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RESEARCH SYNTHESIS FOR MICHIGAN MOBILITY COLLABORATIVE UNITED STATES DEPARTMENT OF TRANSPORTATION (USDOT) AUTOMATED DRIVING SYSTEMS DEMONSTRATION GRANT PROGRAM

LISA J. MOLNAR, DAVID W. EBY, AND RENÉE M. ST. LOUIS

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16. Abstract
Being able to get around in one’s community (referred to as mobility), regardless of the mode of travel, enables people to satisfy important essential needs as well as enrichment needs. Unfortunately, disabilities, many of which disproportionally affect older adults, can negatively impact mobility. The overarching goal of the research synthesis is to understand the state of knowledge about the mobility needs, preferences, attitudes, and broader perspectives of older adults and people with disabilities, especially with regard to automated driving systems (ADSs). Of particular interest is how ADSs can best realize their potential to serve these transportation-challenged populations in terms of accessibility, acceptability, usability, and safety. Findings from the synthesis yielded a number of important insights. People with disabilities and older adults, compared to other groups, have different needs and travel patterns and face different barriers for mobility. As development of ADS technologies continues, it is clear that much more research is needed to address the concerns and needs of older adults and people with disabilities. Trust, acceptance, willingness to use, and attitudes related to ADSs among older adults and people with disabilities is related to a number of factors, and it is important to gain a better understanding of these groups’ needs, preferences, and concerns about ADS technology. It is clear that both older adults and people with disabilities are hopeful and yet skeptical of these technologies. There is a lack of formal evaluation of past ADS projects that include evaluation of user-centered outcomes, such as improved access to healthcare and other services, mobility, and quality of life.

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Executive Summary

Introduction

Being able to get around in one's community (referred to as mobility), regardless of the mode of travel, enables people to satisfy important essential needs as well as enrichment needs. Unfortunately, disabilities, many of which disproportionally affect older adults, can negatively impact mobility. Aspects of disability are generally considered to include hearing, vision, cognition, mobility/ambulation, self-care, and/or independent living. Many of the disabilities experienced by older adults (age 65 or older) result from the aging process itself, as well as certain medical conditions that are more common in old age and the use of medications intended to treat these conditions. In 2020, one in four Michigan adults age 18 or older (26%) reported having a disability (representing over 2 million people). Reported prevalence by disability type was: 5% for a hearing disability; 3% for a vision disability; 13% for a cognitive disability; 12% for an ambulatory disability; 3% for a self-care disability; and 8% for an independent living disability. Automated driving systems (ADSs) hold great promise for helping older adults and people with disabilities get to the places they need and want to go. The overarching goal of the research synthesis is to understand the state of knowledge about the mobility needs, preferences, attitudes, and broader perspectives of older adults and people with disabilities, especially with regard to ADSs. Of particular interest is how ADSs can best realize their potential to serve these transportation-challenged populations in terms of accessibility, acceptability, usability, and safety.

Methods

The research synthesis was conducted through a scoping review of relevant published research literature, including journal articles, technical reports, and relevant websites, building on and extending work conducted by the project team. Topics explored included: cognitive, psychomotor, and perceptual abilities that decline with age, as well as disabilities among people of all ages that adversely affect mobility; travel behavior of older adults and people with disabilities; ADSs and vehicle technology issues; the role of informal caregivers of older adults and people with disabilities with regard to use of ADSs; and findings from other relevant demonstration projects.

Findings and Conclusions

Findings from the synthesis yielded a number of important insights that are highlighted here. People with disabilities and older adults, compared to other groups, generally: take fewer trips; are less likely to travel for social, recreational, or work purposes; and are less likely to drive themselves, walk, or bicycle but more likely to ride with others or use public transit. In thinking about the potential use of ADSs by people with disabilities and older adults, it is instructive to consider the barriers they face in using existing and emerging forms of mobility, especially public transit and ride-sharing services. In addition, it is important to consider these barriers over the course of the full trip, starting with arranging for a ride and ending with the actual arrival at the destination. Thus, the barriers that must be overcome include internal and external factors, and physical as well as social barriers. As development of ADS technologies continues, it is clear that much more research is needed to address the concerns and needs of older adults and people with disabilities. Trust, acceptance, willingness to use, and attitudes related to ADSs among older adults and people with disabilities is related to a number of factors, and it is important to gain a better understanding of these groups' needs, preferences, and concerns about ADS technology. It is clear that both older adults and people with disabilities are hopeful and yet skeptical of these technologies moving into higher levels of automation. Future systems will need to operate as intended, meet the unique mobility needs of these particular populations, and be affordable and easy to use. Finally, much progress still needs to be made in developing methods and programs for teaching older adults and people with disabilities about how to interact with and operate ADSs as well as giving them an understanding of the operational limitations of the technology. Continued research in the area of ADSs and caregivers is warranted. The inclusion of caregivers of older adults and people with various disabilities in future studies is needed to better understand the needs and challenges related to providing transportation assistance, and to inform the development of future ADSs that are accessible and useful for people with varying levels of physical and cognitive abilities. Based on the number and variety of recent/current ADS demonstration projects, it is clear that there is a lot of enthusiasm toward the development of these systems and their future potential. It is also clear that new demonstration projects will continue to need strong collaborative partnerships, high-levels of public support, and technology that meets the real mobility needs of users. There is an unfortunate lack of formal evaluation of past demonstration projects that include both process evaluation and evaluation of user-centered outcomes, such as improved access to healthcare and other services, mobility, and quality of life. Future projects should include more detailed evaluations of the effects of ADS technology on not only the general population, but on mobility-disadvantaged populations such as older adults and people with disabilities.

Based on findings from the research synthesis, a number of recommendations were made for informing the design, planning, implementation, and/or evaluation of the ADS demonstration.

Contents

1 Introduction

1.1 Background

Mobility has been described as one of the cornerstones of healthy aging (University of Alabama at Birmingham, 2013). Being able to get around in one's community (referred to hereafter as mobility), regardless of the mode of travel, enables people to satisfy important essential needs as well as enrichment needs. Mobility enables individuals to engage in activities necessary to their everyday survival such as commuting to and from work, accessing healthcare, shopping, and running other errands, as well as participate in activities that promote their wellbeing and quality of life such as spending time with family and friends, engaging in recreational and social activities, and participating in volunteer activities. Unfortunately, disabilities, many of which disproportionally affect older adults, can negatively impact mobility (Eby, Molnar, & St. Louis, 2019). Reduced mobility (especially in the form of driving cessation) has been associated with numerous adverse consequences such as loss of freedom and independence, reduced social participation and access to health care, decreased life satisfaction, increased depressive symptoms, and acceleration of more general health declines (e.g., Chihuri et al., 2016; Choi, Lohman, & Mezuk, 2014; Harrison & Ragland, 2003; Liddle et al., 2012; Marottoli et al., 1997; Rosso, Taylor, Tabb, & Michael, 2013).

1.2 People with Disabilities

As defined by the Centers for Disease Control and Prevention (CDC, 2020), a disability is any condition of the body or mind that makes it more difficult for individuals with the condition to engage in certain activities and interact with the world around them. In accordance with this definition, the World Health Organization (2001) points to three dimensions that make up disability: 1) impairment in an individual's body structure or function (e.g., loss of limb, vision, or memory); 2) activity limitation (e.g., difficulty seeing, hearing, walking, or problem solving); and 3) participation restrictions in normal daily activities (e.g., working, engaging in social and recreational activities, and accessing healthcare or preventive services). People with disabilities represent a diverse group of individuals and as such, measurement of disability in the population generally encompasses multiple types of functional disability. For example, the United States (US) Census Bureau's American Community Survey (ACS) asks about six aspects of disability, that together, are used to create an overall disability measure and to independently identify populations with specific disability types (US Bureau of the Census, 2021). These six aspects of disability are:

- Hearing disability**:** deaf or having serious difficulty hearing.
- Vision disability**:** blind or having serious difficulty seeing, even when wearing glasses.
- Cognitive disability**:** because of a physical, mental, or emotional problem, having difficulty remembering, concentrating, or making decisions.
- Ambulatory disability**:** having serious difficulty walking or climbing stairs.
- Self-care disability**:** having difficulty bathing or dressing.
- Independent living disability**:** because of a physical, mental, or emotional problem, having difficulty doing errands alone such as visiting a doctor's office or shopping.

Respondents who report any of the six disability types are considered to have a disability. Based on results of the 2019 ACS (Erickson, Lee, & von Schrader, 2022), 12.7% of people of all ages in the US were found to have a disability. Reported prevalence increased with age: 0.7% for age 4 and under; 5.5% for age 5-15; 6.5% for age 16-20; 10.5% for age 21-64; 24.2% for age 65-74; and 47.1% for age 75 or older. Reported prevalence by type of disability across all age groups was: 3.6% for a hearing disability; 2.3% for a visual disability; 5.2% for a cognitive disability; 6.8% for an ambulatory disability; 2.6% for a self-care disability; and 5.7% for an independent living disability. Males and females reported similar prevalence: 12.6% versus 12.8%, respectively. Reported prevalence by race was: 10.5% for White; 13.5% for Black/African American; 4.4% for Asian; 17.2% for Native American; and 9.7% for other races.

Disability among adults (age 18 or older) is examined in the Behavioral Risk Factor Surveillance System (BRFSS), an annual survey conducted in the US using roughly the same six types of functional disability as the ACS (with mobility disability replacing ambulatory disability). Varadaraj, Deal, Campanile, Reed, and Swenor (2021), analyzed the 2019 BRFSS and found that 26.8% of respondents (representing 67.2 million adults in the US) reported any disability and 11.7% reported more than one disability. Reported prevalence by type of disability was: 6.1% for a hearing disability; 5.2% for a visual disability; 12.1% for a cognitive disability; 13.3% for a mobility disability; 3.9% for a self-care disability; and 7.2% for an independent living disability. In analyses stratified by gender and race, reported prevalence of disability was higher among Black women than White women, Hispanic women, and women of other races and ethnicities (58.7% versus 53.6%, 53.0%, and 53.2%, respectively). Reported prevalence was also higher among women overall than men, and respondents with less than a high school education, lower income, and those less likely to be employed. The investigators cautioned that the estimates were likely conservative because the BRFSS is limited to non-institutionalized adults.

