Fully Autonomous Vehicles for People with Visual Impairment: Policy, Accessibility, and Future Directions

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A significant number of individuals in the United States report a disability that limits their ability to travel, including many people who are **blind or visually impaired (BVI).** The implications of restricted transportation result in negative impacts related to economic security, physical and mental health, and overall quality of life. **Fully autonomous vehicles (FAVs)** present a means to mitigate travel barriers for this population by providing new, safe, and independent travel opportunities. However, current policies governing interactions with the **artificial intelligence (AI)** 'at the wheel' of FAVs do not reflect the accessibility needs articulated by BVI people in the extant literature, failing to encourage use cases that would result in life changing mobility. By reviewing the legislative and policy efforts surrounding FAVs, we argue that the heart of this problem is due to a disjointed, laissez-faire approach to FAV accessibility that has yet to actualize the full benefits of this new transportation mode, not only for BVI people, but also for all users. We outline the necessity for a policy framework that guides the design of FAVs to include the concerns of BVI people and then propose legislative and design recommendations aimed to promote enhanced accessibility, transparency, and fairness during FAV travel.

CCS Concepts: • **Human-centered computing** → **Accessibility technologies**; *Accessibility*; • **Social and professional topics** → **Governmental regulations**; *Computing/technology policy*; *Government technology policy*;

Additional Key Words and Phrases: Autonomous vehicles, accessibility (blind and visually impaired), transportation policy, accessible design, artificial intelligence

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1 INTRODUCTION

Fully autonomous vehicles (FAVs) represent the future of accessible transportation by affording safe and flexible mobility for individuals who are limited by current transportation modes due to disability. Unfortunately, the policy landscape guiding the development of FAVs does not adequately consider the needs of transportation-limited populations, particularly those of people who are **blind and visually impaired (BVI)** and many older adults experiencing age-related visual impairments. While the predicted benefits of autonomous transportation have resulted in extensive media fanfare and advocacy by BVI stakeholders, the extant literature offers little clarification for designers and researchers to conceptualize the ever-evolving FAV legal ecosystem and its implications for accessibility. To succeed, we argue that the road ahead for accessible design must include policy promoting the small but growing body of work examining BVI perceptions, needs, and concerns with respect to FAV technology. This article starts by reviewing the current state of FAV policy as it relates to BVI accessibility. Based on these data, we then present recommendations to: (1) eliminate state level laws that discriminate on the basis of disability; (2) extend relevant sections of Part 37 of the Americans with Disabilities Act to FAV related technology; and (3) revise and reinstate the Vehicle Performance Guidance for Automated Vehicles. By discussing our recommendations in concert with existing policy recommendations and current work regarding the expectations and concerns of BVI people, the paper offers a pragmatic and user-driven approach for promoting accessible FAV technology and related policy development. Ultimately, we argue that should technology be reimagined to include the considerations presented here, the future will be bright for current transportation-limited populations who stand to benefit so greatly from autonomous vehicles using FAVs as their core transportation platform.

In the United States alone, there are over 25 million people who report experiencing travel limitations due to a disability, one third of whom assert that they do not leave their homes as a result of these limitations [United States Bureau of Transportation Statistics 2018]. Additionally, there are 26.9 million adults—roughly one tenth of the country's population over the age of 18-reporting some degree of visual impairment [American Foundation for the Blind 2019]. Recent statistics from the World Health Organization detail that there are 2.2 billion people who experience some form of visual impairment worldwide [World Health Organization 2019]. Of these, approximately 36 million experience blindness and 216 million have some form of moderate to severe visual impairment [Bourne et al. 2017]. The foregoing demographic measures can be expected to dramatically increase as populations age rapidly both worldwide and in the U.S., where 10,000 people turn 65 each day [United States Census Bureau 2019] and age continues to be a significant risk factor for experiencing visual impairment [World Health Organization 2019]. As visual impairment often restricts an individual's ability to drive, these figures suggest that there are at least 25 million people within the U.S., and approximately 253 million individuals worldwide, who stand to benefit greatly from the new, safer mobility options yielded by the implementation of FAVs. These benefits can be expected to have broad impacts in terms of supporting increased independence, employment, economic stability, physical and mental health, recreation, and overall enjoyment and quality of life.

The remainder of this article is organized as follows: In Section 2 we briefly review the current state of FAV technology. Section 3 reviews related work concerning BVI perceptions of FAVs and existing policy recommendations. Section 4 outlines the current state and trajectory of FAV policy. In Section 5 we propose future directions with policy recommendations, and in Section 6 we ground our discussion in the context of current problems with FAV consumer acceptance and user trust at large. Finally, in Section 7, we conclude by describing limitations and recommending future work.

