are more difficult to stand out to human drivers because their height is lower when sitting in wheelchairs (Hwang et al., 2020); therefore, they expect that AVs could more accurately recognize them. The road safety with AV technology will ensure that all pedestrians, including people with disabilities, are safe to travel (Sundararajan et al., 2019).

Despite the expected benefits of AVs for people with disabilities, few attempts have been made to determine their perspectives, while several prior studies have examined the general public's view of AVs (Bansal et al., 2016; Kyriakidis et al., 2015; Nordhoff et al., 2016, 2018; Zmud et al., 2016). The primary objectives of this paper are to explore the mobility issues of people with disabilities and to capture their overall perceptions of the potential use of AVs as a viable mode of transportation. In order to understand what people with disabilities think about autonomous vehicle transportation (AVT) services, this study uses mixed methods including focus groups and survey.[1] Pearson's correlation analyses were conducted to elucidate people with disabilities' perceptions of AVs. Additionally, we assess the acceptance level of AVT among people with disabilities by using state preference choice experiments in the survey.

This study focuses on the two types of disabilities, physical disabilities (e.g., difficulty walking or climbing stairs) and visual impairments (e.g., blind or difficulty seeing, even when wearing glasses).[2] People who have these types of disabilities are reported to have more barriers to using public transit than people who have other types of disabilities (Bezyak et al., 2017). The findings of this study are expected to make an important contribution to shaping AVT strategies for improving the mobility of people with disabilities.

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[1] AVT in this paper refers to the on-demand transportation services incorporating AV technologies.
[2] This study referred to the American Community Survey for the definitions of each type of disability (U.S. Census Bureau, 2017).

3.1. Methods

3.1.1. Mixed Methods

This study used an exploratory sequential mixed methods design (ESMD) to develop an instrument that examines how people with disabilities perceive AVT. In many applications of ESMD, researchers have developed instruments for quantitative analyses based on qualitative studies (Creswell & Clark, 2017). ESMD is considered ideal for the exploration of rarely discussed phenomena. Thus, due to the lack of empirical research on the research topic of the current study, ESMD was selected as an appropriate research design. This study was conducted in three main phases: (1) the design and implementation of focus groups, (2) the development of survey instrument, and (3) the collection and analysis of survey data.

3.1.2. Phase 1: Design and Implementation of Focus Groups[3]

Using a qualitative approach, the first phase of the research aimed at soliciting opinions from people with disabilities about their current mobility issues and the potential of AVT to improve their mobility. The authors ran a total of six focus groups in Austin and Houston, Texas, from September 2018 to February 2019. The focus groups consisted of three types of participants, including people with physical disabilities (n = 10), people

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[3] A more detailed discussion about the focus group procedures and results can be found in Hwang et al. (2020).

with visual impairments (n = 13), and transit service professionals (n = 10).[4] The focus group sessions lasted from 60 to 90 minutes, and each session was audio-recorded and transcribed. The transcripts were analyzed using the conventional content analysis approach for qualitative coding, which allows identifying emerging themes and categories (see Hsieh and Shannon, 2005).

The focus group results showed that participants with disabilities still have mobility issues in current public transit services and neighborhood built environments. Participants with disabilities showed a high expectation that AVT can resolve their mobility issues, despite many concerns and anxieties regarding the accessibility and safety of the technology. The results also suggested that people with disabilities' frustrations at the current mobility issues might motivate the interests in AVT, resulting in a high expectation.

3.1.3. Phase 2: Development of the Survey Instrument

Building upon the focus group results, the researchers developed a survey instrument to capture people with disabilities' travel behavior and their perceptions of AVT. The survey consists of the five sections to ask about: (1) travel behavior, (2) attitudes toward neighborhood public transit services and built environments, (3) perceptions of AVT, (4) preferred mode of transportation considering AVT, and (5)

[4] Transit service professionals were recruited to provide professional insights into the potential of AVT.

socio-demographic and economic characteristics. The screen-out questions were used to allow only the eligible people (i.e., individuals aged 18 and over with physical disabilities or visual impairments, living in the Austin or Houston areas) to take part in. The survey was developed using the Qualtrics online platform. To ensure the accessibility of the platform, a pilot survey was administered to 14 people with disabilities and an accessibility expert from the Division of Information Technology and the Department of Disability Services at Texas A&M University. The final survey instrument used in this study can be found in the Appendix C.

3.1.3.1. Phase 2-1: Travel Behavior

The first section of the survey captured the respondent's revealed preference (RP), which describes the actual travel behavior or mode choice (Hensher, 1994). Respondents were first asked to provide detailed information about recent trips. In this survey, a trip meant travelling from one location (origin) to another (destination). If respondents had made multiple trips, they were asked to report up to six individual trips in chronological order. For each trip, respondents reported the origin, destination, departure time, mode of transportation, and trip purpose.

3.1.3.2. Phase 2-2: Survey Items related to Attitudes and Perceptions

In addition to the focus group results, the previous literature on transit service, built environments, and the general public's acceptance of AV provided insights into the development of survey items related to people with disabilities' attitudes toward AVT (Deb et al., 2017; Habib et al., 2011; Mahmoud & Hine, 2013; Murray et al., 2010; Wen et al., 2005; Zmud et al., 2016). We developed 48 survey items under the three themes (i.e., public transit service, neighborhood built environments, and AVT). Respondents were asked to evaluate each item on a 5-point Likert-type scale (1 = Strongly Disagree and 5 = Strongly Agree). A full description of each item can be found in the figures in the next section. The online survey platform presented an average of 10 items per page to reduce the respondent's fatigue due to the length of the survey.

3.1.3.3. Phase 2-3: Stated Preference Choice Experiment

To examine participants' mode choice preferences, this study used stated preference (SP) choice experiments. The SP data describe respondents' potential choices using a set of pre-developed measures. The measures usually consist of the mixes of different attributes of alternatives, based on real and/or hypothetical scenarios (Hensher, 1994). Despite mixed opinions about their reliability and validity, SP methods have been used widely since the late 1960s by scholars and professionals interested in estimating demand for new products (Louviere et al., 2000). The particular attractiveness of SP choice experiments is their capacity to explore the choice preference of non-existent alternatives by using hypothetical scenarios (Hensher, 1994; Kroes & Sheldon, 1988).

SP experiments have been applied to a number of previous studies aimed at exploring how travelers evaluate the trade-offs between modes of transportation, including AVs (Asgari et al., 2018; Correia et al., 2019; Krueger et al., 2016; Shabanpour et al., 2018). The SP experiment for this study was designed using pivoting methods, which create a customized hypothetical choice set based on each respondent's familiar context. This approach enriches the SP data by providing a reference point for making decisions similar to the real-life of respondents (Campbell et al., 2016).

Before the presentation of the SP choice experiments, the respondent was shown an instruction page explaining the concept of choice experiments and the definition of each alternative. In this instruction page, respondents were requested to imagine making the reference trip once again, choosing the most preferred alternative among the five.

This study used respondents' RP data captured in survey section 1 (travel behavior) to build individual-specific choice experiments. The survey platform randomly selected one of the reported trips, then calculated the travel time and travel cost based on the travel distance (linear distance between origin and destination). From this point, we define the selected trip as a reference trip. Since this study used Google Map® to allow respondents to report the exact locations of trip origin and destination, the survey platform was able to automatically calculate the reference trip distance using the X-Y coordinates.

The survey presented 12 choice experiments to each respondent. In each choice experiment, respondents were asked to choose the most preferred mode of transportation among five alternatives: single-ride AVT, shared-ride AVT, ADA paratransit, bus, and personal vehicle (as a driver or a passenger). The following three attributes were determined to specify each alternative and to create trade-offs among alternatives:

- Travel time: the sum of in-vehicle and out-of-vehicle time,
- Travel cost: the approximate monetary cost of the trip per mile, and
- Human-assistance: the presence of a professional human operator to assist passengers.

Table 3.1 presents an overview of the attributes and attribute levels for each alternative in the SP experiment.

Table 3.1 Overview of attributes and attribute levels

Alternative	Attribute	Definition	Attribute level
AVT (single-ride)	Travel time (minute)	$\frac{Reference\ trip\ distance}{(25\ \text{mph}/60)} + 5\ \text{minutes}$	• Reference travel time • Reference travel time + 30% • Reference travel time – 30%
	Travel cost	$\$0.5\ \times Reference\ trip\ distance$	• Reference travel cost • Reference travel cost + 30% • Reference travel cost – 30%
	Human-assistance	The presence of a professional assistant	• Yes • No
AVT (shared-ride)	Travel time (minute)	$\frac{Reference\ trip\ distance}{(25\ \text{mph}/60)} + 10\ \text{minutes}$	• Reference travel time • Reference travel time + 30% • Reference travel time – 30%
	Travel cost	$\$0.4\ \times Reference\ trip\ distance$	• Reference travel cost • Reference travel cost + 30% • Reference travel cost – 30%
	Human-assistance	The presence of a professional assistant	• Yes • No

Table 3.1 Continued

Alternative	Attribute	Definition	Attribute level
ADA Paratransit	Travel time (minute)	$\frac{Reference\ trip\ distance}{(14.9\ \text{mph}/60)} + 15\ \text{minutes}$	• Reference travel time • Reference travel time + 30% • Reference travel time – 30%
	Travel cost	An average fare of ADA paratransit service in the study areas	• $1.83
	Human-assistance	The presence of a professional assistant	• Yes
Bus	Travel time (minute)	$\frac{Reference\ trip\ distance}{(12.1\ \text{mph}/60)} + 15\ \text{minutes}$	• Reference travel time • Reference travel time + 30% • Reference travel time – 30%
	Travel cost	An average fare of fixed-route bus service in the study areas	• $1.25
	Human-assistance	The presence of a professional assistant	• Yes
Personal vehicle	Travel time (minute)	$\frac{Reference\ trip\ distance}{(30\ \text{mph}/60)} + 5\ \text{minutes}$	• Reference travel time • Reference travel time + 30% • Reference travel time – 30%
	Travel cost	$\$0.7 \times Reference\ trip\ distance$	• Reference travel cost • Reference travel cost + 30% • Reference travel cost – 30%
	Human-assistance	The presence of a professional assistant	• No

The first step to estimate the travel time was calculating the in-vehicle time, which is the riding time during which people actually travel onboard. The in-vehicle time was calculated by dividing reference trip distance by the average vehicle speed. For each alternative, the average vehicle speed was predetermined through the literature review. This study assumed that trips were made in urban environments in Texas. According to the previous research, 20 to 30 mph was widely used for AV's average speed (Burns et al., 2013; Chen & Chao, 2011; Childress et al., 2015; Gettman et al., 2017; Zhang et al., 2015). Hence, this study assumed an average vehicle speed of 25 mph for the AVT alternatives. For the public transit vehicle speed, this study referred to the report published by the American Public Transportation Association (APTA). In 2016, an average speed of the fixed-route bus and ADA paratransit/demand-response modes was 12.1 mph and 14.9 mph, respectively (APTA, 2018). Lastly, the average speed of personal vehicle was determined to be 30 mph, based on the Texas speed limits on the streets in urban districts and on the national average traffic speed in urban areas.[5]

The out-of-vehicle time includes wait, boarding/alighting, access/egress, and parking time.[6] This study used the following values based on the previous literature (Asgari et al., 2018):

- Single-ride AVT: 5 min (wait and boarding/alighting time)
- Shared-ride AVT: 10 min (wait and boarding/alighting time)
- ADA paratransit: 15 min (wait and boarding/alighting time)
- Bus: 15 min (wait, boarding/alighting, and access/egress time)
- Personal vehicle: 5 min (parking and access/egress time)

For the two AVT and two public transit alternatives, this study incorporated additional minutes to board and alight, considering the delay involved in using the special equipment for people with disabilities. The boarding/alighting time also reflects the time to wait for other passengers' pick-up and drop-off for the public transit alternatives and shared-ride AVT.

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[5] Speed limits on Texas roads in urban district is 30 mph (TEX. TRANSP. CODE § 545.352) and average traffic speed in urban areas in the U.S. was 27.6 mph (Bureau of Transportation Statistics, 2018).

[6] The wait time refers to the time to wait for the vehicle coming. The access/egress time involves the first- or last-mile travel time (e.g., between the bus stop/parking lot and the origin/destination).

The travel cost was estimated by multiplying the reference trip miles and the base cost per mile. To determine the base cost per mile of each alternative, this study used diverse sources. The American Automobile Association (AAA) reported that an average driving cost is $0.77 per mile when the vehicle is a medium sedan, considering 10,000 miles per year as a benchmark for average vehicle miles traveled (VMT).[7] Therefore, in this study, the base cost of $0.7 per mile was set for a personal vehicle. Also, this study assumed a base cost of $0.4 for a shared-ride AVT. This cost is consistent with the presumptions in the previous literature that shared autonomous vehicles (SAV) will become an affordable mobility option when compared to private vehicles (Burns et al., 2013; Krueger et al., 2016). Considering that Uber's single-ride is $0.1 more expensive than shared-ride, $0.5 was set for a single-ride AVT as the base cost. The cost was intended to create a reasonable trade-off between the two AVT alternatives. For paratransit and bus alternatives, the travel cost was fixed at an average fare of each transit service for a one-way trip in the Austin and Houston areas (i.e., $1.25 for the bus and $1.83 for the paratransit), assuming no added charges.

The attribute levels of each alternative were determined by pivoting around the value of a reference trip. For the travel time attribute, all alternatives have three attribute levels, ranging $\pm$30% of the reference trip. On the other hand, for the travel cost attribute, the two AVT alternatives and personal vehicle have three levels, whereas bus

[7] According to the Federal Highway Administration, the VMT per capita in 2017 was 10,007 miles (USDOT, 2018).

and paratransit alternatives have only one level because of the fixed cost. Also, in terms of the human-assistance attribute, the two AVT alternatives have two levels (i.e., "Yes" or "No"), but the other alternatives have only one level (i.e., "Yes" for the public transit and "No" for the personal vehicle).

Finally, to generate the sets of choice experiments with combinatorial mixes of attribute levels, this study used the Conjoint.ly online platform, which creates a fractional factorial design optimizing balance and overlap (https://conjoint.online). This online platform has been used in several previous studies that applied choice experiments (Golda et al., 2019; O'Dell et al., 2019; Ross & Vidovich, 2018). Whereas a full factorial design includes all possible choice sets with all attributes, a fractional factorial design consists of partial choice sets from a full factorial design (Rose & Bliemer, 2009). A fractional factorial design is used commonly to reduce the number of choice sets combinations, while minimizing the correlation between the attribute levels in the choice sets (Rose & Bliemer, 2009).

To generate choice sets through the Conjoint.ly platform, users need to provide absolute values of attribute levels. However, since this study used the respondent's RP data as a reference point, it was not possible to provide the specific values to Conjoint.ly before the RP data were collected. Thus, we predetermined three different scenarios by using a virtual reference trip distance as follows:

- Scenario 1) Short-Distance Trip of 3 miles
- Scenario 2) Medium-Distance Trip of 8 miles

- Scenario 3) Long-Distance Trip of 15 miles

Based on these reference trip miles, the researcher calculated attribute levels for each scenario, and then uploaded them to the Conjoint.ly platform to create fractional factorial designed choice sets. Table 3.2 shows the calculated attribute levels for each scenario.