Results of the BRFSS are also able to be broken out by state. In the 2020 BRFSS, one in four Michigan adults (26%) reported having a disability (representing over 2 million people; CDC, 2022). Reported prevalence by disability type was: 5% for a hearing disability; 3% for a vision disability; 13% for a cognitive disability; 12% for an ambulatory disability; 3% for a self-care disability; and 8% for an independent living disability. Adults in Michigan with disabilities were more likely to experience health disparities than those without disabilities. For example, they were more likely to suffer from depression (43% versus 13%), obesity (43% versus 32%), diabetes (16% versus 8%), and have heart disease (11% versus 5%) in 2020. They were also more likely to smoke than those without disabilities (32% versus 15%).

1.3 Older Adults

Although older adults with disabilities represent a part of the larger disability population, it is instructive to consider them separately for several important reasons. First, older adults represent the age segment of the population that is at the greatest risk of having a disability (24.2% of people age 65 to 74 and 47.1% of people age 75 or older versus 12.7% of the larger population in 2019; Erickson et al., 2022). Second, because of this, they are more likely as a group to experience adverse consequences that can result from disabilities, including impacts on mobility and health. Third, the population of older adults is growing in the US and elsewhere, resulting in the need for more focused attention on this population, especially in terms of how to ensure that they remain safely mobile as they continue to age (Eby et al., 2019). Finally, it has been argued that similarities between older adults and people with disabilities in terms of functioning and physical requirements for travel do not necessarily translate into shared self-perceptions and aspirations (e.g., Coughlin, 2005, 2007). For example, many older adults tend to see themselves as younger than their chronological age, generally by about 10 years (e.g., Markides & Boldt, 1983; Myers & Lumbers, 2008; Sudbury & Simcock, 2009). In addition, Coughlin (2005) argued that while older adults may have similar functional requirements as people with disabilities, they do not see themselves as disabled or equate their age-related functional declines as disabilities.

Many of the disabilities experienced by older adults result from the aging process itself, as well as certain medical conditions that are more common in old age and the use of medications (prescription and nonprescription) intended to treat these conditions (Eby et al., 2019). In the older adult literature, these disabilities are often discussed within the context of impairments or declines in cognitive, psychomotor, and/or perceptual functioning. A brief review of these age-related impairments or declines is presented here. More detailed discussions of age-related impairments and medical conditions can be found elsewhere (e.g., Charlton et al., 2010; Dobbs, 2005; Eby, Molnar, & Kartje, 2009; Owsley, 2011).

Eby et al. (2019) identified a number of cognitive, psychomotor, and perceptual abilities that can decline with age, as well as some of the more common medical conditions that lead to these declines. Collectively, these declines in abilities can make it challenging for older adults to operate their own vehicle, as well as access and use other non-driving mobility options (e.g., walk to and from the vehicle, enter and exit the vehicle, arrange for rides; Bascom & Christensen, 2017; Bezyak, Sabella, & Gattis, 2017). These cognitive, psychomotor, and perceptual abilities are summarized below by category of ability.

<u>Cognitive abilities:</u> include many aspects of mental functioning including attention, formulation of knowledge, memory, judgement, evaluation, reasoning, problem solving, and decision making. Several cognitive abilities were found to decline with age, despite considerable individual differences among older adults (e.g., Eby et al., 2009; Drag & Bieliauskas, 2010; Harada, Love, & Triebel, 2013; Mather, 2010):

- Attention: sustained (ability to attend to relevant information for some period of time); selective (ability to keep one’s mind on important information while ignoring irrelevant information); and divided (ability to attend to multiple tasks at the same time).
- Information processing speed (the speed at which people can think).
- Spatial cognition (one’s ability to perceive and process the location and movement of objects in space).
- Executive functioning (related to one’s ability to self-regulate goal-directed behavior and effectively organize and use large quantities of information).

These declines come about as part of the normal aging process and/or because of common medical conditions. These conditions include Alzheimer's disease and other dementias, mild cognitive impairment, and Parkinson's disease (Eby et al., 2019; Falkenstein, Karthaus, & Brüne-Cohrs, 2020).

Psychomotor abilities: include all aspects of individuals' ability to move. Psychomotor abilities found to decline with age (e.g., Adams, O'Shea, & O'Shea, 1999; Der & Deary, 2006; Karthaus & Falkenstein, 2016; Klavora & Heslegrave, 2002; Reed, Liu, & Kalu, 2018) include:

- Muscle strength.
- Coordination.
- Reaction time.
- Flexibility.

In addition to the normal aging process, these declines can result from several medical conditions including paralysis, arthritis, Parkinson's disease, and multiple sclerosis (Eby et al., 2019; Falkenstein et al., 2020).

Perceptual abilities: Several perceptual abilities were found to decline with age (e.g., Ball & Sekuler, 1986; Hofstetter & Bertsch, 1976; Kline & Birren, 1975; Owsley, 2011; Owsley & Sloane, 1990) including:

- Visual acuity (the ability to resolve details).
- Contrast sensitivity (the ability to see in low light conditions).
- Glare recovery (due to bright headlights or sunlight).
- Visual processing speed.
- Stereoscopic space perception.
- Sensitivity to motion.

In addition to the normal aging process, these declines can result from several medical conditions including cataracts, diabetic retinopathy, glaucoma, macular degeneration, and visual field loss (Eby et al., 2019; Falkenstein et al., 2020).

1.4 Brief Overview of Research Synthesis and Larger Project

Automated driving systems (ADSs) hold great promise for helping older adults and people with disabilities get to the places they need and want to go. The overall purpose of the Michigan Mobility Collaborative project is to increase safety, trust, and equity in the transportation system by developing a scalable approach to ADS deployments worldwide, starting here in Michigan. The research synthesis presented here has been undertaken by the Behavioral Sciences Group at the University of Michigan Transportation Research Institute and is intended to support and inform later project activities and overall project objectives.

The overarching goal of the research synthesis is to understand the state of knowledge about the mobility needs, preferences, attitudes, and broader perspectives of people age 65 and older (older adults) and people with disabilities, especially with regard to ADSs. Of particular interest is how

ADSs can best realize their potential to serve these transportation-challenged populations in terms of accessibility (e.g., egress, entry, and making the transfer easy), acceptability, usability, and safety. As noted in the USDOT's Notice of Funding Opportunity, this includes securement and restraint systems for wheelchairs and other equipment for people with disabilities. The research synthesis aligns with several of the Michigan Mobility Collaborative's primary program objectives and subobjectives. Of special note are increasing community members' trust and understanding of ADSs (under collaboration objective) and increasing access to transportation (mobility equity objective).

A major outcome of the research synthesis is a set of recommendations to help guide development and selection of the use cases by Ford, and later deployment of the demonstration project. Thus, findings from the synthesis will supplement and extend the insights gained from the community engagement activities conducted for the project. To that end, we have tried to work closely with the Collaboration Partners conducting the community engagement to ensure that our efforts are harmonious and complementary.

2 Methods

The research synthesis was conducted through a scoping review of relevant published research literature, including journal articles, technical reports, and relevant websites, building on and extending work conducted by the project team (e.g., Eby et al., 2015, 2016, 2021; Molnar et al., 2015, 2018, 2021). The synthesis encompassed several tasks including: 1) development of selection criteria to guide the review; 2) identification of topics to be included; 3) development of search terms to capture those topics; 4) collection and storage of relevant information in a bibliographic management system; 5) multiple-level review of stored documents to identify appropriate documents for synthesis and integration of them into a written synthesis document; and 6) development of recommendations for selection of use cases and later deployment.

The research synthesis was guided by a set of selection criteria (e.g., type of document, time period for publication, geographic coverage). These selection criteria, highlighted below, were developed based on our knowledge of this field, recent reviews of the literature conducted by members of the project team (e.g., Eby et al., 2015, 2016, 2019; Molnar et al., 2015, 2018), and discussions among the project team. They were:

- Peer-reviewed journal articles, technical reports, government reports, industry reports/documents, conference proceedings, and book chapters but no dissertations or full books were included.
- The documents above were supplemented with information from relevant websites.
- Literature providing at least some empirical evidence was included, but commentaries, editorials, opinion pieces, or letters to the editor without empirical evidence were not included.
- Literature from 2010 to the present was included as well as key/seminal literature from prior to 2010.

- Literature came primarily from US but also included countries or jurisdictions relevant to the traffic context in the US.
- Included research consisted of studies conducted by researchers at academic institutions, industry, and government.
- Only literature written in English was included.
- Where appropriate, meta-analyses and systematic reviews were prioritized for inclusion rather than individual studies.

The review covered a set of specific topics (see below). Topics were selected with the overall aims of ensuring that they were consistent with what is being explored through the community engagement efforts and to provide insights that are of value to development of the use cases and later demonstration deployment. The topics include:

- Cognitive, psychomotor, and perceptual abilities that decline with age, as well as disabilities among people of all ages that adversely affect mobility: overview and descriptions; prevalence in population.
- Travel behavior of older adults and people with disabilities: where they go (trip purpose/destinations); how they get there (transportation modes); barriers to use.
- ADSs and vehicle technology issues: how older adults and people with disabilities understand, learn about, and use such technologies; barriers to use (e.g., accessibility, affordability); attitudes related to trust and acceptance.
- Role of informal caregivers of older adults and people with disabilities with regard to use of ADSs: facilitation of learning and teaching; role in building trust and acceptance; caregiver burden and resource needs.
- Findings from other relevant demonstration projects: challenges in deployment; successful strategies for deployment; overall lessons learned.