2 CURRENT STATE OF FAV TECHNOLOGY

The proliferation of FAV development and related technologies means driving tasks are increasingly being transferred from a human operator to a computer. The current state of the art for consumer grade **autonomous vehicles (AVs)** involves semi-autonomous operation, where vehicles have the ability to automate specific aspects of the driving process (e.g., lane switching, speed maintenance, and braking) without driver intervention. These operations are considered Level 3 autonomy, with levels for AVs ranging from no assistance (Level 0) to fully autonomous operation (Level 5) [SAE International 2018]. The core tenant of consumer grade semi-autonomous operation is that the driver is ultimately responsible and must always be able to assume vehicle control with sufficient transition time to ensure safe operation [National Highway Traffic Safety Administration 2013]. Fully autonomous operation, as we discuss here, is performed without any human direction or intervention. FAVs can be considered a subset of AVs, and throughout this paper, the term AVs will be used when referring to vehicle autonomy between Level 3 and Level 5, with FAV used to refer specifically to Level 5 autonomy. FAV technology is currently available in commercial shuttle operations active in New York, Detroit, the University of Michigan, Las Vegas, Orlando, and many cities worldwide [EasyMile, 2020; May Mobility 2020; NAVYA 2020; United States Department of Transportation 2018]. The prevailing assumption is that as FAVs become available to consumers, vehicles will operate much like rideshare services are operated today, but without the constraints of a human operator [Narayanan et al. 2020]. This undoubtedly will result in FAVs leading to increased mobility, particularly in rural regions and those with poor public transportation networks. For instance, people who were once limited by the timeframe and reach of bus routes, railways, and human-operated rideshare services will be able to travel without relying on new infrastructure or the availability of human drivers. FAVs will also inevitably be safer than traditional, manually-driven technology, while providing much needed opportunities for populations limited by current transportation modes, including BVI people and older adults [DOT 2020a; Fagnant & Kockelman 2015]. The increased safety of this new class of transportation can best be illustrated through predictions that FAVs will reduce traffic related accidents by up to 90% [Koopman & Wagner 2017; Liu et al. 2019; National Highway Traffic Safety Administration 2017]. These factors will undoubtedly confer many benefits relating to increased mobility, independence, and social engagement for underserved demographics.

3 RELATED WORK

The following offers background on BVI perceptions of FAVs, current ridesharing services (which closely mimic the predicted rollout of FAVs), and existing FAV policy recommendations.

3.1 BVI Perceptions of FAVs

A small but growing body of research investigating accessible FAV technology and its perception by BVI individuals provides useful insight into the needs and concerns that are currently lacking from policy in this domain. Interest in this work has been shared by media and advocacy groups who largely echo the need to design accessible FAVs for people with visual impairments. This section details both the user research exploring BVI perceptions of FAVs, as well as the public interest pieces that offer useful insight in this regard.

In a 2020 study involving both a survey of 516 respondents and a subsequent series of focus groups with 38 people who are blind and low vision, Brinkley and colleagues explored opinions and concerns among individuals with visual impairments regarding FAVs [Brinkley et al. 2020]. The survey results from the study revealed that the vast majority of respondents (88.87%) view FAVs positively (50.18% extremely positively, 30.44% moderately positively, and 7.75% slightly

positively), with more than 90% expressing interest in FAV ownership. Importantly however, 94.3% reported being concerned about laws preventing people with visual impairments from operating FAVs. This sentiment was reiterated in the subsequent focus groups, with a majority of participants (55%) mentioning concerns regarding discriminatory laws that would prevent FAV operation among BVI people. Furthermore, when considering the accessible design of FAVs, more than half of focus group participants believed that the needs of individuals with visual impairments were not being adequately considered in the design of this technology. Although survey respondents were more optimistic about accessible FAV design, those with higher educational attainment echoed these concerns. The authors offered advertising efforts by Google's Waymo, which depict a blind user operating one of their vehicles, and prior experiences with other technology as possible explanations for the mismatch in perceptions of accessible FAV design. While a minority of focus group participants (37%) mentioned that technology currently exists to solve accessibility problems, several concerns emerged related to vehicle localization and orientation. For instance, more than half (53%) of participants mentioned the importance for people with low vision to be able to verify correct vehicle arrival destinations. Other features of interest included tools to locate the vehicle in congested areas, parking guidance, and real-time information regarding the vehicle's operation. Of particular interest to the topic of this paper, results from the focus groups suggested the usefulness of smartphone-based interfaces for BVI people, with many participants noting a desire to use current accessibility features built into their phones to control an FAV. Additionally, a large majority (71%) of participants mentioned the capability for dictation input as a primary interaction mode but, recognizing concerns about the accuracy of speech input and the battery life of cell phones, mentioned the potential for in-vehicle touchscreens to serve as a backup form of interaction. This sentiment was controversial however, with many blind participants noting the inaccessibility of current touchscreens, even when considering voiceover capability.