Table 3.2 Attribute levels for each scenario

Scenario	Alternative	Attribute and Attribute Level							
		Travel Time (minute)			Travel Cost			Human Assistant	
1	AVT (single-ride)	9	12	16	$1.05	$1.50	$1.95	Yes	No
	AVT (shared-ride)	12	17	22	$0.84	$1.20	$1.56	Yes	No
	ADA Paratransit	19	27	35	$1.83			Yes	
	Bus	21	30	39	$1.25			Yes	
	Personal vehicle	8	11	14	$1.47	$2.10	$2.73	No	
2	AVT (single-ride)	17	24	31	$2.80	$4.00	$5.20	Yes	No
	AVT (shared-ride)	20	29	38	$2.24	$3.20	$4.16	Yes	No
	ADA Paratransit	33	47	62	$1.83			Yes	
	Bus	38	55	71	$1.25			Yes	
	Personal vehicle	15	21	27	$3.92	$5.60	$7.28	No	
3	AVT (single-ride)	29	41	53	$5.25	$7.50	$9.75	Yes	No
	AVT (shared-ride)	32	46	60	$4.20	$6.00	$7.80	Yes	No
	ADA Paratransit	53	76	99	$1.83			Yes	
	Bus	63	89	116	$1.25			Yes	
	Personal vehicle	25	35	46	$7.35	$10.50	$13.65	No	

Through the Conjoint.ly platform, we established 384 choice sets for Scenario 1 and 288 choice sets each for Scenario 2 and 3. The platform randomly grouped these choice sets into blocks, with 12 choice sets in each block. As a result, Scenario 1 had 32 blocks and Scenario 2 and Scenario 3 had 24 blocks each. Next, the researcher changed the absolute values of attribute levels in the choice sets into the variables to allow the survey platform to create individual-specific choice sets. Figure 3.1 presents an example of this transition.

Example of a choice set in Scenario 2

	AVT (single-ride)	AVT (shared-ride)	Paratransit	Bus	Personal Car
Travel time	24 minutes	38 minutes	62 minutes	55 minutes	15 minutes
Travel cost	$5.20	$2.24	$1.83	$1.25	$7.28
Human-assistance	Yes	No	Yes	Yes	No

Change the values of attribute levels into variables

	AVT (single-ride)	AVT (shared-ride)	Paratransit	Bus	Personal Car
Travel time	t2_AVT1	t3_AVT2	t3_PR	t2_BS	t1_PC
Travel cost	c3_AVT1	c1_AVT2	c1_PR	c1_BS	c3_PC
Human-assistance	HA_1	HA_2	HA_1	HA_1	HA_2

Figure 3.1 Example of transition from absolute values to variables to create individual-specific choice sets

This step allowed the Qualtrics platform to automatically generate an individual-specific design using the RP data of each respondent. Figure 3.2 describes how a respondent was assigned to scenario and block. When a respondent was assigned to the appropriate scenario, one of the blocks in the scenario was randomly selected, and 12 choice experiments of the selected block were presented to the respondent.

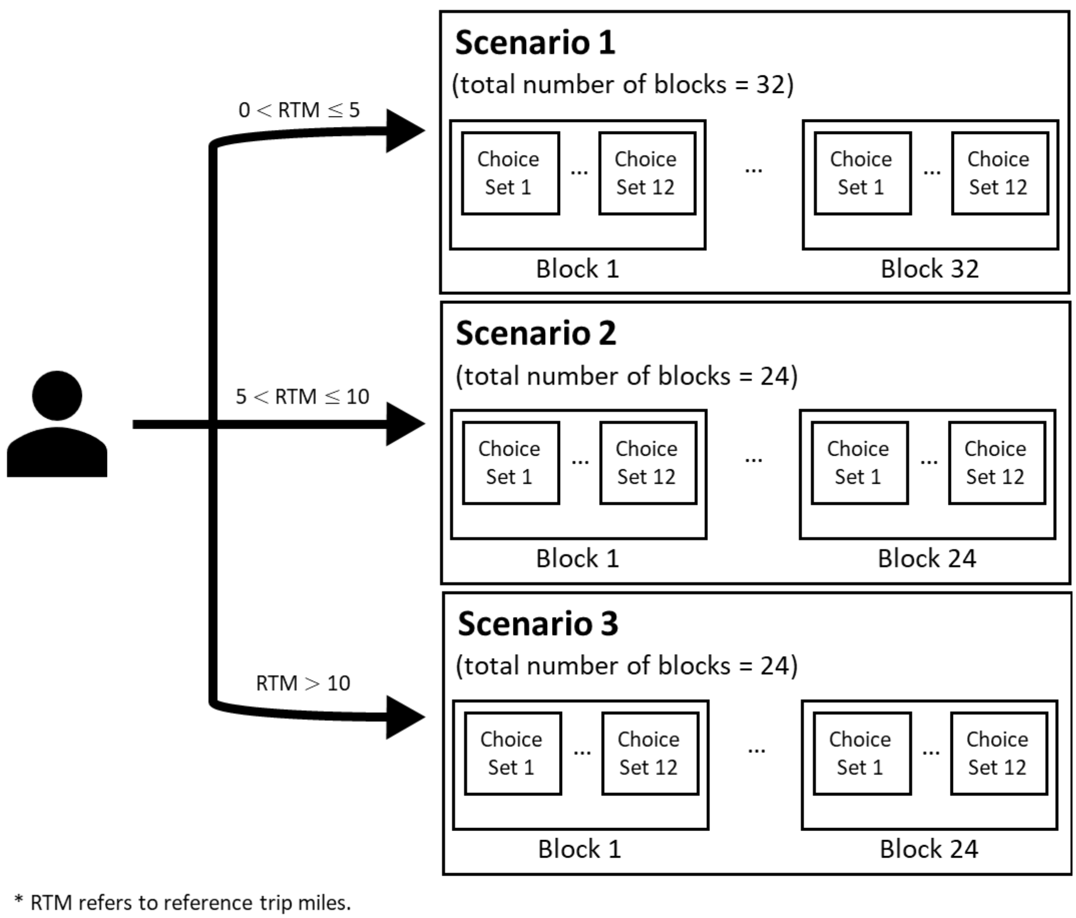

Figure 3.2 The process in which the respondent is assigned to each scenario and block

3.1.3.4. Phase 2-4: Socio-Demographic and Economic Characteristics

Upon completion of the SP choice experiment, respondents were asked to report their socio-demographic and economic characteristics. They were allowed to skip any of these questions to avoid providing what they deemed was sensitive information.

3.1.4. Phase 3: Data Collection and Analyses

The survey developed in the second phase was distributed in Phase 3. To compensate respondents for their time and effort, the researchers sent a $5 electronic gift card from Amazon or Walmart. The survey questions and protocol were reviewed and approved by Texas A&M University's Institutional Review Board.

The survey was available online between June and September 2019. The target population in this study consisted of people with disabilities, which has been considered a hard-to-reach population (Hasnain et al., 2014). In 2017, Austin had 36,559 individuals with ambulatory disabilities (4.3%) and 15,220 individuals with visual impairments (1.7%), while Houston had 116,946 (5.6%) and 46,865 (2.1%), respectively (U.S. Census Bureau, 2018a).

In previous studies, participants were recruited through "gatekeepers," who have access to the target population. The use of gatekeepers is due to difficulties in obtaining a full list of people with disabilities in a community, which is necessary to determine the sample frame (Becker et al., 2004). This study requested recruiting assistance from the three local transit agencies that provide paratransit services, three universities, and 25 disability organizations in the Austin and Houston areas.[8] These gatekeepers distributed the survey information to their clients, registered members, or students, through a mailing list, official websites, and social media. Additionally, survey participants were encouraged to forward the survey invitation link to anyone they knew who was eligible to take part in the survey.

This study used descriptive analyses to assess the response distributions. To gauge the internal consistency of the survey items capturing the respondents' attitudes and perceptions, we used Cronbach's alpha test (Santos, 1999). In turn, we calculated Pearson's correlation coefficients between survey items related to attitudes toward public transit services, built environments, and AVT. All analyses were conducted in R software (R Core Team, 2017).

3.2. Survey Results and Discussion

3.2.1. Descriptive Statistics

A total of 240 survey responses were collected, 18 were excluded due to low-quality answers (e.g., invalid trip locations) or ineligibility (e.g., resident location, disability type). The final dataset consisted of 222 responses, including 114 from the Austin area and 108 from the Houston area. The demographic and socio-economic compositions of the sample data were compared to those of the U.S. Census data from

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[8] The full list of organizations can be seen in Acknowledgement section.

the study areas (U.S. Census Bureau, 2018b). Overall, the sample was younger, more educated, and wealthier than the populations with disabilities in the study areas. This result may be due in part to the data collection method of this study; that is, an online survey was distributed by disability organizations and transit agencies thereby only individuals with disabilities who can access the Internet could take part in the survey (Bethlehem, 2010). Table 3.3 presents the demographic and socio-economic characteristics of the participants.

Table 3.3 Participants' demographic and socio-economic characteristics (N = 222)

Characteristics	n	%
Gender		
Female	138	62.2
Male	84	37.8
Age		
18–24	4	1.8
25–34	34	15.3
35–44	35	15.8
45–54	65	29.3
55–64	49	22.0
65 and over	35	15.8
Disability type *		
Physical disabilities	179	80.6
Visual impairments	61	27.5
Others	17	7.7
Race		
American Indian or Alaska Native	1	0.5
Asian	6	2.7
Black or African American	22	9.9
Native Hawaiian or Other Pacific Islander	1	0.5
White	172	77.4
Other	18	8.1
Not to answer	2	0.9

* Respondents could choose multiple disability types if they had more than one disability. "Other" types of disability in this survey included cognitive disability, hearing impairment, traumatic brain injury, etc.

Table 3.3 Continued

Characteristics	n	%
Ethnicity		
Hispanic or Latino or Spanish Origin	33	14.9
Not Hispanic or Latino or Spanish Origin	186	83.8
Not to answer	3	1.3
Highest education level		
Less than high school degree	4	1.8
High school degree or equivalent	26	11.7
Some college but no degree	42	18.9
Associate degree	46	20.7
Bachelor’s degree	56	25.3
Graduate degree	48	21.6
Employment status		
Full time employed	45	20.3
Part time employed	28	12.6
Self-employed	17	7.7
Unemployed	20	9.0
Student	8	3.6
Retired	70	31.5
Other	34	15.3
Annual household income		
Less than $15,000	45	20.2
$15,000 to $24,999	25	11.3
$25,000 to 49,999	45	20.2
$50,000 to $74,999	48	21.6
$75,000 to $99,999	26	11.7
$100,000 to $149,999	21	9.5
$150,000 or over	7	3.2
Not to answer	5	2.3
Number of available vehicles in household		
0	71	32.0
1	74	33.2
2	55	24.8
3	21	9.5
4	0	0.0
5 or more	1	0.5
Resident area		
Austin or the adjacent area	114	51.4
Houston or the adjacent area	108	48.6

* Respondents could choose multiple disability types if they had more than one disability. “Other” types of disability in this survey included cognitive disability, hearing impairment, traumatic brain injury, etc.

3.2.2. Perceptions of Autonomous Vehicle Transportation

Respondents reviewed 18 statements about their perceptions of AVT, with a focus on expectations and concerns (Cronbach's alpha = 0.90). Figure 3.3 shows the list of the statements and the agreement level. People with disabilities' perceptions of AVT were overall positive. Around 74% of the respondents either strongly agreed or agreed that AVT could solve the transportation problems of people with disabilities such as their own, while only 9% either strongly disagreed or disagreed (AV01). In addition, 73% of the respondents said that AVT would meet their travel needs (AV06). The data also showed respondents' expectations for cost savings from riding AVs; 66% stated that they would use AVT for daily travel because it would be cheaper (AV02). Around 55% of the respondents expected that AVT would bring them to destinations faster (AV04) and would remove the needs for parking (AV05).

On the other hand, respondents expressed concerns and/or doubts about using AVT. Regarding road safety, the respondents had split opinions. On the statement "AVT would make the roads safer (AV08)," 46% of the respondents either strongly agreed or agreed, while 38% neither agreed nor disagreed, and 16% either strongly disagreed or disagreed. Only 38% of the respondents believed that AVT would be safe and reliable in severe weather conditions (AV07) (42% neutral and 20% either strongly disagreed or disagreed). Moreover, 56% of the respondents strongly agreed or agreed that AVT might not be able to respond correctly in unexpected situations (AV14), compared to 30% neutral, and 14% expressing (strong) disagreement. Finally, 48% of the respondents strongly agreed or agreed that "AVT would drive safer than average human drivers (AV10)," while 51% showed doubts (41% neutral and 10% either strongly disagreed or disagreed). Other than the road safety issues, around 68% of the respondents were concerned about the computer or mechanical errors of AVT (AV16).

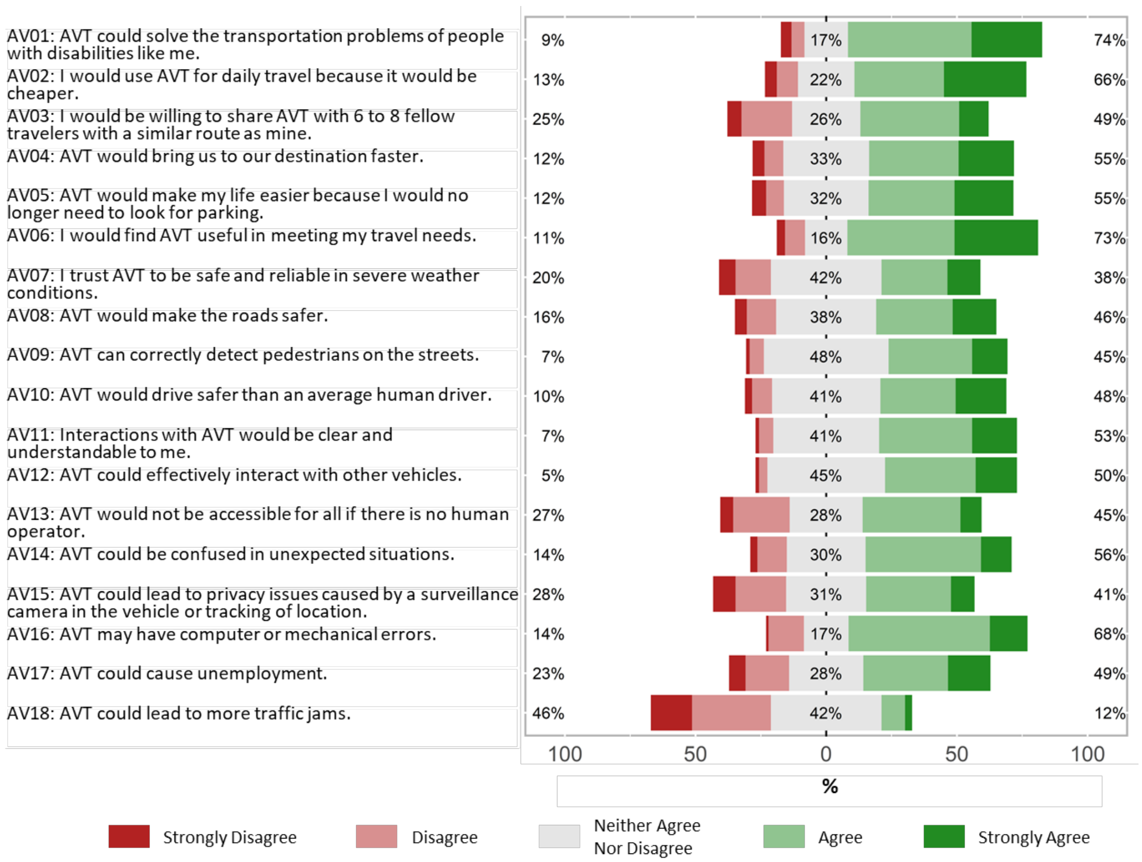


Figure 3.3 Perceptions of autonomous vehicle transportation (N = 222)

It also should be noted that about half of the respondents still preferred the presence of a human operator (AV13). As revealed in the focus group discussions, people with disabilities were perhaps concerned about accessibility and safety issues if there were no human operator in vehicles. In terms of the preferred service type, about half of the respondents were willing to share AVT with six to eight fellow travelers (AV03), whereas the rest held a neutral (26%) or negative (25%) attitude toward sharing an AVT ride. Interestingly, a majority of the respondents were not concerned about increased traffic. Only 12% expressed (strong) agreement that AVT could lead to more traffic jams (AV18). On the other hand, almost half of the respondents were worried about job loss that might be caused by AVs taking over from paid drivers (AV17).