The research team identified starting sets of search terms that were used to search the literature for the identified topics. For each term listed, all permutations of the term were included in the search. For example, for the term "functional", we searched function, functions, functioning, etc. We did this by entering the common stem for all of the expected permutations. Terms were combined into search strings (using AND, OR, etc.) to represent the myriad of ways the topics might be represented in the literature. As the focus of the synthesis is on both older adults and people with disabilities, separate searches were conducted for each population. The document search process was necessarily iterative; as appropriate articles were found, relevant subject and key word terms in those articles were used to refine the search and additional references were gathered.

Several document databases were searched: PubMed, PsycINFO, Transport Research International Documentation (TRID), ProQuest, ScienceDirect, and Google Scholar. Document gathering was facilitated by the University of Michigan's MLibrary, which allows the University of Michigan employees electronic access to multiple literature databases and subscriptions to thousands of journals and other publications. All of the resources were organized using an online bibliographic tool called Zotero (https://www.zotero.org/) that allowed for all research team members to have access to the information. Documents and website information were reviewed by at least two members of the research team. Information deemed appropriate was included in the literature review and synthesized.

3 Travel Behavior

In thinking about the negative impacts on mobility among people with disabilities and older adults, it is important to focus on multiple aspects of travel behavior including frequency and amount of travel, type of travel or trip purpose, and mode of travel. The definitive and only national source of data on personal and household travel in the US is the National Household Travel Survey (NHTS) conducted by the US Federal Highway Administration (FHWA). The 2017 NHTS includes data on 923,572 trips taken by 264,234 people, age 5 or older, residing in 129,696 households across the US (see US FHWA & Westat, 2019 for users' guide). Respondents are considered to have a travel-limiting disability if they respond in the affirmative to a question asking if they have "a temporary or permanent condition or handicap that makes it difficult to travel outside the home" (Brumbaugh, 2018, p. 2). In this section, we cite research findings, based on the NHTS and a few other sources, to examine travel patterns and trends for people with disabilities and older adults in each of the three areas of travel behavior (i.e., frequency, purpose, mode). Of special interest is how the COVID-19 pandemic may have affected travel behavior among these groups. We also discuss barriers to mobility experienced by people with disabilities and older adults. Given that many studies included in this section focus on these groups collectively, research findings are discussed together for people with disabilities and older adults rather than in separate sections but broken out by group when data are available.

3.1 Frequency and Amount of Travel

Evidence suggests that both people with disabilities and older adults are less likely than other groups to travel in general. For example, in a study of travel behavior among older adults, using travel diaries recorded over a 9-day period, older adults with mobility problems were found to take fewer trips and perform fewer activities than older adults without mobility deficits (6.4 versus 13.2 trips, respectively), complete fewer activities per trip, and be less able to travel unaccompanied in the community (42% versus 95%, respectively; Shumway-Cook et al., 2002).

Park et al. (2022) conducted a systematic review of 115 studies of travel behavior of people with mobility, cognitive, and sensory disabilities. They concluded that people with disabilities made 10-30% fewer trips than those without disabilities, especially non-work-related trips. This was based on studies showing that people with disabilities took 5.7-10.2 trips per week and 2.0-3.9 trips per day, while people without disabilities took 7.8-14.0 trips per week and 2.6-4.2 trips per day. These differences were exacerbated by increased disability severity, inclement and seasonal effects, and metropolitan versus non-metropolitan residency.

Several studies have used data from the NHTS to examine travel behavior, including trip frequency, among people with disabilities and older adults (e.g., Bardaka, Jin, McDonald, Steiner, & LaMondia, 2022; Brumbaugh, 2018; Dong, 2020; Henly & Brucker, 2019;

Hutchinson et al., 2019; Mattson, 2012; Mattson & Molina, 2022; Mitra, Bae, & Ritchie, 2019; Myers, Ipsen, & Standley, 2022; Pucher & Renne, 2005; Sadeghvaziri & Tawfik, 2020). One of the most recent and comprehensive of these studies analyzed data from three waves of the NHTS (2001, 2009, and 2017) to better understand travel behavior of four transportation-disadvantaged groups – people with disabilities, older adults, individuals in low-income households, and individuals living in rural areas (Mattson & Molina, 2022). In urban areas, people with disabilities reported 2.3 trips per day, compared to 3.6 for people without disabilities. Trips per day were highest for respondents age 35-49 (3.9), then decreased with age, with the decline accelerating at age 75 (2.8 for age 75-84 and 2.0 for age 85 or older). Trips per day in urban areas were similar for men and women (3.4 versus 3.5, respectively). Trips per day across all geographic regions in 2017 reflected a decrease from 2001 and 2009 among young men but not among young women or older adults of either gender.

3.2 Trip Purpose

Evidence suggests that the travel patterns of people with disabilities and older adults are also different from others in the larger population in terms of certain types of trips. For example, Henly and Brucker (2019) analyzed the travel patterns of 153,242 working-age adults, age 18-64 in the US, using a subsample of the 2017 NHTS. They found that working-age adults with a disability were less likely to take trips for social or recreational purposes than people without disabilities (18.3% versus 27.5%, respectively) or for work (60.7% versus 78.1%, respectively). There were no differences between the groups for shopping or running errands. Length of disability was also important. People with a lifetime disability were less likely to travel for shopping or running errands than people with a temporary disability or a disability of more recent onset. Similar results were reported by Brumbaugh (2018), who also noted that adults age 18-64 with disabilities took as many trips for medical and dental purposes as their counterparts without disabilities. Mattson and Molina (2022) examined trip purpose by age, using 2017 NHTS data for all groups. They found that work trips decreased among people age 65 or older compared to their younger counterparts, while trips for shopping or medical purposes increased. Trip purposes among urban residents did not differ markedly from those of residents in other geographic areas.

3.3 Mode of Travel

The systematic review by Park et al. (2022) found significant differences in travel mode choice between people with and without disabilities. People with disabilities were less likely to drive themselves, walk, or bicycle, and more likely to use other mobility options including riding with others, public transit, paratransit, and taxis. Use rates for most transportation modes varied considerably across studies, however. For example, across all relevant studies, 2.6%-82.7% of people with disabilities drove themselves compared to 23.3%-85.7% of people without disabilities. Use rates for other modes for people with and without disabilities were: 3.0%-46.0% and 11.3%-52.3%, respectively for walking; 5.9%-46.7% and 11.6%-26.6% for riding with others; 4.6%-51.0% and 4.3%-34.8%, respectively for public transit. Older adults with disabilities were less likely to walk or use public transportation and relied more on a personal vehicle and driving with others than the general population of older adults.

Based on analyses of data from the 2017 NHTS, Mattson and Molina (2022) found that people with disabilities in urban areas were more likely to take public transit than people without disabilities (13.1% versus 8.5%, respectively), and also walk (23.1% versus 20.8%). People with disabilities were less likely to travel by personal vehicle (59.5% versus 65.4%). Levels of use for other modes were small and generally similar for people with and without disabilities. Comparisons of 2001, 2009, and 2017 NHTS data indicated that use of public transit and walking have increased overall in urban areas, while travel by personal vehicle has decreased. Across all years and geographic region, use of public transit was generally higher among lower-income groups comprised of people with disabilities. Brumbaugh (2018) pointed out that while adults with disabilities, like their counterparts without disabilities, rely on personal vehicles for most of their travel (although at a reduced level), they experience additional challenges because they are less likely to own their own vehicles and more likely to live in low-income households.

Brumbaugh (2018) also used the 2017 NHTS to examine use of ride-hailing services. He found that people age 18-64 with disabilities were less likely to use ride-hailing services than their counterparts without disabilities (4.6% versus 12.4%, respectively, reported use in past 30 days). He noted that smartphones or tablets, which are generally required for ride-hailing, are used less by people with disabilities than people without disabilities (66.5% versus 86.5%, respectively, use smartphones daily and 30.2% versus 37.2%, respectively, use tablets daily).

3.4 Barriers to Mobility

People with disabilities and older adults often face unique barriers to maintaining mobility in their communities. While many of these barriers have been identified and examined in the scientific literature within the context of fixed-route public transportation, they are also applicable to other mobility options which still require users to arrange for rides and/or payment, get to and from the vehicle, enter and exit the vehicle and so forth.

Kerschner and Harris (2007) conceptualized the mobility barriers of older adults, particularly with regard to public transit, in terms of a lack of availability, accessibility, acceptability, affordability, and/or adaptability. They described these dimensions of mobility as follows:

- Availability: transportation exists and is available when needed.
- Accessibility: transportation can be reached and used (bus stairs can be negotiated, bus seats are high enough, bus stop is readable, van comes to the door).
- Acceptability: standards relate to conditions such as cleanliness (bus is not dirty), safety (bus stops are located in safe areas), and user-friendliness (transit operators are courteous and helpful).
- Affordability: costs (fees) are affordable, comparable to or less than driving a car, and vouchers or coupons help defray out-of-pocket expenses.
- Adaptability: transportation can be modified or adjusted to meet special needs (wheelchair can be accommodated, trip chaining is possible).

Because these dimensions collectively contribute to mobility, it is instructive to think about the interplay of barriers across dimensions. For example, people may be unable to use public transit even when available if physical impairments limit the distance that they can walk without a rest or prevent them from climbing the steps of the bus or standing when the bus is in motion (Eby et al., 2019). It is also important to explore barriers by type of disability to the extent possible, given the heterogeneity of older adults and people with disabilities, and the differing ways that different types of disability affect mobility and travel behavior (Clery, Kiss, Taylor, & Gill, 2017). Owens, Miller, and Shivers (2020), using a nationwide survey of 160 adults age 18-81 with disabilities, and follow-up interviews with a subset of survey respondents, found that reported barriers varied considerably across individuals and to some extent, type of disability. The physical structure of the environment (e.g., steep or slippery routes) was especially challenging for people with physical disabilities, while people with perceptual disabilities reported more difficulty using public transit, and people with intellectual and developmental disabilities reported more difficulty following directions and correctly judging where to go. Challenges with navigation and orientation among people with cognitive disabilities were also identified by Risser et al. (2015) in a review of 34 studies on use of public transit by people with cognitive impairments. In addition, they noted the importance of considering the entire trip from planning the trip to arriving at the destination when thinking about barriers, as well as balancing both internal factors (e.g., knowledge, attitudes, ability, willingness to use public transit) with external factors (accessible and usable infrastructure, personal support from service provides) for this group.