Bennett, Vijaygopal, and Kottasz found in a 2020 survey of 211 BVI respondents in the UK that BVI attitudes toward FAVs were characterized by hope for increased independent and convenient travel, tempered by skepticism that FAVs will be designed to meet the needs of people who are blind [Bennett et al. 2020]. Skepticism included both the design of FAV technology, as well as a lack of trust in state agencies responsible for accessible policy and advocacy. The open-ended responses from this research also indicated that BVI people have concerns regarding safe travel, entry-exit processes, and affordability. Although skepticism did not significantly predict willingness to travel in FAVs, the authors suggest that these respondents may hold a favorable disposition towards FAVs, despite their skepticism.

A 2018 focus group of 15 BVI participants by Brewer and Kameswaran investigated perceptions between AVs and FAVs, the influence of control when using these vehicles, and the ways in which tactile and voice-based designs can support BVI AV navigation across varying levels of vehicle autonomy [Brewer & Kameswaran 2018]. The authors led design-based activities where participants were asked to solve challenges by thinking about and creating either tactile or voice-based artifacts using props. Examples of tactile solutions included a compass for contextual awareness and vibration-based indicators for obstacle avoidance. Voice-based solutions included audio feedback when interacting with control elements in the vehicle (e.g., the door handle) as well as conversational solutions that mimicked current virtual assistants (e.g., Apple's Siri) and GPS. The authors found that both approaches can contribute to feelings of independence across various levels of autonomy, but concerns were raised about potential malfunctions with these solutions. The focus groups also illuminated the connection and tension between control and independence, demonstrating that participants desire accessible control mechanisms (e.g., feedback to the driver/passenger) that can facilitate independence but vary depending on the individual and the level of vehicle automation. The authors offer recommendations that advocate

for conversational user interfaces and route planning features (e.g., an audio-based GPS system), voice-based object identification in the vehicle (e.g., feedback when interacting with control elements), and tactile/vibration-based solutions (e.g., the tactile compass) for understanding, reflecting on, and changing plans in dynamic driving environments.

News outlets have also revealed perceptions towards FAVs among BVI people. For instance, a 2018 Associated Press report reviewed early efforts by Google's Waymo to build excitement for people with disabilities while contrasting these efforts with skeptical sentiments from the BVI community. Although the report offered encouraging results from a University of Florida project by Brinkley and colleagues, entitled Atlas [Brinkley, Posadas, et al. 2019], the author cast uncertainty on academic research translating into automotive development efforts. A BVI consultant for Waymo offered, "Autonomous vehicles aren't being designed for blind people; we're one of the beneficiaries of the technology…I'm patiently waiting" [Dearen 2018]. Advocacy groups echo the concerns of BVI people related to FAVs, as exemplified in the 2016 MIT Technology Review report entitled *The Blind Community Has High Hopes for Self-Driving Cars.* The report detailed efforts by the Perkins School for the Blind, the National Federation of the Blind, and the American Council of the Blind to advocate for FAV policy and development to include BVI considerations, citing a belief among BVI people that the community cannot assume auto-manufacturers will consider their needs [Woyke 2016]. It is worth noting that efforts to address these concerns have increased in recent years, as exemplified by Waymo's December 2020 presentation regarding research into FAV accessibility for people who are blind in 2020's Sight Tech Global [*Accessibility from the Wheels Up* 2020] and a September 2020 MIT podcast demonstrating dialogue between FAV accessibility research and **original equipment manufacturers (OEMs)** [MIT Technology Review 2020]. It remains to be seen, however, if these efforts will impact negative perceptions among BVI people regarding accessible FAV development.

The emerging research surrounding the perception of FAVs among BVI people suggests cautious optimism. While people who are blind and low vision have high hopes for the independence that FAVs are purported to afford, these hopes are tempered by concerns and skepticism related to development efforts to make the technology accessible, as well as policy and laws potentially limiting or failing to encourage BVI use-cases. Results from this body of research, as described above, suggest that BVI people desire FAVs to include a combination of audio-based and haptic/tactile interfaces that can be readily implemented on existing smartphone applications. In-vehicle touchscreens employing magnification and tactile (vibration-based) access can also serve as supplemental channels, especially for those with some residual vision. Common concerns across the corpus of available user research with BVI people suggest that solutions must consider the complete journey of driving by including supports for locating, entering, and exiting the vehicle, as well as accessible operational information during driving.