Despite several concerns and doubts about AVT, the majority of the respondents said they expected that AVT could solve mobility issues. The respondents believed that AVT will enable independent travel, providing a cheaper and faster transportation option. However, the positive perceptions of AVT would not guarantee the success of AVT among people with disabilities. AVT may have to overcome several perceived barriers. Many respondents doubted its safety and reliability, due to possible technical deficits in extreme or unusual situations. The absence of a human operator also could be a serious problem as, without a human operator, AVT may not accommodate the unique travel needs of people with different levels and types of disabilities. It is noteworthy that almost three-quarters of the respondents had a positive attitude toward AVT although they had several concerns and doubts about the technology. Such rosy expectations for AVT might come from the serious frustrations with the many difficulties they found in the current public transit and built environments.

3.2.3. Mobility Issues related to Public Transit Service and Built Environments

Respondents' attitudes toward public transit service and the quality of neighborhood built environments reflected the challenges that the respondents confront when they travel. In the survey, respondents reviewed 12 statements about their neighborhood public transit service (i.e., fixed-route or paratransit). If public transit was not available in the neighborhood, they were asked to choose the "Not Applicable" option. On the other hand, if multiple modes of public transit were available, respondents had to think about what they used most frequently, or most preferred, when reviewing the statements. The Cronbach's alpha for the 12 items is 0.85.

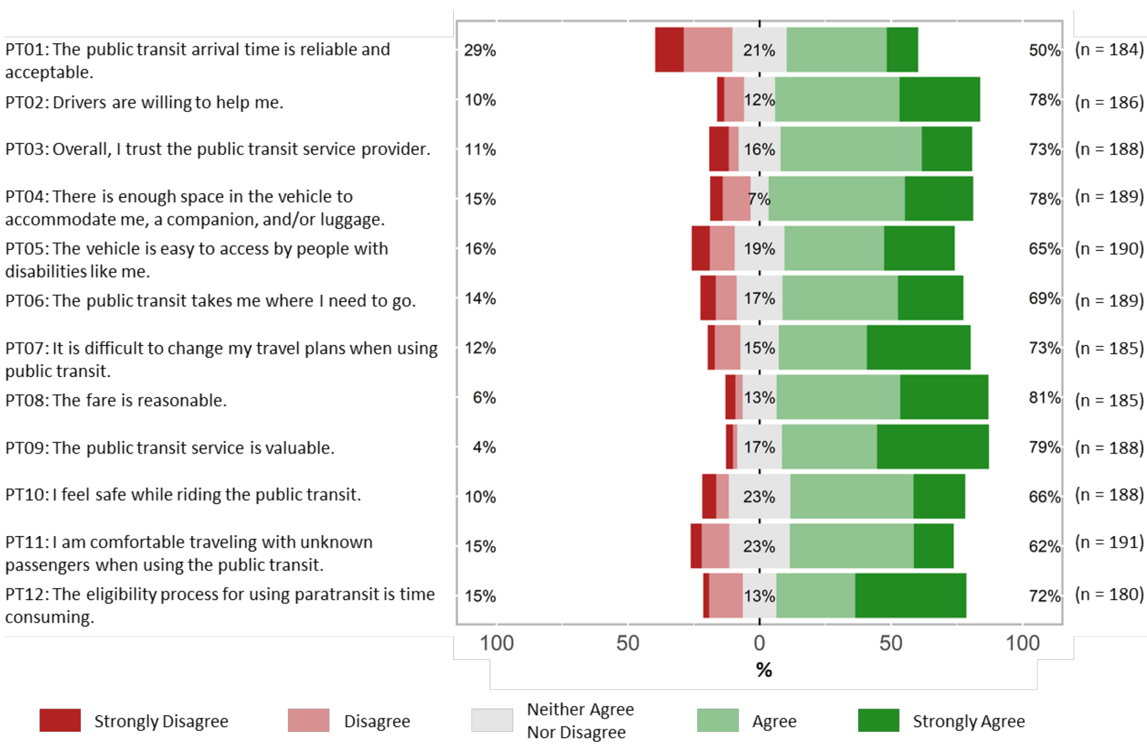


Figure 3.4 Respondents' attitudes toward public transit service

Figure 3.4 shows that the majority of respondents found it difficult to change their travel plans using public transit (PT07), and they found the eligibility-approval process for using paratransit to be time-consuming (PT12). Only half of the respondents considered the time schedule of public transit reliable and acceptable (PT01). The survey confirmed that the majority of respondents found public transit services problematic in terms of flexibility, accessibility, and reliability. However, the fact that respondents expressed a high level of trust (PT03) in them may show that public transit services are inevitably valuable to the respondents, given their very limited alternatives, as more than one-third of the respondents live in zero-vehicle households.

Pearson's correlation analysis supports the association between frustrations at public transit services and a positive attitude toward AVT. Figure 3.6 presents significant correlations ($p < 0.05$) among the variables (see Appendix B for a matrix with a full list of the variables). Although most of the correlations were moderate, we found that people with disabilities who did not like current public transit services tended to have favorable views on AVT. For example, respondents who did not trust public transit service providers had positive attitudes toward AVT, believing that AVT could solve the transportation problems of people with disabilities (PT03 and AV01, $r = -0.19, p < 0.05$). On the other hand, respondents who thought that the arrival time of public transit was reliable and acceptable were less favorable to AVT (PT01 and AV13, $r = -0.20, p < 0.01$). Also, respondents who had complaints about the inflexibility of travel and time-consuming eligibility process of paratransit had favorable attitudes toward AVT (PT07 and AV06, $r = 0.16, p < 0.05$; PT12 and AV01, $r = 0.20, p < 0.01$; PT12 and AV06, $r = 0.26, p < 0.01$). Interestingly, respondents who agreed that public transit drivers are willing to help them (PT02) were worried about unemployment that may be caused by AVT (AV17) ($r = -0.16, p < 0.05$).

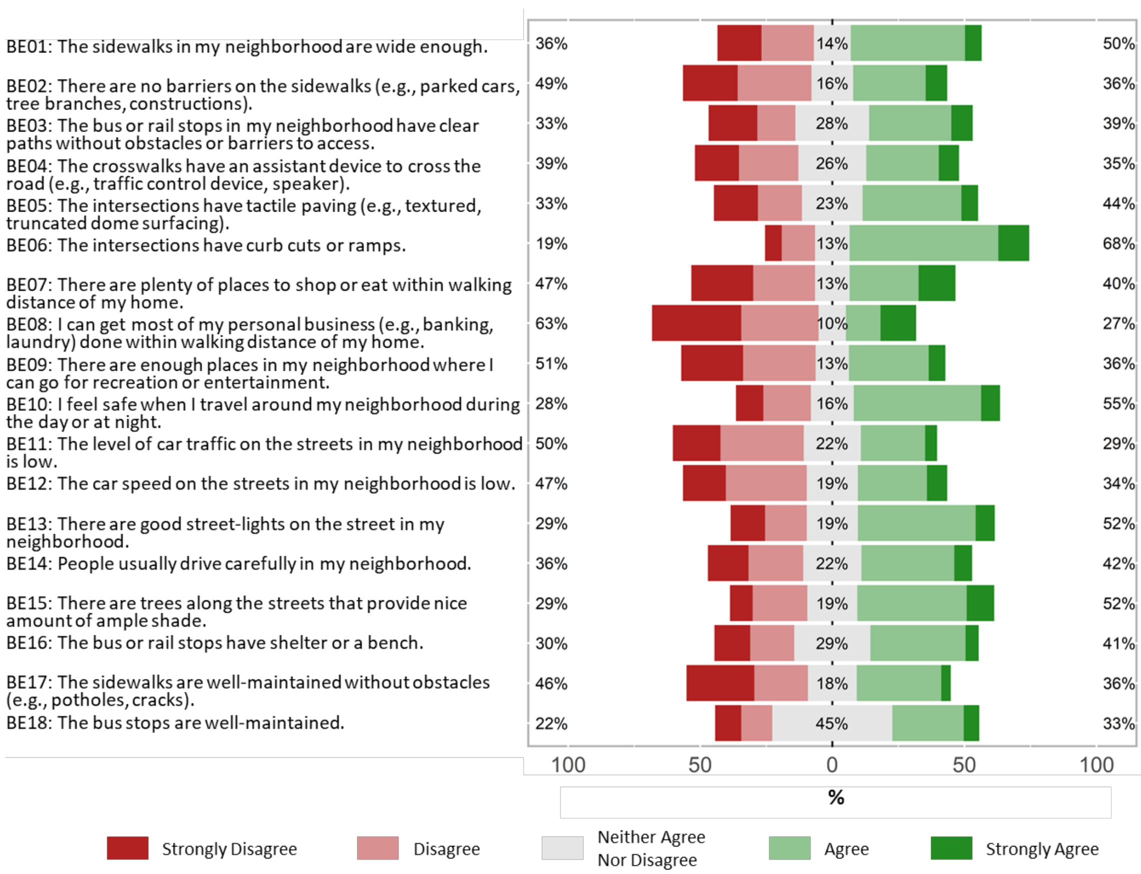
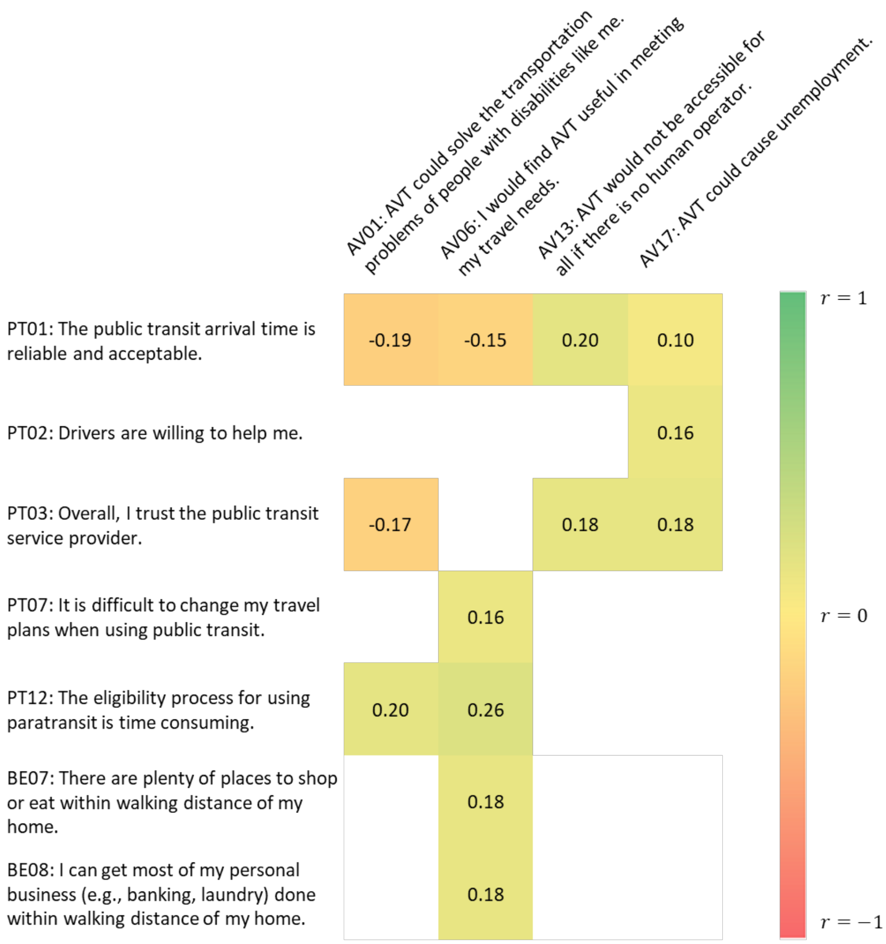


Figure 3.5 Perceived quality of neighborhood built environments (N = 222)

To obtain a general understanding of respondents' perceptions of neighborhood built environments, the survey included 18 items (Cronbach's alpha = 0.90). Figure 3.5

shows that respondents had relatively negative opinions about their neighborhood built environments for travel. Nearly half of the respondents complained about maintenance issues and barriers on the sidewalks, such as parked cars, tree branches, or construction projects (BE02 and BE17). And almost 63% of the respondents lamented the car-dependent land-use patterns of their neighborhoods (BE08). Nevertheless, the results also show that some features, including sidewalk width and curb cuts/ramps at intersections, were positively rated by the respondents. Such split opinions might be related to the differences in the quality of built environments across the neighborhoods.

The results of Pearson's correlation analysis showed that most correlations of the variables related to respondents' attitudes toward built environments and AVT are statistically insignificant except for a few. The results indicated that respondents who think that there are a lot of places for daily activities within walking distance of their home were more favorable to AVT, considering that AVT would be useful in meeting their travel needs (BE07 and AV06, $r = 0.18, p < 0.01$; BE08 and AV06, $r = 0.18, p < 0.01$). That is, AVT could be a viable transportation option for people with disabilities to travel a short distance. Another possible explanation for this is that AVT would be able to provide desirable services for people with disabilities in walkable neighborhoods, which generally have accessible and safe built environments (Forsyth, 2015).



Note. A correlation coefficient highlighted with color shade is statistically significant ($p < 0.05$). The color gradient runs for a coefficient value, from red ($r = -1$) to yellow ($r = 0$) to green ($r = 1$). Insignificant correlations ($p > 0.05$) are left blank.

Figure 3.6 Correlation matrix between attitudes toward public transit services, built environments, and AVT

Perhaps respondents were trying to see the potential of AVT to resolve problems with current public transit services, believing that AVT could considerably expand their transportation options. Meanwhile, the positive characteristics of public transit services, such as helpful drivers, accessible vehicles, and affordable fare, are what people with disabilities desire for AVT. While the issues raised by respondents regarding public transit services revealed a gap that AVT can fill, the problems with built environments can be solved only by policies and plans that supplement AVT and improve mobility for people with disabilities. The survey found that the built environment in the study areas posed several obstacles for people with disabilities who want to travel. Besides barriers on the sidewalks, poor maintenance (e.g., potholes and cracks) was a problem for people with disabilities. Moreover, policy-makers and planners may need to remodel car-dependent land-use patterns, as the majority of the respondents reported the lack of places for daily activities or recreation within walking distance. These mobility issues associated with neighborhood built environments will not be overcome by the advent of AVT. Rather, they require appropriate and detailed policies and plans for designing mobility supportive environments, using, for example, the universal design applications, including barrier-free infrastructure and accessibility-aids (Imrie, 2012; Story, 1998).