Maisel, Choi, and Ranahan (2021) analyzed existing survey data from people with disabilities to examine the factors that impact fixed-route transit decision making and better understand barriers to fixed-route transit. They found several statistically significant differences across disability groups including that: people with mobility disabilities reported two environment-related factors (barriers in the pedestrian environment and distances to/from stops and stations) to be very important and more important than scheduling-related factors; people with visual disabilities reported barriers in the pedestrian environment to be significantly more important than service hours and lack of information, and service frequency and complex or multiple transfers to be significantly more important than other built environment and scheduling-related factors; people with intellectual or cognitive disabilities reported complex or multiple transfers as very important, and more important than environment and scheduling-related factors except for distances to or from stops and stations.

Survey results from 4,161 people with disabilities reported by Bezyak et al. (2017) also indicated differences in perceived barriers by disability type across five categories – vision, hearing, communication, mobility, and mental/learning. People with vision disabilities were more likely than any other group to report that the transit system was inadequate (58.9%), as well as problems with drivers not calling out stops (53.1%) or refusing to stop (18.5%). People with either vision disabilities or mobility disabilities were more likely to report problems with inappropriate driver attitudes (31.8% and 29.9%, respectively), lack of accessible routes to stops/stations (31.4% and 29.6%, respectively), climate conditions (25.1% and 34.8%, respectively), and driver lack of knowledge (31.4% and 25.9%, respectively). People with either vision disabilities or hearing disabilities were more likely to report service animal problems (10.2% and 9.2%, respectively). People with communication disabilities together with people with mental/learning disabilities were more likely to report an inability to navigate public transportation (27.7% and 25.9%, respectively) or that they were ineligible to use paratransit (12.3% and 10.5%, respectively). In addition, people with communication disabilities and people with mobility disabilities were also more likely to report that they were unable to secure a wheelchair (11.3% and 15.4%, respectively). People with mobility disabilities were more likely than any other group to report inaccessible stops/stations (26.9%), problems with gaps or steps to the vehicle (28.8%), or with lifts (34.0%), that the vehicle was full (23.1%), or that the wheelchair was too big/heavy (6.6%).

One theme emerging from these studies is that environmental factors are a significant contributor to mobility barriers for people with disabilities and older adults. This recognition has led to the idea that disability itself is a dynamic process that is affected by both intrinsic factors within individuals and extrinsic factors such as physical and social features of the environment (Shumway-Cook et al., 2002). Henly and Brucker (2019) discussed this within the context of the social model of disability, the idea that "disability results from barriers that prevent full participation in society, rather than in a characteristic of the individual. Some of the barriers may be cultural, but others are observable physical barriers in our environment that present obstacles to participation for persons with certain types of impairments" (p. 104). Shumway-Cook et al. (2002) identified eight dimensions of the physical environment that can impact mobility in older adults with and without mobility disability. Four of these – temporal factors, physical load, terrain, and postural transition – were found to differ between older adults with and without mobility disability. Four others – distance, density, ambient conditions, and attentional demands – did not differ between these groups of older adults. The investigators concluded that certain aspects of the environment may contribute to mobility disability for older adults more than others.

As noted earlier, social aspects of the environment such as public transit drivers' attitudes and behaviors toward people with disabilities and older adults can also lead to mobility barriers. For example, among the challenges faced by older adults in using public transit, Broome, Nalder, Worrall, and Boldy (2010) identified not only physical barriers (bus stops too far from home or too far apart, difficulty with entry and exit, lack of direct routes and connection, lack of shelters), but also social barriers - drivers who are not friendly or helpful and lack of prior knowledge by users about the service. Park et al. (2022) noted that the attitudes of staff, drivers, and other passengers came up in several of the studies they reviewed as a barrier to mobility – specifically that negative personal interactions with other transit users and staff can undermine feelings of confidence, independence, and security of transit users, and lead to increased anxiety. Another theme that emerged from their review was that technology intended to facilitate mobility, particularly access to information, can often itself become a barrier to mobility due to the complexity of the technology or inability to buy or use a smartphone.

The extent to which physical aspects of the environment present barriers and must be accommodated for also depends on whether and what type of mobility aids are used by people with disabilities. Henly and Brucker (2019) examined the use of such aids among people with disabilities and found the following percentage use rates: cane – 31.3%; walker – 12.4%; manual wheelchair – 8.5%; crutches – 4.0%; scooter – 3.2%; motorized wheelchair – 3.1%; seeing-eye dog – 1.6%; white cane – 1.3%; and none – 50.9%. Use of mobility aids was found to be similar in urban and rural areas (Myers et al., 2022). A systematic review of 26 studies on the accessibility of public transit for people using mobility devices (defined as three or four wheeled seated mobility devices or walkers) identified challenges with: traveling to and from the transit stop (e.g., uneven pavement surfacing, lack of dropped curbs, steps instead of ramps, narrow doorways, controls for pedestrian lights or lift access that are too high, and poorly designed street displays); waiting at a transit stop (e.g., placement of information out of reach of users, inappropriate space for wheeled mobility devices, and lengthy wait times with little shelter); boarding and alighting public transit (e.g., drivers' restricting types of mobility devices, uncertainty about accessibility of destination stops, and poor ramp design, deployment, and/or angles); and moving within a public transit vehicle to one's allocated space (e.g., narrow front entrance pathways and access corridors) (Unsworth, So, Chua, Gudimetla, & Naweed, 2019). Limited interior space for wheelchair users in accessible public transit was a challenge identified by participants, especially wheelchair users, in a focus group study conducted by Hwang, Li, Strough, Lee, and Turnbull (2020). A systematic review of studies on automated vehicles and services for people with disabilities also identified inadequate floor or aisle space for mobility devices as one aspect of inaccessible interior configurations on both public transit and low-speed automatic shuttles that are supposed to be accessible to wheelchairs and scooters (Dicianno et al., 2021). The authors noted that because people with disabilities represent a diverse group, accessible and usable design solutions should be tailored to each group's needs, circumstances, and preferences.

3.5 Healthcare

Healthcare-related trips represent an important type of trip for people with disabilities. Evidence suggests that people with disabilities have poorer overall health outcomes than people without disabilities yet spend more time on health-related activities (e.g., Anand & Ben-Shalom, 2014). Brucker and Rollins (2016) examined 20,941 trips taken by 18,539 people for medical care in the 2009 NHTS. They found that people with disabilities experienced longer travel times to receive medical care than people without disabilities, although they traveled similar distances and had similar access to private vehicles. Overcoming mobility barriers to healthcare is especially important, given that transportation problems are a key contributor to missed medical appointments and delayed medical care (e.g., Wolfe, McDonald, & Holmes, 2020). One proposed option for improving access to healthcare for people with disabilities is the use of ride-share services (Fraade-Blanar, Koo, & Whaley, 2021). Based on data from several sources including the NHTS and interviews with experts, these authors concluded that the most likely candidates for ride-share services are a subset of the population of people with disabilities. Specifically, they argued that ride-sharing services are best suited to people requiring curb-to-curb services (i.e., services appropriate for people able to get to the curb independently and enter vehicle with little or no assistance) and area-to-area assistance (i.e., services appropriate for those who are highly ambulatory, and have the ability to walk distances independently and enter a vehicle without assistance). People with disabilities who required greater levels of assistance (door-to-door and hand-to-hand) were not considered to be prime candidates for ride-share services, with the exception of children traveling with a parent or caregiver.

3.6 Effects of COVID-19 on Travel Behavior

Understanding the effects of the COVID-19 pandemic on people with disabilities is of special interest given this populations' already increased vulnerability in terms of mobility. Given the relative recency of the onset of the COVID-19 pandemic and its ongoing nature, it is not surprising that the literature on its effects on people with disabilities is sparse. Many of the published studies are limited to small nonrepresentative samples (e.g., Cochran, 2020; Koon et al., 2022). However, one benefit of these studies is that they are able to explore issues in an in-depth manner through interviews or open-ended survey items. To that end, Cochran (2020) interviewed 21 people with disabilities in the San Francisco Bay area in the spring of 2020, just after the first shelter-in-place order in that area. She identified several themes including: health and safety concerns posed barriers to using public transit and shared services; barriers to seeking medical care increased; greater perceived dependency on others to get around and access essential services; lack of up-to-date information and communication made decisions about whether and how to travel difficult; concerns about getting needed assistance and asking too much of others; and varied experiences using delivery services. The open-ended responses of a survey of 39 people with mobility disabilities (Koon et al., 2022) indicated that the aspect of community engagement most negatively affected by the pandemic was access to family and friends, followed by access to food and groceries, transportation, employment, living independently, caring for others, and participating in the community in general. In response to these challenges, respondents reported using technology to connect with others and have essential goods delivered.

Data from a larger survey sample that included both people with and without disabilities (161 and 232, respectively) focused on changes in travel behavior and activities of community living (Park et al., 2022). The authors found that people with disabilities were more likely to reduce their daily travel than people without disabilities, but the extent of reduction depended on type of disability, travel mode, and type of trip. For example, people with cognitive and perceptual disabilities reported the greatest reduction in taxi rides and ride-hailing services. People with cognitive disabilities were more likely to report reductions in trip taking for grocery shopping, eating in restaurants, recreation, and healthcare.