3.2 BVI Travelers and Ridesharing Services

As previously mentioned, current predictions among major auto-manufacturers situate the roll-out of Level 5 FAVs to prioritize ride-sharing and ride-hailing models, termed **mobility-as-a-service (MaaS).** Therefore, one advantage of the MaaS ecosystem is that existing ride-hailing services (e.g., Uber and Lyft) provide a useful proxy for understanding the unique challenges and needs that BVI people may experience during the widespread implementation of FAVs. Studies investigating the ways in which people with visual impairments experience ridesharing services offer a lens through which to conceptualize FAV travel.

Brewer and Kameswaran's 2019 study involving 16 interviews with BVI rideshare users revealed the interplay between independence and trust formation during experiences with services like Uber and Lyft [Brewer & Kameswaran 2019]. The authors identified the critical role the driver

plays to facilitate entry and exit processes for BVI people (e.g. using convenient drop off locations), environmental awareness during driving (such as landmarks and potential obstacles at the destination), and trust building through conversation and social contracts. The authors also found that locating the vehicle, even when communicating with the driver, was often referred to as the most difficult process when using ridesharing services. These results offer useful insight into the challenges that BVI people will face in MaaS systems when a driver is no longer at the wheel.

In a 2019 study involving 18 interviews with drivers of rideshare services with experience driving people with visual impairments, Brewer, Austin, and Ellison explored the different forms of physical and relational labor that drivers engage in to support BVI passengers [Brewer et al. 2019]. Physical forms of labor included helping people enter and exit the vehicle, as well as walking them to their destination. Emotional and relational labor included conversing with passengers to respond to their needs and building a relationship over multiple trips. Drivers indicated that most passengers with visual impairments would self-disclose their disability to receive additional assistance and that this was appreciated and useful, especially at the beginning and end of the trip. Although this process of self-disclosure could help ameliorate challenges for BVI people by enabling proactive assistance from the driver (e.g., finding and entering the vehicle), the authors noted that self-disclosure is not without its disadvantages. For example, some drivers admitted to not wanting to accept rides with guide dogs, while others mentioned the possibility of taking advantage of those with visual impairments by driving longer routes to increase the fare. The authors concluded by proposing means through which passengers could selectively disclose their disability (i.e., through a profile in a ridesharing app), as well as ways for this information to be shared with drivers to limit the potential for discrimination.

The foregoing research echoes several of the challenges that emerged in studies investigating BVI perceptions of FAVs. Vehicle location, entry and exit processes, information relating to the driving environment, and the ability to disclose a disability are all critical considerations for rideshare services that are also relevant to accessible FAV design and related policy. Indeed, Brewer and Ellison extended the results from their ridesharing studies in a 2020 report to analyze how to support people with visual impairments in FAVs [Brewer & Ellison 2020]. This report offered several design recommendations for the future of FAVs in accordance with the rideshare studies including the importance of voice-based interfaces for environmental awareness and entry and exit, ways to connect passengers to other humans to increase trust, and ethical approaches for self-disclosure of disability. While these recommendations are important to the future design of FAVs, the following section illustrates a critical disconnect between the accessibility needs revealed by the literature and policies guiding development.

3.3 Policy proposals

Despite significant advocacy by BVI stakeholders and growing research interest and support from the **Department of Transportation (DOT)** in examining autonomous vehicle accessibility, such as through the Inclusive Design Challenge [DOT 2020b], as of 2020, only one article to our knowledge has sought to examine the FAV regulatory environment as it pertains to people with visual impairments. Brinkley and colleagues' 2019 article detailed the legislative and policy landscape surrounding AVs as of 2018 [Brinkley et al. 2019]. In addition to noting state laws in response to a lack of federal legislation, the authors found that a promising 2016 initiative by the **National Highway Transportation Safety Administration (NHTSA),** the **Vehicle Performance Guidance for Automated Vehicles (VPGAV),** was ultimately abandoned in the DOT's 2017 *Automated Driving Systems: A Vision for Safety 2.0 (Automated Vehicles 2.0)* in the name of spurring innovation. The authors called for a reinstatement and revision of the VPGAV in the 2018 *Preparing for the Future of Transportation: Automated Vehicles 3.0* to include a dedicated

section on accessibility. Although we agree that enforceable policy with a dedicated section on accessibility is essential to promoting widespread FAV use, the article did not detail what a dedicated section might look like, or what specific considerations should be included.