3.2.4. Mode Choice Preferences

3.2.4.1. Revealed Preferences

Many people with disabilities still relied on a personal vehicle to meet their various travel needs. Over half (52.5%) reported that they took trips with personal vehicles. However, this study also confirmed their reliance on other people for their travel, as 70% of personal vehicle trips were made as a passenger. Public transit services also played an important role. About one third (30.4%) of all trips were taken with paratransit, many of which were for medical service purposes. Such a percentage was higher than that reported in previous studies (Brumbaugh, 2018; Rosenbloom, 2007). This result may be explained by the oversampling of paratransit users through local transit agencies. Although not as great as paratransit, ride-sharing services (e.g., Uber or Lyft) also showed potential for future growth, as they had a similar level of shares compared to fixed-route service; 5.7% of the trips were taken with ride-sharing services, while 6.9% were by fixed-route transit services including bus and rail.

3.2.4.2. Stated Preference Choice Experiments

As described in the previous section, respondents were allocated to three different scenarios according to their RP data, that is, trip distance and purpose. Scenario 1 (S1: short-distance trips) was assigned to 136 respondents whose reference trip distance was below 5 miles; 47 respondents with reference trip distance of between 5 and 10 miles were allocated to Scenario 2 (S2: medium-distance trips); and Scenario 3 (S3: long-distance trips) was assigned to 39 respondents whose reference trip distance was longer than 10 miles. Since each respondent took 12 choice experiments, the three scenarios (S1, S2, and S3) had 1,632, 564, and 468 SP choices, respectively.

Table 3.4 SP mode choices by scenario

	AVT (single-ride)	AVT (ride-sharing)	Paratransit	Bus	Personal car
Scenario 1	757 (46.4%)	377 (23.1%)	201 (12.3%)	68 (4.2%)	229 (14.0%)
Scenario 2	168 (29.8%)	102 (18.1%)	147 (26.1%)	24 (4.2%)	123 (21.8%)
Scenario 3	139 (29.7%)	99 (21.2%)	108 (23.1%)	9 (1.9%)	113 (24.1%)
Total	1,064 (39.9%)	578 (21.7%)	456 (17.1%)	101 (3.8%)	465 (17.5%)

Table 3.4 presents the SP mode choice shares in each scenario. For all the scenarios, AVT dominated a mode share. About seven out of ten respondents chose AVT for their short-distance trips (S1). AVT's mode share was about 50% for either of the medium-distance (S2) and long-distance trips (S3) scenarios as well. Only 12.3% of the respondents chose paratransit for their short-distance trips; however, the share increased to 26.1% and 23.1% for medium-distance and long-distance trips, respectively. A similar pattern was observed for personal vehicle mode shares, which were 14% for the short-distance compared to 21.8% and 24.1%, respectively, for the medium-distance (S2) and long-distance trips (S3).

Compared to RP, there were drastic changes in mode choice shares for SP. First, the personal vehicle shares plummeted from 52.5% to only 17.5% (see Figure 3.7). Such a change may be due largely to respondents shifting to AVT. The paratransit and fixed-route shares also dropped from 30.4% to 17.1%, and from 6.9% to 3.8%, respectively. Instead, 61.6% of the respondents chose AVT for either a single-ride or ride sharing in the SP choice experiments. This shift might be attributed to a combination of the strong will of people with disabilities to travel independently and the expectation that AVT will make it possible. Moreover, considering AVT as a viable alternative, the mobility issues in current public transit services might contribute to the shift.

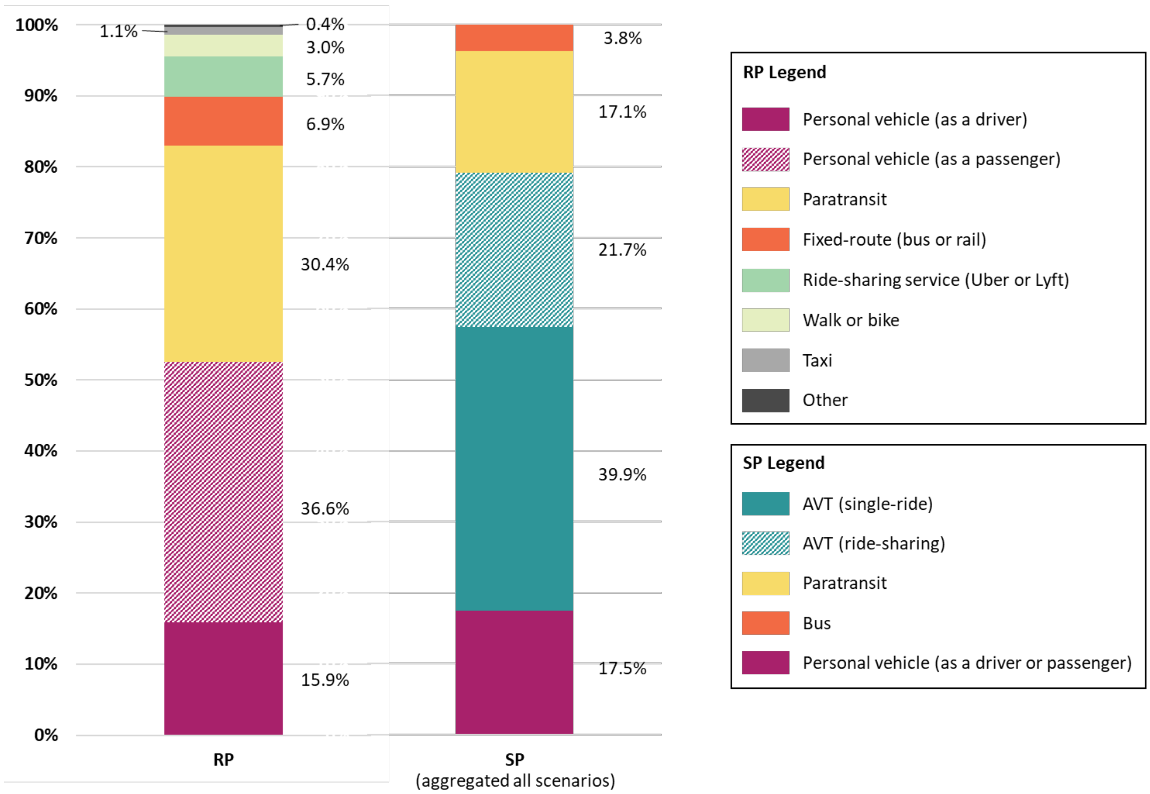


Figure 3.7 RP and SP mode choice shares

The results of the SP choice experiments corroborated that people with disabilities had a strong willingness to use AVT, despite the concerns they expressed in previous survey items. Regardless of the scenario, the respondents chose AVT more frequently than other modes of transportation. The decline of mode choice shares of personal vehicles could be a sign showing that people with disabilities desire to enjoy enhanced, independent mobility as people with disabilities mostly had to rely on someone else to use a personal vehicle. Furthermore, if paratransit users shift to AVT, which is expected to reduce operating costs with lower labor costs, it could alleviate the financial burden of transit agencies. As the operating cost of paratransit services is much greater than that of fixed-route services (U.S. Government Accountability Office, 2012), AVT could be an efficient, attractive alternative for public transit agencies.

However, service providers and policy-makers should be alarmed that nearly twice as many respondents chose the single-ride AVT over the shared-ride AVT. This might cause problems because ride sharing leads to more environmental benefits and improved cost efficiency. Many respondents might choose single-ride AVT because of saved travel time. Also, majority of participants were perhaps worried about traveling by AVT with strangers, and preferred enhanced privacy by the single-ride AVT. Nevertheless, the possibility of enticing them to opt for a ride-sharing service is still open. As revealed in Figure 3.4, it is remarkable that nearly half of the respondents were willing to share AVT with six to eight fellow travelers with a similar route (AV03). Therefore, service providers may need to explore strategies to encourage ride sharing, such as providing incentives or improving route optimization. In addition, policy-makers should come up with appropriate regulations or demand-management policies, for example, congestion pricing and subsidizing the cost of ride sharing, to prevent the roads from overflowing with single-ride AVs.

3.3. Conclusions

In this study, we employed an exploratory sequential mixed-methods design to examine the current mobility challenges faced by people with disabilities and their opinions about AVT use. This study reveals their interesting mode choice preferences as well. Findings show the promising potential of AVT to improve people with disabilities' mobility. This study confirms that many mobility issues related to the current public transit service and, to some extent, neighborhood built environments may be solved by AVT if appropriate strategies and policies are in place. Also, AVT would enable transit agencies to improve operational efficiency. People with disabilities expected that affordable and flexible AVT could give them more freedom of travel. At the same time, they also expressed doubts and concerns about the safety, reliability, and accessibility of AVT. Despite these concerns, they chose AVT as a preferred mode of transportation in the SP choice experiments, showing a high acceptance level.

The methodological framework of this study can be used in later research to explore people with disabilities' perceptions of a new transportation technology. In addition, the results can be the basis of future studies, specifically those empirically examining whether people with disabilities accept AVT, based on various factors, such as type and severity of disability. The authors recommend further research on more appropriate and supportive built environments to maximize the benefits of AVT for people with disabilities.

It is also important to recognize the limitations of this study. First of all, the study sample could be biased due to the data collection process. Online recruiting of participants might introduce bias, as not all people with disabilities have access to the Internet, given lack of online accommodations. Future research may consider using various data collection methods, as well as other types of disabilities (e.g., hearing disabilities and cognitive or learning disabilities) in other places. Also, the RP survey may not have captured the respondents' general travel pattern because the survey asked about the most recent trips, which probably are not representative of their typical travel behavior. Regarding the SP choice experiments, the results may be unreliable due to "hypothetical bias," which may occur if respondents do not fully understand the experiment, or if respondents strategically choose the answer in order to influence the policy outcomes (Correia et al., 2019; Stathopoulos et al., 2017).

Despite the several limitations, the findings provided meaningful insights into the development of AVT strategies for people with disabilities. When it comes to mobility improvement for people with disabilities, AVT can be a supplementary service rather than a complete solution. Considering the respondents' concerns and doubts about accessibility and safety of AVT as well as complex mobility issues related to public transit and built environments, we conclude that AV technology alone cannot overcome all the hurdles. Therefore, rather than expecting AVT to be a panacea for solving all problems, policy-makers and planners need to prepare more targeted strategies to help AVT become an available, accessible, and affordable mode of transportation for all.

AVT services had the promising potential to improve people with disabilities' mobility when appropriate strategies ensure the technology and built environments to be accessible and safe.

4. A STUDY ON THE STRATEGIES FOR AUTONOMOUS VEHICLE TRANSPORTATION TO IMPROVE MOBILITY FOR ALL

Autonomous vehicle (AV) technology has been expected to become a beneficial mode of transportation to some people since driving skills are not necessary to ride a vehicle any longer. People with disabilities are one of the most beneficiary groups from AVs as they currently cannot enjoy independent travel. Due to their limited health conditions, people with disabilities are more likely to rely on someone else when traveling. Thus, the benefits that people with disabilities can expect from AVs would be the improved mobility by expanding the available transportation options besides getting a ride from other persons or public transportation services. For people with disabilities, improved mobility means not only just *moving* but also more opportunities to access health-care services, jobs, physical or social activities, and education (Blais & El-Geneidy, 2014; Bowe, 1979; S. Kim & Ulfarsson, 2013; Lubin & Deka, 2012; Montarzino et al., 2007).

Given the potential benefits of AVs, it will be important to make AVs accessible to all people, not just the selected few. When AVs were introduced into transportation services—either by public transit agencies or private companies, it would be appropriate, righteous to reflect people with disabilities' views to ensure accessibility. Considering the recent trends in the growing number of populations with disabilities as the society is aging, understanding about their acceptance level or opinions would play a pivotal role in anticipating the success of autonomous vehicle transportation (AVT) services. While various studies have been conducted to explore the *general* public's views on AVs, people with disabilities' perspectives have been rarely discussed. Especially, few studies have investigated the impacts of AVs on people with disabilities' mode choice. People with disabilities' views on AVs may differ from that of people without disabilities because of their special needs and concerns (Bennett et al., 2019; Hwang et al., 2020). Hence, further empirical studies are needed to examine how people with disabilities' would react to the introduction of AVs into transportation services.

Using a stated preference (SP) experiments and a choice model, this study estimates AVT's likelihood of being chosen as a mode of transportation by people with disabilities. This study focuses on individuals with physical disabilities (i.e., having difficulty walking or climbing stairs) and individuals with visual impairments (i.e., blind or difficulty seeing, even when wearing glasses).[1] The modeling framework used in this study considers various factors, including individual characteristics and mode attributes. Also, built upon the previous studies, the modeling framework includes individuals with disabilities' attitudes toward public transportation services, built environments, and AVT as psychological factors that affect mode choice behavior (Hwang et al., 2020). To integrate such psychological factors into a choice model, this study employs a hybrid choice model (HCM), which explains both observable explanatory variables and

[1] This study referred to the American Community Survey for the definitions of each type of disability (U.S. Census Bureau, 2017).

unobservable latent variables (Ben-Akiva et al., 2002; Bolduc & Alvarez-Daziano, 2010).

The results of this study can identify the factors influencing people with disabilities' mode choice behavior when AVT was introduced. The findings can also be used to suggest appropriate strategies to serve people with disabilities in the era of AVs. The following section provides a brief overview of previous studies on individuals' perceptions or attitudes toward AVs. The methods used in this study are described next, followed by the presentation of the modeling results. The last section discusses the AV strategies to improve mobility for all people based on the findings.

4.1. Literature Review

The public perspectives on AVs have been examined in various studies. As AVs are not yet available for the public, most studies investigated the public acceptance of AVs focusing on awareness, expectations, and concerns, using descriptive analyses (Asgari et al., 2018; König & Neumayr, 2017; Kyriakidis et al., 2015; Liljamo et al., 2018; Schoettle & Sivak, 2014). Specifically, this group of studies explored individuals' previous knowledge of AVs, preferred type of AVT services (e.g., on-demand, single-ride), considerations in mode choice decision-making process, expected benefits of AVs, and psychological barriers or resistance towards AVs.

Some other studies also explored the factors influencing the public acceptance of AVs, using stated preference (SP) survey and econometric models (Bansal et al., 2016;

Daziano et al., 2017; Haboucha et al., 2017; Shabanpour et al., 2018; Yap et al., 2016). These studies, for example, investigated the impacts of individuals' characteristics (e.g., demographics and socioeconomic status), travel characteristics, built environment factors, and unobserved psychological factors (e.g., technology awareness, environmental concern, driving preference, public transit attitude, and AV preference) on individuals' decision-making process, such as willingness-to-pay, mode choice, and vehicle type preference.

Most previous studies were interested in the general public opinions about AVs with emphasis on the automation level or the transfer of vehicle control to machines. Only a few studies investigated the change of travel behavior of non-drivers, including the elderly and people with disabilities (Harper et al., 2016; Kröger et al., 2018). They forecasted the increasing vehicle miles traveled (VMT) by AVs due to the growing travel needs of non-drivers. Nonetheless, empirical research studies and discussions on people with disabilities' needs, perceptions, expectations, and concerns are still lacking in this area. Thus, very little is known about what people with disabilities think about AVs thereby it is not clear what factors affect their decision-making process.