A final study of COVID-19 effects focused exclusively on healthcare access in North Carolina, using mobile device data to identify visits to health care facilities (Bardaka et al., 2022). Cluster analysis yielded three distinct clusters; all experienced a reduction in medical care visits during the lockdown, but to different extents and with differing recovery patterns. Compared to the second and third clusters, the first cluster, composed of greater percentages of older adults, minorities, low-income individuals, and people without vehicle access, had lower numbers of medical visits before the pandemic and experienced a slower recovery after the lockdown. This cluster also had a higher population density which the authors noted is likely linked to greater public transit use which was, in turn, likely affected by the pandemic, creating more difficulty in accessing health care. Collectively, their results led the authors to conclude that the areas at greatest risk for decreased healthcare access during the pandemic are the same areas with lower healthcare access prior to the pandemic.

3.7 Conclusions

People with disabilities and older adults, compared to other groups, generally: take fewer trips; are less likely to travel for social, recreational, or work purposes; and are less likely to drive themselves, walk, or bicycle but more likely to ride with others or use public transit. In thinking about the potential use of ADSs by people with disabilities and older adults, it is instructive to consider the barriers they face in using existing and emerging forms of mobility, especially public transit and ride-sharing services. In addition, it is important to consider these barriers over the course of the full trip, starting with arranging for a ride and ending with the actual arrival at the destination. Thus, the barriers that must be overcome include internal and external factors, and physical as well as social barriers.

4 Automated Driving Systems

Over the past two decades, societal mobility options have been transforming through the development and deployment of technologies that can take over control of the vehicle from the driver under certain circumstances (i.e. ADS, or Automated Vehicles, AV) (USDOT, 2020). There are several potential benefits of ADS technology (National Highway Traffic Safety Administration, NHTSA, 2022):

- *Safety Benefits*: ADSs can reduce the primary cause of roadway crashes—driver error—helping to reduce crashes and associated injuries.
- *Mobility Benefits*: ADSs have the potential to improve and increase community mobility options for older adults and people with disabilities as well as expanding mobility options among underrepresented communities.
- *Economic and Societal Benefits*: ADSs have the potential to increase access to jobs and services for people who have difficulty with transportation, and reduce the costs associated with traffic crashes.
- *Efficiency and Convenience Benefits*: ADSs can reduce congestion and make travel more efficient, saving countless travel hours and increasing the convenience of travel.
- *Environmental Benefits*: ADSs could benefit the environment in several ways including reducing the need for parking spaces, increasing the use of shared mobility options, which saves fuel and energy resources, and decreasing transportation-related air pollution.

The acceptance of ADSs, an important component of use, is a multi-faceted construct that extends beyond simply the safety benefits of the systems (Rahman et al., 2019). For example, Stevens (2016), viewed acceptance as including five distinct components: usability; perceived safety benefits; understandability; desirability; and security and privacy. Others have identified user trust as an important element in the long-term acceptance of not just automation, but any technology (e.g., Krum at el., 2019; Molnar et al., 2018). Several models or frameworks of technology acceptance have been examined as a basis for better understanding acceptance of ADSs. These include the Technology Acceptance Model (TAM; Davis, 1985, 1989) and the Unified Theory of Acceptance and Use of Technology (Venkatesh et al., 2003). Using an online survey and a driving simulator, Rahman et al. (2017) explored attitudes toward use of either a fatigue monitoring system or adaptive cruise control system combined with a lane keeping system and found that each of the models successfully predicted driver acceptance in terms of intent to use the system. TAM was the best performing, with attitudes toward using a system being the strongest predictor of intent to use that system. Attitudes were in turn influenced by beliefs around perceived usefulness and ease of use. Another study examined the role of trust in the acceptance of ADSs by extending TAM to include initial trust, as well as two types of perceived risk (Zhang et al., 2019). The investigators found that trust was the most important factor underlying a positive attitude toward ADSs.

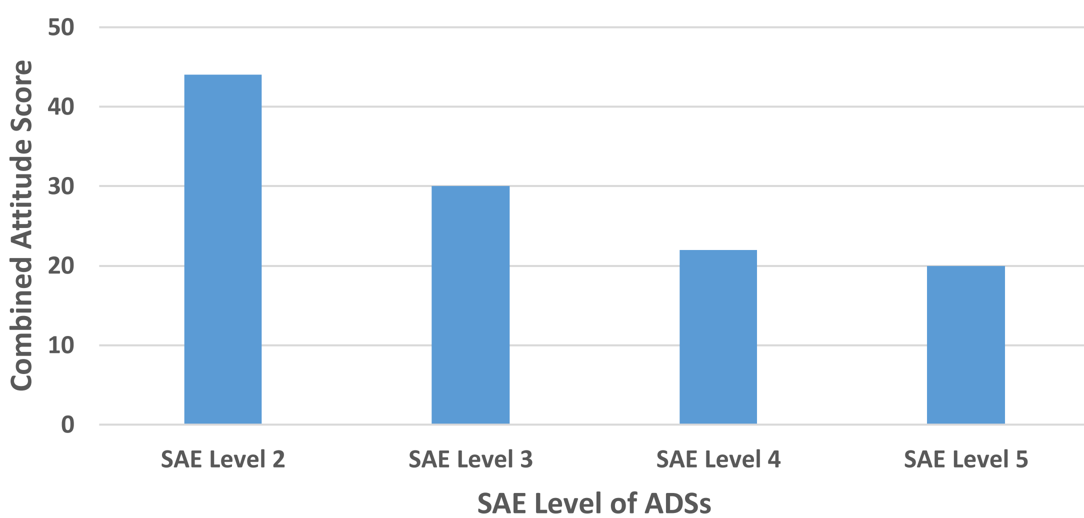
Here we focus on synthesizing what is known about willingness to use, attitudes, and thoughts about ADSs as well as examining preferences for training/learning among two potential user groups mentioned by NHTSA (2022)—older adults and people with disabilities. The results are limited to empirical research findings that explored some form of ADS as opposed to technologies that aid drivers such as the variety of Advanced Driver Assistance System (ADAS) technologies that are becoming increasingly common in passenger vehicles (Eby et al., 2021). Because fully automated driving technologies (i.e., automation Levels 3-5, Society of Automotive Engineers, SAE, 2018) are in development and not available to the general public, one of the challenges with investigating use, attitudes, and preferred training methods for these systems is providing research participants with a realistic understanding of how the technology would operate and what the associated user experience would be in its use on actual roadways (Eby, Molnar, & Stanciu, 2018; Molnar et al., 2018). The review found several methods were used to convey the experience of using an ADS: questionnaires and focus group designs that provided written or verbal descriptions of ADSs and their function (e.g., Kadylak, Cotton, & Fennell, 2021); driving simulators that had programmed ADS features (e.g., Hartwich et al., 2019); role-playing user-enactment which used a classroom mock-up of an ADS (e.g., Gluck et al., 2020a); and automated, low-speed shuttles running on a preprogrammed course as pilot tests of Level 3 ADSs or on a closed test track (e.g., Classen et al., 2021b; Hartwich et al., 2019). Here we include results from all types of studies with the methodology noted.

4.1 Older Adults

Although contemporary researchers in aging and mobility typically define older adults as being age 65 or older (e.g., Eby et al., 2019), the definitions from several studies on ADSs and older adults include younger participants age 50 and older (Peng, Yawen, & Zhen, 2019) and 55 or 60 and older (e.g., Gluck et al., 2020a, 2020b; Huff et al., 2019; Rahman et al., 2019). All definitions of older adults are included in this review.

Studies report that older adults' perceptions of ADSs are generally negative overall and less positive than younger age groups (e.g., Diepold et al., 2017; Hassan et al., 2021; Kadylak & Cotton, 2020; Kadylak et al., 2021; Lajunen & Sullman, 2021; Peng et al., 2019; Rovira et al., 2019). For example, a study that included respondents from the United Kingdom (UK), US, Canada, and Australia (Lajunen & Sullman, 2021) asked older adults about their attitudes toward four levels of increasingly automated driving (SAE, 2018, Levels 2-5). The study found that as the level of automation increased, older adults reported less positive opinions of safety, trustworthiness, enjoyability, reliability, comfort, perceived ease-of-use, and attractiveness. The largest decreases in positive attitudes occurred between Level 2 vehicles, which are currently on the road, and Level 3 vehicles, which are not available to the public. Figure 1 shows the combined positive attitude scores across all measures for each level of automation.

Figure 1: Overall Attitudes Toward ADSs among Older Adults by Level of Automation (Lajunen & Sullman, 2021)



A questionnaire study of 1,000 older Canadians also found clear negative attitudes towards ADSs (Hassan et al., 2021). Respondents reported their level of agreement with a series of questions. Table 1 shows the percentage of older adults responding with "strongly agree" or "agree" (note that this study used the phrasing "fully-automated vehicles", FAV). The research also examined concerns that older adults had about ADSs and found that older adults were concerned: about being legally responsible if the ADS failed and caused a crash (64% strongly agree/agree), that ADSs have not received enough testing (54%); that they would not purchase an ADS if it were more expensive than a conventional vehicle (48%); and that ADSs would not perform safely in all road and weather conditions (40%).

Statement	% Responding "Strongly Agree/Agree"
FAVs will improve the mobility of older adults and persons with disabilities	42%
FAVs will make transportation more efficient	30%
Overall, I will use a FAV in the future	23%
FAVs will be safer because they eliminate human error	21%
Eventually, a FAV will be my preferred mode of transportation	17%
I would own a FAV, even though I would not drive it	12%
I like the idea of using a FAV Taxi Service	12%

Table 1. Older adults' level of agreement with statements about ADSs.

Other research shows that the negative attitudes toward ADSs among the older adult population is moderated somewhat by several factors including: gender, with older adult males having more positive attitudes toward ADSs (e.g., Hassan et al., 2019; Hohenberger, Spörrle, & Welpe, 2016; Hulse, Xie, & Galea, 2018); education and income level, with attitudes being more positive with increasing education and household income (e.g., Hassan et al., 2019; Kadylak et al. 2021); urbanicity, with those living in areas of increasing density having more positive attitudes (e.g., Hassan et al., 2019; Kadylak et al., 2021); and functional limitations, with more positive attitudes among older adults who need help with transportation—an indication of functional disability (Classen et al., 2021a; Kadylak et al., 2021). For example, Kadylak et al. (2021) reported that in a large sample of US older adults, 16% of older adults who needed no assistance with instrumental activities of daily living reported that they were willing to use an ADS as compared to 28% who required assistance with transportation.

Qualitative studies with older adults show that while older adults have an interest in ADSs and can see potential future benefits, these benefits are closely tied to the features of the future ADSs such as door-to-door mobility, ability to travel with friends, travel flexibility, adjustable interior seating, and some level of control over the ADS operation (e.g., Gluck et al., 2020a, 2020b; Zandieh & Acheampong, 2021). Qualitative studies also revealed concerns that older adults had with ADSs including: not being able to manage the hand-over of control if an ADS were to fail or encounter a situation outside of its operational domain (e.g., Faber & van Lierop, 2020; Huff et al., 2019; Li et al., 2019; Molnar et al., 2018); an inability to afford the technology (e.g., Huff et al., 2019; Zandieh & Acheampong, 2021); lack of adequate licensing and training to use the technology (e.g., Huff et al., 2019; Zandieh & Acheampong, 2021); reliability and safety (e.g., Classen et al., 2021b; Faber & van Lierop, 2020; Gluck et al., 2020b; Huff et al., 2019; Zandieh & Acheampong, 2021); an erosion of good driving etiquette (Zandieh & Acheampong, 2021); and a reduction in social interactions with a driver (Siegfried et al., 2021; Zandieh & Acheampong, 2021).

Another strong factor that moderates older adults' attitudes toward ADSs is experience with technology in general and with ADSs specifically (e.g., Lee et al., 2017; Molnar et al., 2018; Rahman et al., 2019). For example, Rahman et al. (2019) found in a questionnaire of 173 older US adults that greater familiarity with ADSs significantly increased positive attitudes, perceived usefulness, trust, perceived safety, and acceptance. In a study of older adults who were exposed to ADSs through a driving simulator and riding in an automated Level 4 shuttle, Classen et al. (2021b) found that older adults' perceptions of safety, trust, and perceived usefulness all increased after exposure to the ADS technology.

4.2 People with Disabilities

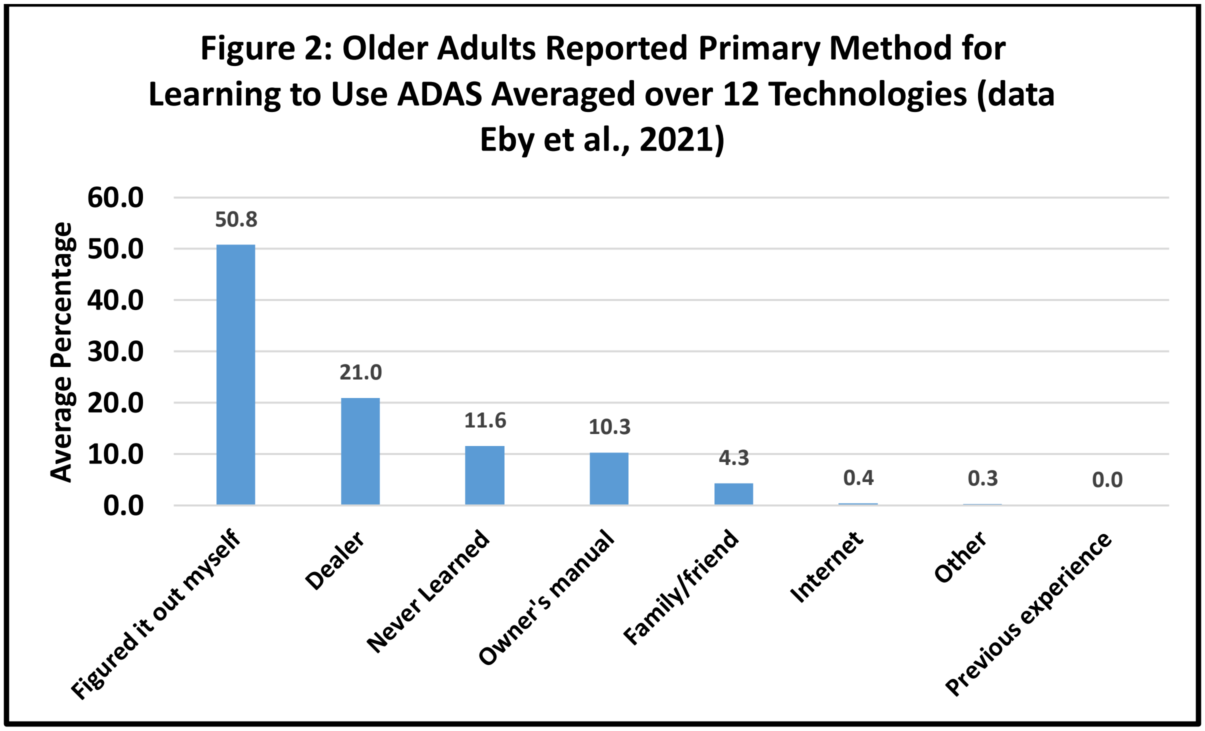
Given the prevalence of disabilities in the US, as discussed earlier (Erickson et al., 2022; Varadaraj et al., 2021), it is not surprising that several researchers have pointed out the potential for ADSs to improve mobility for people with disabilities (e.g., Allu et al., 2017; Bayless & Davidson, 2019; Hwang et al., 2020; Kuzio, 2021; Milakis & van Wee, 2020; Riga & Pande, 2021). The review found only a modest number of empirical articles related to attitudes and opinions of ADSs among people with disabilities and the majority of this work focused on people with visual impairment, while others did not differentiate among the types of disabilities. In addition, most of the work was qualitative using small sample sizes and focus group or structured interview techniques. Overall, the studies found that people with visual and/or physical/mobility disabilities are hopeful and optimistic about the potential for ADSs to improve their mobility and independence (e.g., Bennett, Vijaygopal, & Kottasz, 2020; Brinkley et al., 2017, 2019; Hwang et al., 2020, 2021; Ketankumar et al., 2021). These studies, however, also report that these groups have several concerns about ADSs including: accessibility in terms of interacting with the vehicle (interfaces, maintaining situational awareness, utilizing the interior vehicle space, and ingress/egress); skepticism that future ADSs will actually address their needs; a lack of travel flexibility; lack of safety and how to deal with crashes; designers of ADSs not taking into account the needs of people with disabilities; and ADSs being too expensive (Bennett et al., 2020; Brinkley et al., 2017, 2019; Hwang et al., 2020, 2021).

A few studies have addressed perceptions of ADSs among people with mental health disabilities. One study in the UK interviewed a sample of 177 people with intellectual disabilities in an open-ended question format about their willingness to use ADSs (Bennett, Vijaygopal, & Kottasz, 2019). The study found that the most common perceptions of ADS technology was the sense of "freedom" (46%), followed by "fear" (34%), and "curiosity" (20%). A study in the US recruited people with Autism Spectrum Disorder (ASD) to ride in an experimental ADS shuttle and then complete a structured interview (Feeley et al., 2020). The study reported very positive impressions of ADSs among this population as well as strong interest in traveling in an ADS in the future. Respondents noted that ADS technology would benefit their independence, freeing them from their reliance on family for transportation, along with several other potential benefits. Concerns were also expressed that were similar to the concerns of people with other types of disabilities: lack of accessibility, lack of safety, prohibitive cost, potential problems with the vehicle interface, and availability. Collectively, the studies suggest that people with mental health disabilities, like people with other disabilities, are hopeful about the potential of ADS technology but also have important concerns about the technology.

4.3 Learning to Use/Training for ADSs

Even though ADS technology is designed to operate the vehicle without a drivers' input, there is still a need to learn about the ADS including: how do you call for or locate a vehicle; how do you pay for the service if there is a cost; how do you let the vehicle know where you want to go; how do you store personal equipment like a walker; how does the ADS let you know when you have arrived at your destination; what do you do if there a system failure; and so on. As such, training and/or education about any ADS technology will be required. Unfortunately, the literature search found no articles of training or learning to use ADS technology specific to older adults or people with disabilities. However, research on learning to use ADAS technologies (the precursor to ADS technologies) among older adults provides some insights.

As discussed by Eby, Molnar, and St. Louis (2019), there is an ample body of literature showing that older adults have difficulty understanding how automotive technologies work as well as their operational limitations (e.g., AAA Foundation for Traffic Safety, AAAFTS, 2008; Dickie & Boyle, 2009; McDonald et al., 2016; Shaw et al., 2010). To this end, several studies have investigated how older adults learn to use ADAS technologies (e.g., AAAFTS, 2008; Braitman et al., 2010; Eby et al., 2018, 2021; Eichelberger & McCartt, 2014). These studies report that older adults use a variety of methods to learn about ADAS technology; a significant portion of older adults learn about the ADAS by themselves through trial-and-error; many rely on the dealer or the owner's manual to teach them about their vehicle's ADAS; a sizable proportion of older adults never learn how to use the technology; and very few use the Internet as a source of learning or training about ADAS. These findings are highlighted by the results of a recent study that reported on how 2,374 older drivers indicated they learned to use 12 ADAS technologies in their personal vehicle (Eby et al., 2021). Figure 2 shows the percentage of older adults reporting the primary way they learned to use ADAS technologies averaged over 12 ADASs. As can be seen, more than half of older adults figured the systems out by themselves, 31% learned from the dealer or owner's manual, nearly 12% never learned to use the technology, and less than 0.5% sought out learning sources on the Internet. Such results suggest that concerted effort is needed to not only develop training/educational resources but also to determine how to best implement these programs among potential older adults and people with disabilities who will be using ADS technology.