As one of the very few examples of studies on people with disabilities' perceptions of AVs, Bennett et al. (2019, 2020) investigated the factors that influence the attitudes toward AVs among people with physical disabilities and people who are blind. Using the open-ended questionnaire and a structural equation model (SEM), they found that people with disabilities' new technology interest, anxiety, the intensity of disability, prior knowledge, locus of control, and action orientation can affect the attitudes towards AVs. In another study, Hwang et al. (2020) conducted focus groups to explore perceptions of AVs among people with physical disabilities and people with visual impairments. They found that the absence of human operators can be a critical factor that increases people with disabilities' anxiety to use AVT. Also, people with disabilities' mobility issues related to the current public transit services and built environments can motivate them to be interested in AV technology and increase their preference for AVs.

The limited number of previous literature demands the apparent need for further study on the impacts of AVs on people with disabilities travel behavior and mobility. The factors influencing people with disabilities' AV preferences have not been closely examined through the SP survey and econometric models. This paper attempts to fill such a gap by investigating how the introduction of AVs would have impacts on people with disabilities' mode choice decisions. The primary objectives of this study are 1) to identify the factors influencing people with disabilities' AVT mode choice and 2) to suggest appropriate AVT strategies to improve people with disabilities' mobility. Specifically, this study uses a hybrid choice model to explain the impacts of individuals with disabilities' psychological factors on their preference for AVs and mode choice decision-making process. In the following section, the modeling framework and research methods used in this study are described.

4.2. Methods

4.2.1. Hybrid Choice Model

This study used the survey data collected in the Austin and Houston areas from June to September 2019.[2] Only those with physical disabilities or visual impairments who were over 18 years old, speaking English, and living in the Austin or Houston areas were eligible to take part in the survey. The survey mainly investigated participants with disabilities' (1) travel behavior, (2) attitudes toward public transit services, built environments, and AVs, and (3) demographic characteristics. In addition, using a stated preference (SP) choice experiments, the survey asked respondents to choose the most preferred mode of transportation among five modes, including single-ride AVT, shared-ride AVT, ADA paratransit, fixed-route bus, and personal car, considering travel time, travel cost, and the presence of a human assistant.

Built upon the collected survey data, this study developed a choice model to examine the factors influencing people with disabilities' AVT mode choice. While multinomial logit (MNL) models have been widely used to develop mode choice modeling framework, this study used Hybrid Choice Model (HCM) that integrates discrete choice and latent variable models to explain not only observable variables (e.g., characteristics of the decision-maker and attributes of the alternatives) but also psychological factors (e.g., decision-makers' attitudes and perceptions) that affect

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[2] A more detailed description of the survey study can be found in Chapter 3.

decision-making process (Ben-Akiva et al., 2002; Bolduc & Alvarez-Daziano, 2010). More detailed methodological concepts used in this study can be found in Ben-Akiva et al. (1999, 2002), Temme et al. (2008), and Bolduc and Alvarez-Daziano (2010).

The modeling framework for HCM shown in Figure 4.1, which is adapted from Ben-Akiva et al. (1999), consists of a discrete choice model (DCM) and a latent variable model (LVM). A solid line arrow represents structural relationships in DCM that link the observable explanatory variables and latent variables to the utility (U); a dashed line with double dots arrow represents structural relationships in LVM that link observable explanatory variables to latent variables as well as interactions between latent variables; and a dashed line arrow represents measurement relationships that link the latent variables and utility (U) to their observable indicators (i.e., observed preference y and indicators I). As the latent variables (z^*) and utility (U) are unobservable, they have been normally measured by survey items to ask respondents' perceptions or attitudes (Bolduc & Alvarez-Daziano, 2010).

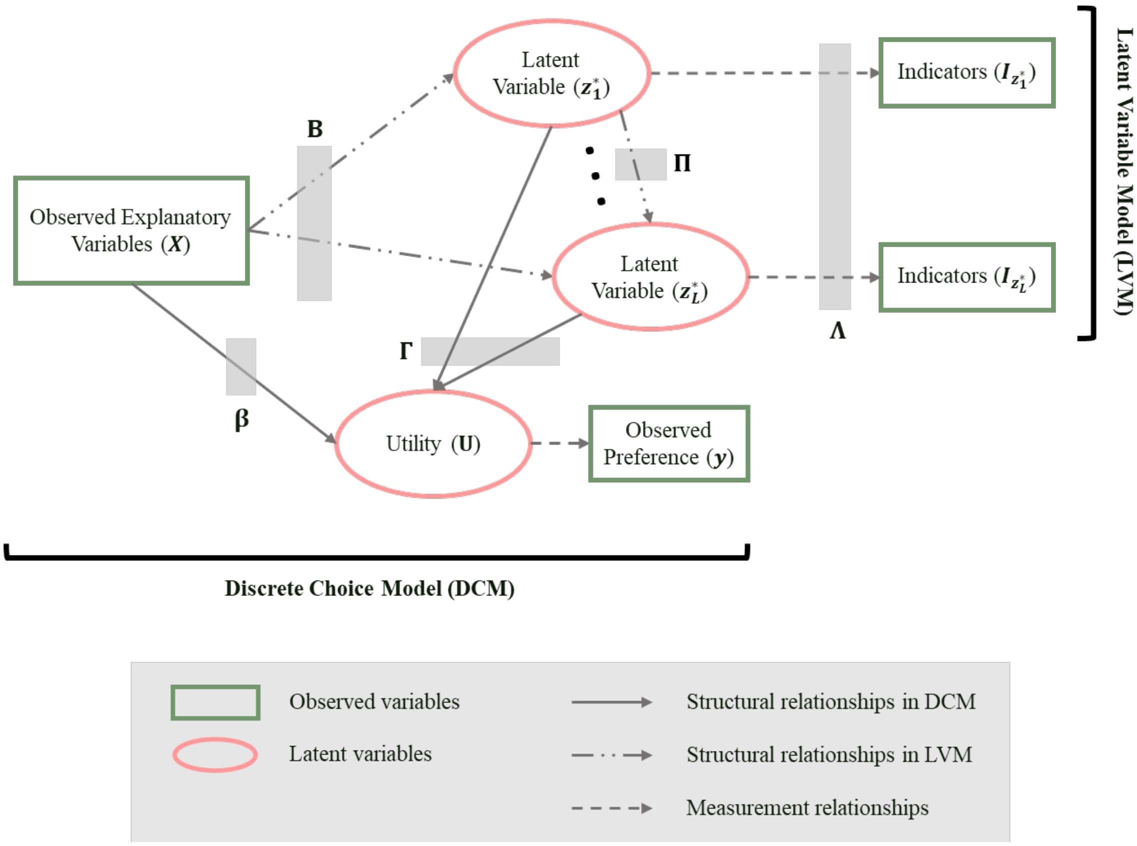

Figure 4.1 Modeling framework of Hybrid Choice Model

The output of DCM corresponds to the choice probability of individual n choosing alternative i instead of j. When we assume that there are J alternatives and K observable explanatory variables, the structural equation (Equation 1) and the measurement equation (Equation 2) in DCM can be expressed as (Bolduc et al., 2005):

$$U_n = X_n \beta + \Gamma z_n^* + \nu_n \tag{1}$$

$$y_{in} = \begin{cases} 1 & \text{if } \ U_{in} \geq U_{jn}, \text{ for all } j \in C_n,\ j \neq i \\ 0 & \text{otherwise} \end{cases} \tag{2}$$

where

U_n = $(J \times 1)$ vector of utilities,

X_n = $(J \times K)$ matrix with X_{in} designating a row vector of attributes of alternative i and characteristics of individual n,

β = $(K \times 1)$ vector of unknown parameters to be estimated for observable explanatory variables,

Γ = $(J \times L)$ matrix of unknown parameters associated with the latent variables presented in the utility function,

ν_n = $(J \times 1)$ vector of error terms associated with the utility terms,

y_{in} = a choice indicator of whether alternative i is chosen by individual n or not,

U_{in} = the utility of alternative i as perceived by individual n, and

C_n = a set of available alternatives.

In LVM, there are L latent variables, M observable explanatory variables, and R indicators. The structural equation (Equation 3) and the measurement equation (Equation 4) in LVM can be written as (Bolduc et al., 2005):

$$z_n^* = \Pi z_n^* + \mathrm{B}w_n + \zeta_n, \quad \zeta_n \sim N(0, \Psi) \tag{3}$$

$$I_n = \alpha + \Lambda z_n^* + \varepsilon_n, \quad \varepsilon_n \sim N(0, \Theta) \tag{4}$$

where

z_n^* = $(L \times 1)$ vector of latent variables,

Π = $(L \times L)$ matrix allowing the presence of simultaneity or interactions among the latent variables,

B = $(L \times M)$ matrix of unknown parameters used to describe the effect on the latent variables,

w_n = $(M \times 1)$ vector of explanatory variables affecting the latent variables,

Ψ = $(L \times L)$ variance covariance matrix which describes the relationship among the latent variables through the error term,

I_n = $(R \times 1)$ vector of indicators of latent variables associated with individual n,

α = $(R \times 1)$ vector of constants,

Λ = $(R \times L)$ matrix of unknown parameters that relate the latent variables to the indicators, and

ε_n = $(R \times 1)$ vector of independent error terms, which implies that Θ is a diagonal matrix with variance terms on the diagonal.

For the estimation of unknown parameters, maximum likelihood techniques were employed in this study. Given the assumptions that all the error terms ν, ζ, and ε are independent, the likelihood function could consist of the joint probability function $P(y_{in} = 1, I_n) \equiv P_n(i, I)$, meaning that individual n selecting alternative i and indicator I. The joint probability function can be written as (Bolduc et al., 2008):

$$P_n(i, I|X_n, w_n, \delta) = \int_{z_n^*} P_n(i|z_n^*, X_n, \theta) f(I_n|z_n^*, \Lambda) g(z_n^*|w_n, B, \Pi, \Psi)\, dz_n^* \quad (5)$$

where

$P_n(i|z_n^*, X_n, \theta)$ = the choice probability of individual n selecting alternative i, given values for the latent variables z_n^*, the explanatory variables X_n, and θ designating all the unknown parameters in the choice model of Equation (1),

$g(z_n^*|w_n, B, \Pi, \Psi)$ = the density of z_n^* defined in Equation (3),

$f(I_n|z_n^*, \Lambda)$ = the density of I_n defined in Equation (4), and

δ = the full set of parameters to estimate jointly the DCM and LVM (i.e., $\delta = \{\theta, B, \Pi, \Psi, \Lambda\}$).

To estimate the integrated model, this study used a full-information estimation technique, which allows relatively consistent and unbiased estimates for the random utilities and the test of behavioral theories including more complex relationships between latent variables and choice behaviors (J. H. Kim et al., 2012; Temme et al., 2008). Also, in this study, the attitudinal responses representing the indicators I_n were treated as multinomial ordered choices for more sophisticated estimation (Bolduc et al., 2008; Daly et al., 2012). Thus, the measurement equation (Equation 4) should be rewritten as follows (Bolduc et al., 2008):

$$I_{rn} = \begin{cases} 1 & \text{if } \gamma_0 < I_{rn}^* \leq \gamma_1 \\ 2 & \text{if } \gamma_1 < I_{rn}^* \leq \gamma_2 \\ \dots & \\ Q & \text{if } \gamma_{Q-1} < I_{rn}^* \leq \gamma_Q \end{cases} \tag{6}$$

where

I_{rn}^* = an unobserved continuous indicator,

I_{rn} = r^{th} element of I_n, and

γ's = cutoff terms that need to be estimated.

By convenience, γ_0 and γ_Q are fixed to $-\infty$ and ∞, respectively. For identification, the constant terms α must be set to 0. Given the assumptions, the density function $f(I_n)$ in Equation (5) now can be written as (Bolduc et al., 2008):

$$f(I_n) = \prod_{r=1}^{R} f(I_{rn}) \tag{7}$$

$$f(I_{rn} = l) = \Phi(\gamma_l - \Lambda_r z_n^*) - \Phi(\gamma_{l-1} - \Lambda_r z_n^*) \tag{8}$$

where Φ is the cumulative distribution function of a standard normal.

All the estimations were conducted by using R package *Apollo* (Hess & Palma, 2019). Finally, the modeling framework used for the analyses of this study is shown in Figure 4.2.

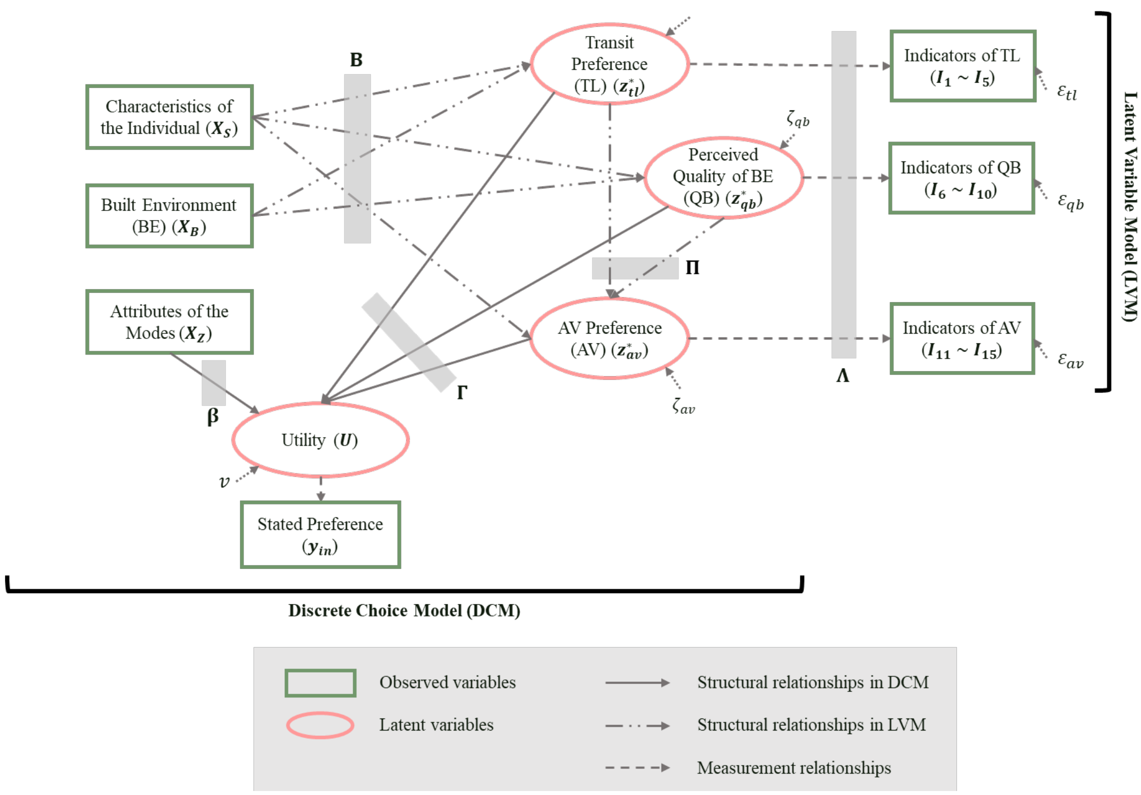

Figure 4.2 Modeling framework for HCM used in this study

4.2.2. Data Collection and Hypotheses

The study area included the Austin areas within Travis County, Texas and the Houston areas within Harris County, Texas. The survey collected 240 responses, but 48 were excluded for this study due to the lack of eligibility (e.g., out of study area) and incomplete answers (e.g., invalid trip locations). After the data cleaning process, a total of 191 survey responses remained, which produced 2,292 SP choice experiment cases. A SP choice experiments consisted of five alternatives (y_i), including single-ride AVT, shared-ride AVT, ADA paratransit, fixed-route bus, and personal car. Three mode attributes (X_z) were used to provide a tradeoff between alternatives, including travel time, travel cost, and the presence of a human assistant. The multinomial logit model was employed for DCM. Through DCM, this study examined the impacts of latent variables on individuals with disabilities' mode choice. Particularly, this study focused on testing a hypothesis that the presence of a human assistant has a positive effect on individuals with disabilities' AVT mode choice (H_1).