4.4 Conclusions

As development of ADS technologies continues it is clear that much more research is needed to address the concerns and needs of older adults and people with disabilities. Trust, acceptance, willingness to use, and attitudes related to ADSs among older adults and people with disabilities is related to a number of factors, and it is important to gain a better understanding of these groups' needs, preferences, and concerns about ADS technology. It is clear that both older adults and people with disabilities are hopeful and yet skeptical of these technologies moving into higher levels of automation. Future systems will need to operate as intended, meet the unique mobility needs of these particular populations, and be affordable and easy to use. Finally, much progress still needs to be made in developing methods and programs for teaching older adults and people with disabilities about how to interact with and operate ADSs as well as giving them an understanding of the operational limitations of the technology.

5 Informal Caregivers

Caregiving is an important component of public health that affects the quality of life for millions of individuals in the US, including both caregivers and care recipients. Caregivers provide assistance with another person's social, emotional, or health needs, and may include help with one or more activities important for daily living (National Association of Chronic Disease Directors, 2018). While there are both paid and unpaid caregivers, this synthesis focuses on the role of informal caregivers; that is, family members or friends who provide ongoing, unpaid assistance to an older adult or a person with a disability (National Alliance for Caregiving, NAC, & AARP, 2020). Informal caregivers are often referred to as the backbone of our care system (see e.g., Hoffman & Zucker, 2016; NAC & AARP, 2020), as both health care and long-term services and supports rely on the day-to-day at-home care provided by informal caregivers to meet the basic needs of older adults and people with disabilities.

Approximately one in five Americans have provided care to an adult or child with special needs in the last year (NAC & AARP, 2020). This equates to an estimated 53 million caregivers in the US overall, an increase from the estimated 43.5 million caregivers reported in 2015 (NAC & AARP, 2020). This increase is primarily driven by a significant increase in the prevalence of caring for adults age 50 or older. In addition to rising numbers of caregivers, caregivers also report increasing complexity of their caregiving tasks due to greater health and functional needs of their care recipient. Caregivers are now more likely to report their care recipient requires care due to long-term physical health conditions (63%), emotional or mental health issues (27%), and memory problems (32%) such as Alzheimer's disease and dementia (NAC & AARP, 2020). Care recipients age 65 and older were most likely to have long-term physical conditions and memory problems, while mental health issues and development or intellectual disorders were more common among care recipients age 18-49 (NAC & AARP, 2020). It is well documented that without effective support, caregivers face substantial psychological, physical, and financial health risks. Programs that assist caregivers can reduce caregiver depression, anxiety, and stress and enable them to provide care longer, reducing the need for institutionalization (Lopez-Hartmann, Wens, Verhoeven, & Remmen, 2012).

5.1 Transportation Assistance and Challenges

Help with transportation is the most commonly reported form of assistance provided by caregivers in the US, with 80% reporting providing this type of support (NAC & AARP, 2020). On a more local level, a study conducted in Michigan found that more than 90% of caregivers of older adults reported that they provide some form of transportation assistance (Eby, Molnar, Kostyniuk, St. Louis, & Zanier, 2011), and of those providing transportation assistance, 98% reported providing rides in a personal vehicle (Eby, Molnar, Kostyniuk, St. Louis, & Zanier, 2017). The most frequently reported trip purpose was providing transportation assistance to medical or dental appointments (91%), followed by shopping/errands (65%), family/personal business (62%), social or recreational activities (58%), and school/religious activities (33%).

For many caregivers, providing transportation is the most trustworthy and cost-effective solution to meeting the transportation needs of their care recipient when that person can no longer or chooses not to drive. However, transportation problems are among the most troublesome issues for caregivers, and challenges are greater when the care recipient has mobility problems that require the use of an assistive device, such as a wheelchair or scooter (Eby et al., 2019). Due to declines or disabilities that affect physical functioning, such as reduced strength and flexibility, providing transportation can be a physically demanding task for a caregiver. Older adults and people with disabilities often need assistance getting from the home and to the vehicle, entering the vehicle, locating and buckling the seatbelt, and exiting the vehicle. When focused just on vehicle ingress and egress, several factors influence the ability of a caregiver to safely assist their care recipient. These factors include the extent and type of mobility limitation, size of the care recipient, height of the vehicle, design of the vehicle seat, and availability of devices to assist with ingress and egress (e.g., grab handles or a step). These difficulties may cause some caregivers to stop transporting their care recipient completely or to transport them only for the most essential appointments, which can lead to a reduction in quality of life (Eby et al., 2019).

While providing transportation is often an essential component to caregiving, transportation is also one of the most frequently identified service gaps in providing care (e.g., Whittier, Scharlach, & Dal Santo, 2005). The lack of available and accessible transportation serves as a barrier to accessing services for the caregiver as well as for those receiving care. Given a rapidly aging population and increases in long-term physical health and memory conditions that require care, innovative solutions to supporting older adults, people with disabilities, and their caregivers are necessary to decrease the physical and emotional burden on caregivers and promote the health and well-being of both caregivers and their care recipients.

5.2 Potential Use of ADSs

Limited research exists on the role of caregivers and ADSs; however, recent research has begun to explore caregivers' acceptance of ADS use by people with cognitive declines and disabilities. For example, Haghzare et al. (2021) examined caregivers' attitudes and acceptance of ADS use (i.e. a fully automated vehicle) by people with dementia as well as their views about the potential usefulness of ADSs for people with dementia. Caregivers reported that the main potential benefit of the use of ADSs was continued independence of people with dementia, particularly with participation in social activities as this type of trip would not have been prioritized by the caregiver. It was also reported that use of ADSs could also provide freedom to caregivers who are responsible for transporting their care recipient.

While caregivers reported some possible benefits, a much higher number of major concerns about the use of ADSs were expressed. These included, for example, possible distress or agitation of the person with dementia while riding in a fully automated vehicle, lack of ability to initiate the trip or locate the destination upon arrival, inability to independently get in the car and fasten the seatbelt, and allowing more dangerous wandering behavior. Additionally, caregivers expressed concern over the ability of an ADS to function properly without system failure, and reported significantly lower levels of trust in and perceived safety of fully automated vehicles if used by the person with dementia in their care compared to themselves (Haghzare et al., 2021).

Another study examined caregivers' attitudes toward the use of ADSs by people with ASD under their care with the goal of designing a prototype autonomous vehicle for people with ASD (Padmanaban et al., 2021). Research shows that people with ASD have issues with coordination, attention allocation, tolerating unexpected changes in driving routes, and understanding non-verbal communication of other road users, all of which can make independent driving and the use of public transportation challenging (Classen et al., 2013). Caregivers reported low levels of trust in AVs with regard to allowing their care recipient to travel alone in an ADS. To alleviate this concern, design of ADSs included monitoring and updates of the passenger with ASD. The ability to monitor the location of the vehicle as well as to observe the in-vehicle behavior of the passenger could be beneficial to increasing caregiver trust and acceptance of this technology for aging adults as well as people with disabilities.

While caregivers provide the most transport-related support following driving cessation, caregivers can also play an important role in the safe mobility of an older adult when that person is still engaged in independent driving (Eby et al., 2019). As discussed in section 4, research on ADASs in the older driver population has suggested the potential for ADASs to improve safety and driving comfort by helping aging drivers overcome functional declines commonly experienced in later-life. Results from Eby et al. (2021) found that the prevalence of ADASs has increased among older adults, yet only a small proportion report receiving training about these technologies and their use. An opportunity exists for caregivers to help fill this gap by educating older adults about ADASs that have the potential to prolong safe driving. Training of older adults in the use of ADASs may then result in increased trust and acceptance of higher levels of automation in the future.

5.3 Conclusions

Continued research in the area of ADSs and caregivers is warranted. The inclusion of caregivers of older adults and people with various disabilities in future studies is needed to better understand the needs and challenges related to providing transportation assistance, and to inform the development of future ADSs that are accessible and useful for people with varying levels of physical and cognitive abilities.

6 Shared Automated Driving System Demonstration Projects Overview

One purpose of the research synthesis was to gain some insights into the challenges encountered in recent Shared Automated Driving System (SADS) technologies that have been, or are being, conducted in the US and elsewhere so that the Michigan Mobility Collaborative can be better-suited to develop and implement a SADS in the Detroit region. To this end, the literature and Internet were searched for recent/current SADS demonstration projects. The search found that there was an overwhelming number of demonstration deployments in the US and beyond. For example, the CTSO Cooperative Automated Transportation & CAT Coalition Infrastructure-Industry Working Groups (CTSO-CAT, 2020) surveyed 34 state DOTs and cities across of the US and found that 84% reported having at least one recent or current SADS being tested or deployed in their region. As such, we selected a sample of projects that show the variety of demonstration projects and searched for further details on these projects. Table 2 summarizes the details of 10 example projects that utilized SADSs in real traffic conditions.

Name	Target User	Summary	Reference/Link
61AV	All riders	Operated in a suburban area East of Denver International Airport from January to July 2019. Demonstration was a 1 mile, fixed-route service that connected to a transit district's bus/rail system using low	Regional Transportation District, 2019

		speed, shared Level 4 EasyMile shuttles.	
A2GO	All riders	Demonstration in downtown Ann Arbor. On-demand shared free rides to set pickup and drop off locations in a 2.64 sq mile service area accessed through a May Mobility app. Uses a fleet of vehicles, including one wheel-chair accessible vehicle. Project started October 2021 and is ongoing.	https://maymobility.com/deployments/
Arlington RAPID	UTA students, residents, workers, people with limited mobility	Located in 1 sq mile area in downtown Arlington, Texas and around the University of Texas at Arlington (UTA). Shared on-demand paid rides to user-selected destinations with dynamic routing. Service is accessed through a May Mobility app or a telephone. Demonstration started in March 2021 and is ongoing.	https://maymobility.com/deployments/
Autonomous Vehicle Grand Rapids (AVGR)	All riders, especially people with mobility disability	Downtown Grand Rapids, MI. Demonstration took place from July 2019 to April 2022. Free on-demand service accessed through a May Mobility app in 4.21 sq mile area. Four vehicles, one was wheel-chair accessible.	https://maymobility.com/deployments/
Auton-Mass	Students, faculty, staff	Demonstration took place from March 2021 to June 2022 on Hiroshima University's Higashi-Hiroshima campus Japan (3.2 sq mile area). The demonstration was a low speed, fixed-route, shared shuttle service. The free service was access by waiting at one of the stops and boarding an arriving vehicle.	https://maymobility.com/deployments/
Hillsborough Area Regional	All riders	Demonstration project in Tampa, FL started in October 2020. Demonstration uses a	https://ridebeep.com/location/hart-hillsborough-area-regional-transit/

Transit (HART) Smart AV		fixed, 1 mile route with four stops and two Navya shared low speed shuttles that are ADA accessible. Access is open by boarding arriving vehicles. Project is ongoing.	
DMC Self-Driving Shuttle Service	Residents of two specified retirement communities	Demonstration project in Downtown Detroit to connect residents of two retirement community to the Detroit Medical Center Heart Hospital between August and October 2020. The project operated a Navya Autonom® Shuttle on a fixed 1.31 mile route during specified hours.	https://www.prnewswire.com/news-releases/self-driving-shuttle-service-launched-to-transport-senior-citizens-and-underserved-to-detroit-hospital-301114838.html
Mcity Driverless Shuttle	U-M faculty, staff, and students	Operated on the University of Michigan campus, Ann Arbor, from June, 2018 to December, 2020. Fixed-route, low speed, Level 4 Navya shuttle.	Kolodge, Cicotte, & Peng, 2020
Robo Ride	All riders	Demonstration project in Peoria, AZ started in February 2020. Demonstration uses a fixed, 1 mile route with four stops and a Navya shared low speed shuttles that are ADA accessible. Access is open by boarding arriving vehicles. Project is ongoing.	https://ridebeep.com/location/robo-ride/
Together in Motion	All riders	Operated in Indianapolis and Fishers, IN during July 2019 to April 2021. The demonstration was a fixed-route, low speed, 2.9 mile route. The free service was accessed by waiting at one of nine stops and boarding an arriving vehicle. Project utilized five shuttles, one of which was wheelchair accessible.	https://maymobility.com/deployments/

Table 2. 10 example projects that utilized SADSs in real traffic conditions.

Most of the demonstration projects utilized SAE (2018) Level 4 shuttles traveling along a fixed-route, in a similar fashion as a bus service, whereby boarding and disembarking occurred at set destinations. Other demonstration projects tested technologies that allowed dynamic routing and destination selection. These services were generally accessed by "booking" a trip through a smartphone application and sometimes required the rider to walk a short distance to a safe boarding location. Many of the demonstrations utilized at least some shuttles that were wheelchair accessible, but few of the projects were targeted specifically toward people with disabilities or even people with mobility challenges. Only one of the projects was designed to provide transportation to older adults, and this project was a fixed-route from two retirement communities to a large urban hospital. Most of the demonstration projects were either ongoing or did not receive a formal evaluation.

The review found one formal synthesis and comparison of six case-studies of larger scale SADS demonstration projects in the US (Haque & Brakewood, 2020). In this study, detailed information about each project was gathered and then synthesized across the projects over three dimensions: deployment location; service characteristics; and stakeholders. The study reported that all demonstrations were employed in populated metropolitan areas where reducing congestion and increasing accessibility were needed. The frequency at these locations were responsive to the demands of the riders and destinations (e.g., the frequency of shuttle service increased on important sports event days for college campuses). There were several similarities between program service characteristics: all provided service for free; all had an on-board staff member for safety; the routes were relatively short, ranging from 0.5 to 2.5 miles; stop spacing on the routes ranged from 0.1 to 1.0 miles; all routes had at least two stops; routes were either circular or linear; all were slow-speed, ranging from 10-15 mph; and the vehicle capacities range from 6-12 passengers (Haque & Brakewood, 2020). The study also reported that four stakeholder groups were identified with each project: public organizations (e.g., city, state DOT), partner organizations (e.g., University, entertainment center); shuttle manufacturers (Navya, May Mobility); and operators (e.g., TransDev, Keolis). This study did not present information on barriers/challenges to deployments or lessons learned.

We found one recent study that did provide some of this information from 34 respondents from jurisdictions across the US that have recent or ongoing testing or deployments of SADS technology (CTSO-CAT, 2020). In this study, respondents cited several factors that were critical for success: safety, coordination, collaboration/partnership; public engagement and acceptance; and the need to test new technologies to improve them. Results were mixed about requirements for special authorization to deploy the shuttles; most reported that a waiver was needed from the Federal Government, but several were also required to obtain state or local licenses, registrations, or permits. Nearly all deployments collected data about the deployment, most commonly ridership, rider perceptions including satisfaction and acceptance, video data, and data on unexpected events. Several respondents noted that data from the shuttle operator were not available or provided. Finally, respondents reported on the lessons they learned including: the importance of high public acceptance and enthusiasm for the deployment; the need to involve emergency responders as partners; the importance of a good relationship between the agency and vendor; the need for the SADS technology to be reliable; and the importance of carefully considering the costs.

6.1 Conclusions

Based on the number and variety of recent/current ADS demonstration projects, it is clear that there is a lot of enthusiasm toward the development of these systems and their future potential. It is also clear that new demonstration projects will continue to need strong collaborative partnerships, high-levels of public support, and technology that meets the real mobility needs of users. There is an unfortunate lack of formal evaluation of past demonstration projects that include both process evaluation and evaluation of user-centered outcomes, such as improved access to healthcare and other services, mobility, and quality of life. Future projects should include more detailed evaluations of the effects of SADS technology on not only the general population, but on mobility-disadvantaged populations such as older adults and people with disabilities.

7 Discussion and Recommendations

This research synthesis focused on the mobility-related experiences, perspectives, and behaviors of people with disabilities and older adults, as well as their informal caregivers, especially within the context of ADSs. As noted earlier, ADSs have the potential to help these populations get to the places in which they need and want to go. The synthesis is intended to support and complement the larger Michigan Mobility Collaborative project, the goal of which is to increase safety, trust, and equity in the transportation system by developing a scalable approach to ADS deployments worldwide, beginning in the state of Michigan. In this section, we present recommendations, based on findings from the research synthesis, for informing the design, planning, implementation, and/or evaluation of the ADS demonstration.

1. Because this project focuses on people with disabilities and older adults, careful thought should be given to how outreach efforts, selection of locations and routes, and other design and planning activities can best ensure that the ADS targets these groups specifically rather than just the more general community at large. For example, incorporating locations where people with disabilities and older adults reside, such as retirement communities or housing, is one way to ensure that these populations will have access to the system.

2. People with disabilities and older adults represent overlapping but distinct populations, often with differing perspectives on their own impairments, as well as their mobility needs and preferences. Therefore, decisions regarding outreach to the community, implementation of the demonstration, and provision of information and training about the ADS need to be tailored to each group to address these differences.

3. While the ADS demonstration is intended to benefit the overall populations of people with disabilities and older adults, it is clear that not all individuals within these populations will be candidates to use the system. Those best suited for the ADS will likely be individuals who have the capacity to use curb-to-curb and area-to-area services. In addition, people with disabilities and older adults who require door-to-door or door-through-door service, and have an informal caregiver to assist them, may be candidates.

4. Design of and planning for the ADS demonstration should focus not only on overcoming barriers to accessibility but also, to the extent possible, on ensuring that the system is available, affordable, acceptable, and adaptable to target groups. Collectively, these attributes should contribute to a system that is more equitable and user-friendly.

5. Design and planning considerations for the ADS should take into account the 'whole trip' rather than just the time that users are on the system. This includes, for example, arranging for and scheduling trips, paying for the trip, boarding, riding, and exiting the system at the destination.

6. Collaboration and communication with community stakeholders, including the potential users of the ADS, is critical for the success of the demonstration project. Therefore, engaging the public and other stakeholders in the community early on and throughout the demonstration project is critical for the success of the project.

7. It has been proposed that user acceptance of ADSs includes multiple components including usability, perceived safety benefits, understandability, desirability, security and privacy, and trust. To address these components, system users should be provided with information about how the system works and the benefits of using it. Careful thought should be given to how to educate people about system capabilities, with education and training available in multiple media formats.

8. Many people in the target groups for the ADS demonstration will have informal caregivers who provide transportation assistance. Therefore, this group of informal caregivers will also need to be educated in what the system can do and how it works.

9. Given the important role that trust has been shown to play in user acceptance of ADSs and technology more generally, the system itself will need to be very reliable and operate as intended and advertised.

10. In thinking about routing for the ADS demonstration, using dynamic routing rather than fixed routes would be optimal. This is because people with disabilities and older adults travel to a wide range of destinations to meet their needs, many of which fixed routes would be unable to accommodate.

11. Access to healthcare is especially important for people with disabilities and older adults and the negative consequences of a lack of such access are well known. Given this, the ADS demonstration should provide rides for healthcare purposes (e.g., medical facilities, pharmacies), but should also provide rides to other places to which people with disabilities and older adults needs to go.

12. The system, including boarding and exiting locations, needs to be able to accommodate a wide range of disabilities and the use of mobility devices. For example, ramps should be included to accommodate those with wheeled assistive devices.

13. To the extent that safety riders will be interacting with passengers on the ADS, they should be trained in working with target groups and be respectful of their needs.

14. It is important to conduct a comprehensive evaluation of the demonstration project. A comprehensive evaluation includes not only measures of how the program was implemented (e.g., was it implemented as intended, what were the barriers to implementation), but there should also be measures of user experience, including whether there was improved access to healthcare and other services and improved quality of life.

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