The data related to the built environment (X_B) were retrieved from publicly available sources (e.g., Texas Department of Transportation, U.S. Census TIGER, City of Austin, Houston-Galveston Area Council). However, due to the limited availability, the author had to digitize some data using a virtual audit instrument, such as Google Earth or Google Street View, that can be used as a proxy of the real street audit if the resources are limited. Since a virtual audit provides a reliable indicator with high cost-effectiveness, it has been widely used in previous studies (Badland et al., 2010; Clarke et al., 2010; Vanwolleghem et al., 2014). In this study, a virtual audit was conducted by using Google Earth and ArcGIS software within a buffer area of radius 0.25-mile around the respondents' first trip origins. Table 4.1 shows a list of the variables included in the analyses.

Table 4.1 Summary of the variables used in this study

Variable	Definition
Individual characteristics (X_S)	
Physical disability	Binary (1 = individual with physical disability, 0 = else)
Visual impairment	Binary (1 = individual with visual impairment, 0 = else)
Elderly	Binary (1 = age 65 and over, 0 = age under 65)
Female	Binary (1 = female, 0 = male)
High education level	Binary (1 = college or higher level, 0 = else)
Low-income	Binary (1 = annual household income below $25,000, 0 = else)
Zero-car household	Binary (1 = household with no car available, 0 = else)
Mode attributes (X_Z)	
Travel time	Total travel time in minutes
Travel cost	Monetary cost of travel in dollar amount
Human assistant	Binary (1 = presence of a professional assistant, 0 = absence)
Built environments (X_B)	
Sidewalk coverage	Mean value of sidewalk coverage for each street in a buffer area. Sidewalk coverage was calculated as follows: $$(sidewalk\ coverage) = \frac{(sidewalk\ length)}{(2 \times street\ length)}$$
Land use diversity	Entropy index of diversity calculated as follows: $$(entropy) = -\sum_k p_k \frac{\ln(p_k)}{\ln(K)},$$ where p_k = proportion of total land area of k^{th} land-use category within a buffer area and K = total number of land-use categories present

Table 4.1 Continued

Variable	Definition
Retail job	Density of retail jobs within a buffer area
4-way intersection	Density of 4-way intersections within a buffer area
Traffic volume	Mean value of annual average daily traffic for each road within a buffer area
Bus stop	Density of bus stops within a buffer area

In HCM, this study included three latent variables related to individuals' attitudes toward public transit service ($z_{t}^{*}{}_{l}$), perceived quality of built environments (z_{qb}^{*}), and preference for AVs (z_{av}^{*}). Through an exploratory factor analysis, five indicators that have higher factor loadings were selected for each latent variable among the Likert-type attitudinal questions used in the survey (see Appendix E). The selected indicators for each latent variable are shown in Table 4.2. The previous literature suggested that individuals with disabilities' mobility issues related to current public transit services and built environments might increase the preferences for AVT (Hwang et al., 2020). Built upon the previous results, this study proposed the following hypothesis to be tested in the empirical analysis: individuals with disabilities' negative perceptions and attitudes toward public transit services and neighborhood built environments would increase the preference for AVT (H_2).

Table 4.2 Latent variables and indicators

Latent Variables	Indicators (Notation)
Public Transit Attitude	Overall, I trust the public transit service provider. (I_1)
	I feel safe while riding the public transit. (I_2)
	The vehicle is easy to access by people with disabilities like me. (I_3)
	The public transit arrival time is reliable and acceptable. (I_4)
	The public transit service is valuable. (I_5)
Perceived Quality of Built Environments	I can get most of my personal business (e.g., banking, laundry) done within walking distance of my home. (I_6)
	The car speed on the streets in my neighborhood is low. (I_7)
	The sidewalks are well-maintained without obstacles (e.g., potholes, cracks). (I_8)
	There are enough places in my neighborhood where I can go for recreation or entertainment. (I_9)
	The bus or rail stops in my neighborhood have clear paths without obstacles or barriers to access. (I_{10})
AV Preference	I would find AVT useful in meeting my travel needs. (I_{11})
	I would use AVT for daily travel because it would be cheaper. (I_{12})
	I trust AVT to be safe and reliable in severe weather conditions. (I_{13})
	AVT would make the roads safer. (I_{14})
	AVT could solve the transportation problems of people with disabilities like me. (I_{15})

4.3. Estimation Results and Discussion

This section presents and discusses the results of a hybrid choice model, focusing on the estimated values of the parameters in a discrete choice model (DCM) and a latent variable structure model (LVSM). The results of the latent variable measurement model are shown in Appendix F. Using DCM, this study attempts to examine the factors influencing individuals with disabilities' mode choice, particularly considering the probability of choosing AVT. The results of DCM include a test of the first hypothesis (H_1) that shows the impact of the presence of a human assistant on the likelihood of AVT being chosen. Also, based on the results of LVSM, this study primarily examines individuals with disabilities' psychological factors that can affect the preference for AVT by taking into account the relationship among the latent variables in the model (H_2).

4.3.1. Discrete Choice Model

The results of DCM are summarized in Table 4.3. The DCM results revealed that the latent variables had statistically significant effects on individuals with disabilities' mode choice. Not surprisingly, individuals with disabilities who had a higher preference for AVs were more likely to choose AVT, regardless of service types either single-ride or shared-ride. Also, individuals with disabilities who had a positive attitude toward public transit service more preferred a bus and paratransit, but not a personal car. Interestingly, the perceived quality of built environments had the opposite effects on the probability of choosing a bus and paratransit. In particular, when individuals with disabilities had a positive perception of the quality of neighborhood built environments, the likelihood of bus being chosen increased whereas that of paratransit decreased. This result might imply that adequate built environments that can positively affect individuals with disabilities' perception may actually provide better access to bus stops and other transportation options so that they did not have to rely on paratransit. However, although it is possible that the accessible built environments affected individuals with disabilities' choice of bus and paratransit, there is another possible explanation that individuals with disabilities who can use or prefer to using buses were more likely to choose to live in the neighborhoods with accessible built environments (also known as residential self-selection) (Cao et al., 2009; Mokhtarian & Cao, 2008).

Table 4.3 Mode choice model results

Variable	Mode	Estimates	t-ratio
Alternative specific constant (personal car is the base category)	Single-ride AVT	*−0.939*	−2.39
	Shared-ride AVT	**−1.323**	−3.22
	Paratransit	**−5.124**	−5.41
	Bus	**−1.953**	−2.89
Attributes of the mode			
Travel time (minute)	ALL	**−0.089**	−14.35
Travel cost ($ per trip)	ALL	**−0.807**	−11.16
Presence of a human assistant	Single-ride AVT	**0.485**	3.97
	Shared-ride AVT	**0.862**	6.87

Note: Bold numbers mean statistically significant at 1% level. Italic numbers mean statistically significant at 5% level. Adjusted rho-square = $1 - (\mathrm{LL}(\mathrm{final, choice\ model})/\mathrm{LL}(0, \mathrm{chioce\ model}))$, where $\mathrm{LL}(0, \mathrm{choice\ model})$ = choice model log-likelihood with only constants and $\mathrm{LL}(\mathrm{final, choice\ model})$ = final log-likelihood of choice model.

Table 4.3 Continued

Variable	Mode	Estimates	t-ratio
Latent variables			
AV preference	Single-ride AVT	**2.131**	8.54
	Shared-ride AVT	**1.675**	8.10
Public transit attitude	Paratransit	**2.585**	9.00
	Bus	**1.062**	2.75
	Personal Car	**−3.124**	−9.15
Perceived quality of built environments	Paratransit	**−1.290**	−3.08
	Bus	**1.654**	4.49
	Personal Car	0.048	0.18
Number of individuals	191		
Number of observations	2,292		
Number of Sobol draws	500		
Initial log-likelihood (global)	−15,854.7		
Final log-likelihood (global)	−5,640.6		
Adjusted-rho squared	0.41		

Note: Bold numbers mean statistically significant at 1% level. Italic numbers mean statistically significant at 5% level. Adjusted rho-square = $1 - (\mathrm{LL}(\mathrm{final, choice\ model})/\mathrm{LL}(0, \mathrm{chioce\ model}))$, where $\mathrm{LL}(0, \mathrm{choice\ model})$ = choice model log-likelihood with only constants and $\mathrm{LL}(\mathrm{final, choice\ model})$ = final log-likelihood of choice model.

With regard to the mode attributes, the estimated values of the parameters were in agreement with prior expectations. The results showed that all modes' likelihood of being chosen decreased when travel time and travel cost increased. The results also confirmed the first hypothesis (H_1) that, for individuals with disabilities, the presence of a human assistant increased the probability of choosing AVT. The results in Table 4.4 show the respondents' marginal willingness-to-pay (WTP) calculated from the estimates of DCM as the ratio of the coefficients of presence of a human assistant to that of travel cost per trip. The results indicate that the presence of a human assistant was valued at $0.60 for single-ride AVT, while $1.07 for shared-ride AVT. A higher WTP of an onboard human assistant for shared-ride service perhaps reflects individuals with disabilities' concerns about traveling with strangers when no one controls the vehicle. This finding corroborates the previous study, which reported people with disabilities' anxieties regarding the absence of human operators or attendants (Hwang et al., 2020).

Table 4.4 Results of willingness-to-pay (WTP) estimation

Variable	WTP ($ per trip)	Robust S.E.	Robust t-ratio
Human assistant for single-ride AVT	0.60	0.22	2.72
Human assistant for shared-ride AVT	1.07	0.20	5.33

4.3.2. Latent Variable Structure Model

Table 4.5 presents the results of the latent variable structure model. The estimated structural relationships between individuals with disabilities' AV preference and their socioeconomic and demographic characteristics were similar to the previous research studies on the general public (Haboucha et al., 2017; Hohenberger et al., 2016; Yap et al., 2016). The results showed that people with disabilities—both physical disabilities and visual impairments—and those with high education levels had a higher preference for AVs, whereas the elderly and women had a lower preference for AVs.

One interesting finding was that latent variables of the public transit attitude and the perceived quality of built environments were negatively associated with the AV preference. This finding confirmed the second hypothesis (H_2), which indicates that individuals with disabilities who had negative attitudes toward public transit service and those with negative perceptions of built environments had a higher preference for AVs. This result supports evidence from previous observations that individuals with disabilities' mobility issues and complaints related to current transit service and built environments affect their preference and expectations for AVs (Hwang et al., 2020).

In terms of public transit attitudes, the elderly, the low-income, and individuals in zero-car households had positive attitudes toward public transit services. Although built environment variables, such as sidewalk coverage, 4-way intersection density, and bus stop density, were positively associated with public transit attitudes, they were not statistically significant. Regarding the relationship between the perceived quality of built environments and observed built environment variables, retail job density had a statistically significant, positive effect on the perceptions of the quality. Perhaps this result indicates that more activity points within the vicinity have a positive effect on people with disabilities' perceptions of the quality of built environments. On the other hand, the results showed that a higher land use diversity index was associated with a negative evaluation of built environments. While this result can be interpreted as individuals with disabilities had positive perceptions of monotonous land uses, it could be disputable because the Entropy index only measures the equality of land use proportions. None of the other built environment variables turned out to be statistically significant.

Table 4.5 Latent variable structural model results

Variable	AV Preference		Public transit attitude		Perceived quality of built environments	
	Estimates	t-ratio	Estimates	t-ratio	Estimates	t-ratio
Individual Characteristics						
Physical disabilities	*0.417*	2.53	0.274	1.67	**−0.781**	−3.05
Visual impairments	*0.354*	2.27	0.301	1.92	**−0.907**	−3.73
Elderly	**−0.927**	−4.60	**0.884**	5.53	-	-
Female	**−0.349**	−2.51	-	-	-	-
Higher education level	**0.523**	3.71	-	-	-	-
Low-income	-	-	**0.464**	3.72	-	-
Zero-car household	-	-	**0.455**	3.16	-	-
Built Environments						
Sidewalk coverage	-	-	0.058	0.17	0.414	1.12
Land use diversity	-	-	-	-	*−0.996*	−2.56
Retail job density	-	-	-	-	**0.208**	2.80
4-way intersection density	-	-	0.054	0.40	0.258	1.66
Traffic volume	-	-	-	-	−0.017	−0.38
Bus stop density	-	-	0.129	0.45	-	-
Latent Variables						
Public transit attitude	*−0.157*	−2.39	-	-	-	-
Perceived quality of built environments	*−0.225*	−2.43	-	-	-	-

Note: Bold numbers mean statistically significant at 1% level. Italic numbers mean statistically significant at 5% level.

4.4. Conclusions

This study examined the factors influencing individuals with disabilities' choice of transportation modes including AVT through empirical analyses of HCM that explain both observed and unobserved variables. Among many points of the findings revealed, this study aims to encourage planners and policy-makers to consider a few implications to prepare strategies for improved mobility for all. In the coming sub-sections, this study discusses the reflections regarding the following two findings. First, this study found that the presence of onboard assistants had positive effects on individuals with disabilities' choice of AVT. Second, the results corroborated that individuals with disabilities who had a negative attitude towards public transit service and neighborhood built environments had a higher preference for AVT.

4.4.1. Accessible and Safe Autonomous Vehicle Transportation Service

A positive relationship between the presence of onboard human assistants and the probability of choosing AVT modes suggested that some people with disabilities still need someone who can help them use AVT. Even though vehicle automation enables the machine drives without a human operator, it does not enable people with disabilities to ride a vehicle by themselves. Service providers may have to come up with a variety of services, such as allowing customers to choose whether or not to board human attendants, in order to remove barriers to using AVT. For the service without onboard attendants, service providers may need to ensure AVs to be equipped with accessibility aids (e.g., lift, curb ramp, seat-securement, and audio-alert systems) for people who may require special needs. While this study only focused on individuals with physical disabilities and visual impairments, people with disabilities may have unique needs when boarding, alighting, or traveling, depending on their physical or mental ability levels and types. Unless the safe and accessible travel is guaranteed, AVT will be only for the selected few, not for all people.

The positive effect of human assistants on individuals with disabilities' choice of AVT mode is probably due to their fear or concern that comes from traveling with strangers without anyone who can control the situations. Especially in the early stage or transition period of AVT services, users' anxieties would be high enough to be hesitant to use the service. To mitigate the anxieties, service providers may have to develop various public information campaign, outreach, education, and training programs (Bennett et al., 2019, 2020; Hwang et al., 2020). Many of the anxieties or concerns, mostly related to safety and mechanical errors, are likely to disappear when the public obtains reliable information about technological advances, just like we cannot find an attendant in elevators any longer. In this context, various educational, training programs, and pilot projects involving both people with and without disabilities could help ease anxieties.

Many public transit agencies and private transportation network companies (TNCs, such as Uber and Lyft) are examining the strategies to improve the efficiency of the services by replacing traditional vehicles with AVs. However, when it comes to the establishment of accessibility, safety, and reliability of the future service, there has been a rare discussion. Prior to the introduction of AV technology into transportation systems, social consensus should be reached through a collaborative process to assure that AVT services are accessible and safe to all thereby the benefits would be distributed to all. As though the ADA requires public transit agencies to provide complementary services for people with disabilities who are not able to use the regular services, if needed, policy-makers need to consider developing solid guidelines or legislations for practitioners to provide all user groups with accessible and safe AVT services.

4.4.2. The Potential of AVT to Resolve People with Disabilities' Mobility Issues

This study found that individuals with disabilities who had negative attitudes toward public transit services and neighborhood built environments tended to have a higher preference for AVT. This finding confirmed the possibility that mobility issues and complaints regarding public transit services and built environments among people with disabilities motivate a higher preference for AVs. It may therefore be assumed that individuals with disabilities' preference for AVs came from the expectations that AVs would resolve the mobility issues that they are facing. However, one thing that policy-makers and planners should note is that mobility issues related to current public transit service and built environments would be hardly resolved by introducing AVT only.

There is little doubt that AV technology is likely to improve the operational performance of public transit services. Replacing the existing public transit vehicles with AVs to operate on-demand AVT services might have a high potential to remedy many problems with current public transit services by improving operational efficiency, increasing service capacity, and reducing the risk of car crashes. Nonetheless, other issues, such as ensuring accessibility and safety of AVT, would not be resolved without the incorporative strategy. For example, to enable people with disabilities' independent travel, it is significantly important to provide accessible built environments along the entire paths of travel, including first-/last-miles and pick-up/drop-off areas. Such tasks should be accomplished through the planning process that involves diverse stakeholders. Also, ensuring the safety of AVs requires cooperation through a multi-disciplinary approach across mechanical engineering, computer science, policy, and planning (Koopman & Wagner, 2017). Therefore, without support from diverse sectors, it is hard to overcome many complex issues that should be resolved to ensure mobility improvement for all.

It is futile to expect that AV technology alone will improve mobility for all: in other words, technology is not a panacea. Furthermore, AVT service providers cannot be expected to be solely responsible for improving mobility for all. Instead, mobility improvement, which refers to people with disabilities' desire to independently and spontaneously travel as their conditions allow, will be achieved by cooperation across diverse sectors including public transit agencies, local and regional authorities, the federal agencies, private companies, and user groups.

4.4.3. Areas for Future Studies

As with the majority of studies, the research design of this study is subject to limitations. One source of weakness which could have affected the measurements of individuals with disabilities' SP choice was hypothetical bias, which arises when respondents misunderstood the experiment or deliberately made their decision to influence the policy outcomes (Correia et al., 2019; Stathopoulos et al., 2017). While this study provided detailed text-descriptions about the concept of AVT, it would be recommended to use diverse media, such as video, to illustrate a more intuitive picture of AVT.

Another caveat should be noted is possible sampling bias due to the survey method. Since the survey was distributed online, only individuals with disabilities who have access to the Internet could take part in the survey. It is also difficult to generalize the results to other disability types and places. This study only considered two types of disabilities, i.e., physical disability and visual impairments, in the Austin and Houston, Texas areas in the U.S. Future studies will be worthwhile to replicate the examination in other regions using a more diverse sample.

Despite some limitations, this study provides intriguing insights into the understanding of the factors influencing people with disabilities' AVT choice that can be used to develop more targeted AVT strategies to bring benefits not only to a few groups but to all people. Given the enormous potential of AVs to improve mobility for many groups, it is important to ensure that there are no underrepresented populations. Also, the social consequences of AVs would be wide and complex, thereby further research on AVs should focus more on the interdisciplinary approach across diverse fields from mechanical engineering to human behavior to urban planning.

5. CONCLUSIONS

The dissertation examined the potential impacts of AVs on people with disabilities' mobility improvement. The study focused on only two types of disabilities, i.e., physical disabilities and visual impairments. Chapter 1 and Chapter 2 presented focus groups and survey studies on people with disabilities' mobility issues and their perceptions and attitudes toward AVT with emphases on expectations, concerns, and needs. The results showed that mobility issues for those with disabilities still remain in the current public transportation services and neighborhood built environments. The findings also suggested that people with disabilities' expectations that AVT would improve their mobility might come from the frustrations at current public transportation services and built environments. Also, people with disabilities' concerns about AVT provided insights into policy implications to ensure the accessibility and safety of AVT. In Chapter 3, the study examined the impacts of the factors that influence the probability of AVT being chosen by people with disabilities using a hybrid choice model (HCM).

The findings of this dissertation showed that AVT services are expected to be chosen as a desirable transportation option among individuals with physical disabilities and individuals with visual impairments. However, although AVT can be definitely attractive and promising transportation services among people with disabilities, AVT alone hardly ensures to be a complete solution to improve the mobility of people with disabilities. The results showed that some people with disabilities were still concerned about the absence of a human assistant. The remaining concerns and anxieties regarding accessibility and safety of AVT travel would be a significant hurdle for AVT to overcome. Moreover, the model results corroborated that people with disabilities' high expectations for AVT were associated with complains about the mobility issues that they face (i.e., current transportation services and built environments). People with disabilities' mobility issues, however, cannot be resolved by AV technology alone because the problems are complex and intertwined. To improve mobility of people with disabilities, it is important to ensure the accessibility and safety of AVT service through the interdisciplinary and cooperative approach across diverse fields.

5.1. Policy Implications

AVT services can be a hope for people with disabilities who desperately wait for alternative modes of transportation. However, unless AVT services are accessible, the benefits cannot be distributed to all. Not only vehicles but also built environments should be accessible for all to freely use the service. Vehicles can be accessible by equipping with barrier-free devices that help riders board, alight, secure the seat, and communicate with the vehicle during traveling. Whether AVT services will be provided by public or private sectors, vehicles should be accessible for all. Accessibility of the vehicle could also be achieved by an onboard attendant depending on riders' needs. Additionally, paths for the first- and last-mile travel, including pick-up and drop-off areas, should be accessible without barriers (e.g., parking cars, branches, cracks, and missing sidewalks or curb cuts). Even if vehicles are accessible, AVT services would not be a viable option without barrier-free built environment features, such as sidewalks, access ramps, or curb cuts, that allow people with disabilities to complete independent travel.

Furthermore, travel by AVT should be reliable to ensure safety throughout the entire journey (i.e., first- and last-mile, boarding, alighting, and in-vehicle). Considering the high anxiety of AV technology in the early stage, ensuring safety would play a key role in increasing the reliability of AVT. The safety of AVT can be achieved not only by advanced technology but by a multi-disciplinary approach across a variety of fields, including computing hardware, software, robotics, security, testing, human-computer interaction, social acceptance, safety engineering, and legal (Koopman & Wagner, 2017). To support a safe trip by AVT, quality improvement of built environments would also be required. For example, well-maintained roads without cracks or blurred lanes can increase the capability of AVs to recognize objects on the roads. In addition, appropriate technology should be incorporated into built environments to enable communication between AVs and infrastructure (vehicles-to-infrastructure [V2I]). As the absence of a human operator could be a significant factor that increases people with disabilities' safety concerns, service providers might need to consider a service option for people to choose to board with a human attendant who can observe and serve customers if needed.

Technology itself does not bring a complete solution to problems. People must establish appropriate plans, policies, and systems through the process of discussing how technology will be used for all people. Disability is not a problem that an individual is forced to overcome. Our society should not encourage people with disabilities to overcome their disabilities but establish a system where people with disabilities are not uncomfortable living. In this regard, urban planning and transportation policy in the era of AVs need to carefully consider how we use the promising technology to benefit all people.

5.2. Limitations and Future Research

The study, nonetheless, is subject to several limitations. The first is the bias of focus group and survey sample. Despite it is important to examine the unique needs and thoughts of diverse groups of people with disabilities, this study only included limited types of disability. The focus group study could not include young people with disabilities age under 35. The survey data collection process might also introduce bias, as not all people with disabilities have access to the Internet to take part in online recruiting. Future research would be recommended to use multiple approaches to recruit more diverse age groups and types of disability (e.g., hearing, cognitive, or learning disabilities).

Future research has the potential for improvement in model estimation when some factors included. For example, care-givers, the severity of a disability, or the quality of built environments in the destinations might have effects on people with disabilities' mobility and mode choice decisions. Other built environment variables, such as the type of curb cut, tactile paving (or truncated domes and detectible paving), and accessible pedestrian signals, could be included in future research to increase understanding of the impacts of built environments on people with disabilities' mobility. In addition, the more specific scale of audits could provide different perspectives on what people with disabilities need in terms of accessibility. For instance, the needs or challenges among people with disabilities can vary by the spatial scale from narrow spots adjacent to home (e.g., 100-yard) to neighborhoods (e.g., 0.25-mile).

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APPENDIX A

FOCUS GROUP GUIDE QUESTIONS FOR PARTICIPANTS WITH DISABILITIES

Sequence	Topic	Question
Opening	Introduction (5 minutes)	1) Could you tell us how you travelled here today?
Discussion	Travel Behavior (25 minutes)	2) What activities do you usually engage in on a typical day and how do you usually get to those places? a. Could you please tell us why you used paratransit or why not? 3) When you decide the mode of transportation, what are the most important factors? What makes you decide that mode?
	Built Environments (25 minutes)	4) Please briefly describe your neighborhood built environments and tell us how you feel about them when you travel. a. Did the built environment make your travel either easy or difficult?
	Autonomous Vehicle Transportation (25 minutes)	5) If available, would you use self-driving paratransit service for your travel? Why or why not? a. What factor(s) do you think would mostly restrict or encourage your self-driving paratransit service use? 6) If self-driving demand responsive service (SDRS) is available, instead of self-driving paratransit service, would you use it? Why or why not? 7) Let's think about the relationship between your neighborhood built environments and SDRS. How the built environment would make SDRS or autonomous vehicles more accessible and favorable?
Closing	Conclusion (5 minutes)	8) Do you have any additional comments or suggestions about how SDRS or neighborhood built environments could be used to help people with disabilities?

APPENDIX B

FOCUS GROUP GUIDE QUESTIONS FOR PUBLIC TRANSIT SERVICE EXPERTS

Sequence	Topic	Question
Opening	Introduction (5 minutes)	1) Could you tell us your job title and how long you have been working at that position?
Discussion	Autonomous Vehicle Transportation (10 minutes)	2) What impacts do you think the autonomous vehicle transportation service would have on people with disabilities' mobility? How do you think this service would change their mobility?
	Legal/Policy-Related Issues (15 minutes)	3) Do you have any policy related concerns from external regulations (state or federal level) and internal agency policies when the agency provides this service? a. Do you have any suggestions about policy implications or changes to provide this service for people with disabilities?
	Technology (15 minutes)	4) In addition to the current AV technology, what kind of technological improvements do you think we need to provide this service for people with disabilities? a. What operational concerns would you have about adopting AV technology into paratransit service or other public transit service?
	Built environments (15 minutes)	5) People with disabilities have reported some challenges related to the built environment when they try to use paratransit and bus in their neighborhood. Do you have any policies or strategies to improve this problem? 6) Could you tell me your opinions on urban design interventions when we provide autonomous vehicle transportation service in the future?
Closing	Conclusion (5 minutes)	7) Do you have additional comments or suggestions about how APS or neighborhood built environments could be used to help people with disabilities?

APPENDIX C

SURVEY QUESTIONNAIRE

Part 1. Screen out questions and basic information of respondents

Q1. What is your age?

- Less than 18
- 18 – 24
- 25 – 34
- 35 – 44
- 45 – 54
- 55 – 64
- 65 and over

Q2. Do you have any of the following disabilities? *Check **all** that apply.*

- Physical disabilities (e.g., difficulty walking or climbing stairs, including spinal cord injury)
- Visual impairments (e.g., blind or low vision)
- Other __________
- None of above

Q3. Which type of mobility aid are you using? *Check **all** that apply.*

- Wheelchair (non-motorized)
- Scooter (motorized or electric wheelchair
- Cane
- Crutches
- Walker
- Other __________
- None of above

Q4. Do you have a service animal?

- Yes
- No

Q5. Which region are you living in?

- Austin or the adjacent metropolitan area
- Houston or the adjacent metropolitan area
- Other than above areas

Part 2. Travel behavior

Please recall the most recent day that you made at least one trip. A trip means traveling from one location (the trip's origin) to another (the trip's destination).
The following examples illustrate the number of trips a person can make.

- Example 1. If you travel from home to school, then from school to the grocery store and then back home again you will have made three trips.
- Example 2. If you travel from home to school and back home again, you will have made two trips.

Screen reader users can skip the below images.

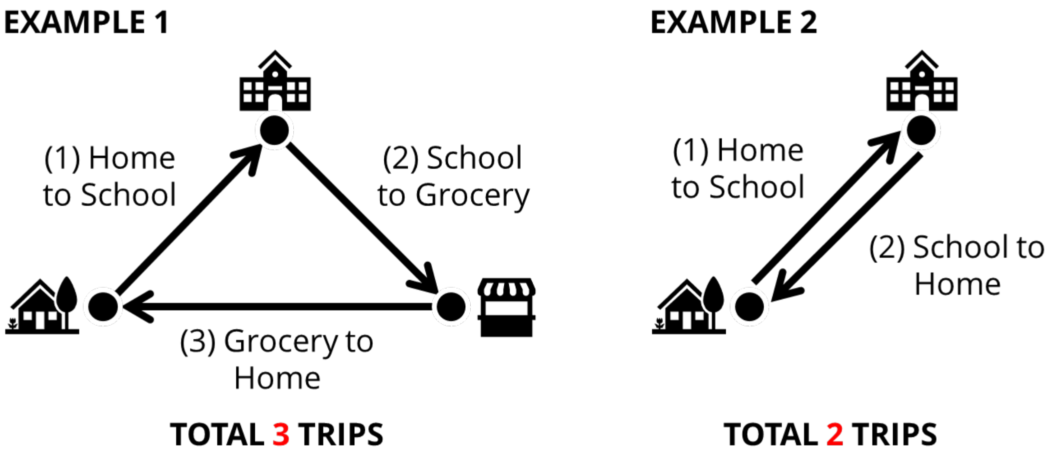

Figure A. 1. Example figures explaining the definition of trip.

Q6. What day was **the most recent day that you made at least one trip**?

- Monday
- Tuesday
- Wednesday
- Thursday
- Friday
- Saturday
- Sunday

Q7. On [*the answer to Q6*], how many trips did you make?[1]

- 2
- 3
- 4
- 5

[1] Respondents had the same set of questions (Q8 – Q12) repetitively according to the number of the most recent trips.

- 6 or more (if you choose this option, you will report only 6 trips)

Q8. Of the [*the answer to Q7*] trips you made, where was **the starting point of your first trip?**

- The map below will help you find the location. You can type in the exact address or the location's name (e.g., Walmart, Post Office).
- When you type in the location's name, the search box will automatically generate a list of suggestions for you to choose.
- All responses are anonymous.

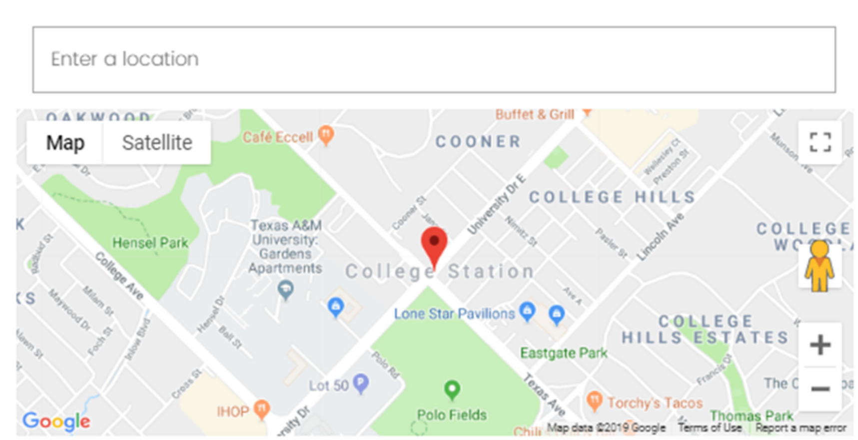

Figure A. 2. Example screen captured image of the Google Map for the survey.

Q9. Where was the destination of your first trip?
Q10. What time did you leave from your starting point?
Q11. What mode of transportation did you use for most of the trip? Check one.

- Personal vehicle (as a driver)
- Personal vehicle (as a passenger)
- Bus
- Taxi
- Paratransit (e.g., Metro Lift or Metro Access)
- Rail
- Ride-sharing service (e.g., Uber or Lyft)
- Walk
- Bike
- Other __________

Q12. What was your trip purpose?[2]

- Work or school
- Shopping
- Grocery
- Eating out
- Medical service
- Social or religious activities
- Workout
- Entertainment (e.g., movie, stadium)
- Other __________

Part 3. Attitudes and perceptions

Q13. Think about the public transit service (e.g., bus, rail, paratransit) that you most use in your neighborhood. How much do you agree or disagree with the following statements?
Please respond based on your experience. If you do not use public transit, you can choose the "Not applicable" option. If you use multiple modes, please think about your most preferred mode.

	Strongly Disagree – Strongly Agree	Not Applicable
The public transit arrival time is reliable and acceptable.		
Drivers are willing to help me.		
Overall, I trust the public transit service provider.		
There is enough space in the vehicle to accommodate me, a companion, and/or luggage.		
The vehicle is easy to access by people with disabilities like me.		
The public transit takes me where I need to go.		
It is difficult to change my travel plans when using public transit.		
The fare is reasonable.		
The public transit service is valuable.		
I feel safe while riding the public transit.		
I am comfortable traveling with unknown passengers when using the public transit.		
The eligibility process for using paratransit is time consuming.		

Q14. Think about the built environment in your neighborhood. How much do you agree or disagree with the following statements?

[2] In the analyses, 'Grocery' and 'Eating out' categories were combined as 'Grocery or Eating out'; 'Shopping' and 'Other' were combined as 'Shopping or errands'; 'Social or religious activities' and 'Entertainment (e.g., movie, stadium)' were combined as 'Social, recreational, or religious activities.'

When answering the following, please respond based on your experience.

	Strongly Disagree – Strongly Agree
The sidewalks in my neighborhood are wide enough.	
There are no barriers on the sidewalks (e.g., parked cars, tree branches, constructions).	
The bus or rail stops in my neighborhood have clear paths without obstacles or barriers to access.	
The crosswalks have an assistant device to cross the road (e.g., traffic control device, speaker).	
The intersections have tactile paving (e.g., textured, truncated dome surfacing).	
The intersections have curb cuts or ramps.	
There are plenty of places to shop or eat within walking distance of my home.	
I can get most of my personal business (e.g., banking, laundry) done within walking distance of my home.	
There are enough places in my neighborhood where I can go for recreation or entertainment.	
I feel safe when I travel around my neighborhood during the day or at night.	
The level of car traffic on the streets in my neighborhood is low.	
The car speed on the streets in my neighborhood is low.	
There are good street-lights on the street in my neighborhood.	
People usually drive carefully in my neighborhood.	
There are trees along the streets that provide nice amount of ample shade.	
The bus or rail stops have shelter or a bench.	
The sidewalks are well-maintained without obstacles (e.g., potholes, cracks).	
The bus stops are well-maintained.	

Q15. The following questions are about your opinions and attitudes toward the Autonomous Vehicle Transportation (AVT) service.

- The AVT provides the on-demand service using autonomous vehicle (also known as driverless vehicle or self-driving car), in which there is no human driver.
- You can book your trips through a smartphone or call center, and the vehicle will pick you up timely.
- You may ride it privately or share it with other passengers.
- The vehicle options available are as a sedan, a van, or a small, single-seat pod. All vehicles would be wheelchair accessible by using a ramp or lift and have a securement system. They are also equipped with audio systems to tell riders where the car is located when they get in and off the car.

Think about autonomous vehicle transportation (AVT) service. How much do you agree or disagree with the following statements?

	Strongly Disagree – Strongly Agree
AVT could solve the transportation problems of people with disabilities like me.	
I would use AVT for daily travel because it would be cheaper.	
I would be willing to share AVT with 6 to 8 fellow travelers with a similar route as mine.	
AVT would bring us to our destination faster.	
AVT would make my life easier because I would no longer need to look for parking.	
I would find AVT useful in meeting my travel needs.	
I trust AVT to be safe and reliable in severe weather conditions.	
AVT would make the roads safer.	
AVT can correctly detect pedestrians on the streets.	
AVT would drive safer than an average human driver.	
Interactions with AVT would be clear and understandable to me.	
AVT could effectively interact with other vehicles.	
AVT would not be accessible for all if there is no human operator.	
AVT could be confused in unexpected situations.	
AVT could lead to privacy issues caused by a surveillance camera in the vehicle or tracking of location.	
AVT may have computer or mechanical errors.	
AVT could cause unemployment.	
AVT could lead to more traffic jams.	

Part 4. SP choice experiments (example when respondent's reported trip distance was 0.8 miles)
One of your reported trips was for **shopping**, and the trip distance was about **0.8** miles. In the next few pages, you will be put into **12** hypothetical scenarios.
For each scenario, you will imagine making the same trip as you reported. We will present to you some hypothetical information about travel time, cost, and human attendant; and then you will choose one of the following as your preferred travel mode.

1. **Autonomous Vehicle Transit Service (single-ride):** This option is an on-demand transportation service using a self-driving car. You would travel without other passengers for single-ride. There may or may not be a human observer.
2. **Autonomous Vehicle Transit Service (ride-sharing):** Like the previous, this option is also an on-demand AVT. But for this option, you would travel with other passengers for ride-sharing. There may or may not be a human observer.
3. **Paratransit:** This option refers to the current demand-responsive paratransit service operated by a local transit agency.
4. **Bus:** This option refers to the current fixed-route bus service.
5. **Personal car:** This option refers to the use of your personal vehicle as a driver or passenger.

Q16. Scenario 1 (out of 12)[3]

Mode	AVT (single-ride)	AVT (ride-sharing)	Paratransit	Bus	Personal Car
Travel Time	5 minutes	16 minutes	13 minutes	19 minutes	9 minutes
Travel Cost	$0.40	$0.32	$1.83	$1.25	$0.39
Human Assistance	No	No	Yes	Yes	No

Figure A. 3. Example screen captured image of the stated preference experiments.

- Travel Time refers to total travel time including waiting time, riding time, and time to get in and out.
- Travel Cost is the approximate monetary cost of your trip.
- Human Assistance indicates whether you travel with a human observer.

Which mode would you choose?

- AVT (single-ride)
- AVT (ride-sharing)
- Paratransit
- Bus
- Personal car

Part 5. Demographic and socio-economic characteristics

Q17. What is your gender?

- Female
- Male

Q18. What is your race?

- American Indian or Alaska Native

[3] Respondents answered similar questions 12 times. For people with visual impairments, the different style was presented, using multiple-choice of alternatives with attribute levels instead of a table.

- Asian
- Black or African American
- Native Hawaiian or Other Pacific Islander
- White
- Other __________

Q19. What is your ethnicity?
- Hispanic or Latino or Spanish Origin
- Not Hispanic or Latino or Spanish Origin

Q20. What is the highest degree or level of school you have completed?
If you are currently enrolled in school, please indicate the highest degree you have received.
- Less than high school degree
- High school degree or equivalent (e.g., GED)
- Some college but no degree
- Associate degree (e.g., AA, AS)
- Bachelor's degree (e.g., BA, BS)
- Graduate degree (e.g., MA, MS, PhD, EdD, MD)

Q21. What is your current employment status?[4]
- Full-time employed (40 or more hours per week)
- Part-time employed (less than 40 hours per week)
- Unemployed and **not** currently looking for work)
- Unemployed and currently looking for work
- Self-employed
- Homemaker
- Student
- Military
- Retired
- Other __________

Q22. Which category includes your total **annual household income** before taxes?
- Less than $15,000
- $15,000 to $24,999
- $25,000 to $49,999
- $50,000 to $74,999
- $75,000 to $99,999
- $100,000 to $149,999

[4] For the analysis, unemployed options were aggregated.

- $150,000 or over

Q23. What is your marital status?
- Single (never married)
- Married
- In a domestic partnership
- Divorced
- Widowed

Q24. Including yourself, how many people currently live in your household?
- 1 (only you)
- 2
- 3
- 4
- 5 or more

Q25. How many children currently live in your household?
- 0
- 1
- 2
- 3
- 4
- 5 or more

Q26. Do you have a driver's license?
- Yes
- No

Q27. How many vehicles are available in your household?
- 0
- 1
- 2
- 3
- 4
- 5 or more

APPENDIX D

CORRELATION MATRIX WITH A FULL LIST OF THE VARIABLES

	AV01	AV02	AV03	AV04	AV05	AV06	AV07	AV08	AV09	AV10	AV11	AV12	AV13	AV14	AV15	AV16	AV17	AV18
PT01	-0.19*	-0.26*		-0.20*	-0.20*	-0.15		-0.5		-0.21*	-0.23*		0.20*			0.21*		0.19*
PT02										-0.16							0.16	
PT03	-0.17									-0.18			0.18	0.22*			0.18	0.18
PT04										-0.19*			0.22*	0.17	0.17		0.20*	
PT05					-0.23*													
PT06					-0.22*													
PT07		0.17		0.16	0.25*	0.16		0.24*				0.16*						
PT08								0.15				0.16*						
PT09					-0.22*				-0.17		-0.15				-0.23*	0.19*		
PT10									-0.15		-0.15		0.15					0.15
PT11			0.18															
PT12	0.20*	0.27*		0.28*	0.20*	0.26*		0.35*	0.19	0.20*	0.25*	0.30**		-0.27*		-0.23*		-0.20*
BE01											0.15	0.14			0.19*			
BE02			0.15						0.18*						0.18*	-0.19*	0.18*	
BE03												0.14			0.18*			
BE04																-0.18*		
BE05				0.17											0.17	-0.19*		
BE06								0.15	0.14							-0.21*		
BE07		0.17		0.19*		0.18*		0.16	0.13		0.15				0.23*	-0.19*	0.19*	
BE08		0.16		0.20*	0.16	0.18*		0.19*	0.21*		0.14	0.18*			0.31*	-0.30*	0.18*	
BE09															0.32*			
BE10								0.15	0.15						0.25*	-0.19*		
BE11					0.18*									0.15	0.30*		0.25*	
BE12			-0.13		0.22*			0.16							0.38*	-0.14	0.19*	
BE13								0.14	0.14						0.30*			
BE14					0.22*			0.21*				0.15			0.30*	-0.22*	0.16	
BE15					0.14										0.28*		0.16	
BE16												0.18*			0.16			
BE17								0.14	0.16		0.16				0.24*	-0.21*	0.16	
BE18															0.18*		0.13	

Note. *: $p < 0.01$; Insignificant correlations ($p > 0.05$) are left blank.

APPENDIX E

RESULTS OF EXPLORATORY FACTOR ANALYSIS

Survey Item	Attitudes toward public transit services (Factor 1)	Perceived quality of built environments (Factor 2)	Preference for autonomous vehicles (Factor 3)
Overall, I trust the public transit service provider.	0.73		
I feel safe while riding the public transit.	0.71		
The vehicle is easy to access by people with disabilities like me.	0.68		
The public transit arrival time is reliable and acceptable.	0.62		
The public transit service is valuable.	0.62		
Drivers are willing to help me.	0.57		
I am comfortable traveling with unknown passengers when using the public transit.	0.56		
The public transit takes me where I need to go.	0.52		
There is enough space in the vehicle to accommodate me, a companion, and/or luggage.	0.47		
The eligibility process for using paratransit is time consuming.			
The fare is reasonable.			
It is difficult to change my travel plans when using public transit.			
I can get most of my personal business (e.g., banking, laundry) done within walking distance of my home.		0.68	
The car speed on the streets in my neighborhood is low.		0.68	
The sidewalks are well-maintained without obstacles (e.g., potholes, cracks).		0.67	
There are enough places in my neighborhood where I can go for recreation or entertainment.		0.66	
The bus or rail stops in my neighborhood have clear paths without obstacles or barriers to access.		0.65	
There are plenty of places to shop or eat within walking distance of my home.		0.63	
People usually drive carefully in my neighborhood.		0.63	

APPENDIX E Continued

Survey Item	Attitudes toward public transit services (Factor 1)	Perceived quality of built environments (Factor 2)	Preference for autonomous vehicles (Factor 3)
There are no barriers on the sidewalks (e.g., parked cars, tree branches, constructions).		0.62	
There are good street-lights on the street in my neighborhood.		0.62	
I feel safe when I travel around my neighborhood during the day or at night.		0.60	
There are trees along the streets that provide nice amount of ample shade.		0.56	
The intersections have tactile paving (e.g., textured, truncated dome surfacing).		0.55	
The sidewalks in my neighborhood are wide enough.		0.53	
The level of car traffic on the streets in my neighborhood is low.		0.53	
The bus or rail stops have shelter or a bench.		0.52	
The bus stops are well-maintained.	0.42	0.49	
The crosswalks have an assistant device to cross the road (e.g., traffic control device, speaker).		0.43	
The intersections have curb cuts or ramps.			
I would find AVT useful in meeting my travel needs.			0.77
I would use AVT for daily travel because it would be cheaper.			0.76
I trust AVT to be safe and reliable in severe weather conditions.			0.76
AVT would make the roads safer.			0.75
AVT would bring us to our destination faster.			0.70
AVT could solve the transportation problems of people with disabilities like me.			0.70
AVT could effectively interact with other vehicles.			0.69
AVT would drive safer than an average human driver.			0.68
Interactions with AVT would be clear and understandable to me.			0.66
AVT could lead to more traffic jams.			-0.63
AVT can correctly detect pedestrians on the streets.			0.62
AVT would make my life easier because I would no longer need to look for parking.			0.49
AVT could be confused in unexpected situations.			-0.46
AVT would not be accessible for all if there is no human operator.			-0.40

APPENDIX E Continued

Survey Item	Attitudes toward public transit services (Factor 1)	Perceived quality of built environments (Factor 2)	Preference for autonomous vehicles (Factor 3)
I would be willing to share AVT with 6 to 8 fellow travelers with a similar route as mine.			
AVT could lead to privacy issues caused by a surveillance camera in the vehicle or tracking of location.	0.49		
AVT may have computer or mechanical errors.			
AVT could cause unemployment.			

APPENDIX F

RESULTS OF LATENT VARIABLE MEASUREMENT MODEL

Latent Variable	**Indicator***	**Estimates**	**t-ratio**
Public Transit Attitude	I_1	0.659	4.23
	I_2	0.875	4.56
	I_3	0.846	4.84
	I_4	0.860	4.56
	I_5	0.966	5.17
Perceived Quality of Built Environments	I_6	1.553	4.84
	I_7	2.410	5.43
	I_8	1.673	5.66
	I_9	0.893	5.13
	I_{10}	1.451	6.43
AV Preference	I_{11}	2.097	6.48
	I_{12}	2.341	6.35
	I_{13}	2.752	5.04
	I_{14}	1.530	6.43
	I_{15}	1.672	6.57

* Note: Indicator definitions are given in Table 4.1.