A significant contribution of the work presented here is to take on the mantle of reviewing the legislative and policy developments in the quickly moving FAV timeline after Brinkley et al.'s publication. Much has changed since 2018, both in terms of the regulatory environment, as well as what we know about FAV accessibility as a result of the survey, focus group, and ridesharing research with BVI users. Unfortunately, the VPGAV was not reinstated in *Automated Vehicles 3.0*, nor was it reinstated, much less discussed, in the 2020 *Ensuring American Leadership in Automated Vehicle Technologies: Automated Vehicles 4.0*. Although we echo support for Brinkley et al.'s call to reinstate the VPGAV, we do so with specific recommendations derived from the emerging BVI user research. We also expand our recommendations to include similar sentiments from a recent policy brief concerning FAV accessibility at large [Fink & Giudice 2021], applicable sections from the **Americans with Disabilities Act (ADA)** of 1990, and the SELF DRIVE Act of 2020 to provide a comprehensive road ahead for accessible FAV policy.

4 CURRENT STATE OF FAV POLICY

We argue that legislative efforts should be expanded to guarantee that FAV use is both legal and accessible to those with visual impairments. To achieve this goal, policy development informed by the user research with BVI people would realize the full potential of this transformative technology. Such an expansion would undoubtedly help assuage the skepticism related to discriminatory FAV laws revealed in prior literature, while also promoting widespread and beneficial FAV usage among BVI people. Before providing our recommendations in detail, however, it is necessary to review policy efforts to date as context for proposed expansions.

4.1 Scope and Selection

The policies reviewed in this work include both state and federal efforts in the United States. Although BVI skepticism with regard to FAV policy extends beyond the United States, as evidenced by Bennet et al.'s [2020] previously discussed survey in the UK, policies outside of the United States are beyond the scope of this paper. State-level policies were identified using databases from the Insurance Institute for Highway Safety, the National Conference of State Legislatures, and the Governors Highway Safety Association, as well as legislative tracking tools on individual state websites. Federal policy efforts were identified using the legislative tracking tool for the U.S. Congress, the Department of Transportation's series of Automated Vehicles Reports, and related news media.

4.2 State Policy

FAV policy has thus far been characterized by a piecemeal mosaic of state-specific laws focusing on a critical qualifier: driver licensure. As of January 2021, 30 states have passed legislation or enacted executive orders regarding autonomous vehicle testing or deployment. Of these, 25 states currently address whether a passenger must be licensed, 11 of which definitively require a driver's license in all situations, and 7 of which require a driver's license dependent on the level of vehicle automation [Insurance Institute for Highway Safety 2020]. Table 1 illustrates the state laws and provisions that include driver's license requirements in autonomous vehicles. 'Yes' denotes that the state requires an operator with a driver's license even in a fully autonomous vehicle. It is worth noting that some of these laws (e.g., Michigan's) enable remote operation of the vehicle, where the licensed operator can monitor vehicle performance and assume control from a designated location.

A primary consideration for policy is whether FAVs should require a driver's license when manual driving is unnecessary. We argue that the answer is no. Laws requiring a driver's license in

Table 1. State Laws and Provisions that Include Driver's License Requirements in AVs (adapted from Insurance Institute for Highway Safety, 2020)

State	AV Driver's License Requirement
Arizona	Dependent on level of vehicle automation
Arkansas	Yes (effective 8/1/21)
Connecticut	Yes
District of Columbia	Yes
Florida	Dependent on level of vehicle automation
Georgia	Dependent on level of vehicle automation
Illinois	Yes
Iowa	Yes
Michigan	Yes
Nebraska	Dependent on level of vehicle automation
Nevada	Dependent on level of vehicle automation
New Hampshire	Yes
New York	Yes
North Carolina	Dependent on level of vehicle automation
North Dakota	Dependent on level of vehicle automation
Ohio	Yes
Utah	Yes
Vermont	Yes

FAVs are ultimately unnecessary, imposing needless limitations on the populations poised to benefit most from the technology (i.e., people who are unable to pass a driver's test because of visual impairments). The logic here is that FAVs are designed to forego the in-vehicle elements that enable traditional driving, including steering wheels, gas pedals, and other control mechanisms [Choksey 2020]. In other words, FAVs are predicted to eliminate the features that enable traditional driving and vehicle operation, thus rendering manual driving behavior as unnecessary for all users, irrespective of visual status. Existing state laws are therefore problematic by effectively precluding people without a driver's license from reaping the benefits of driverless technology, while also contributing to the sentiment among BVI people that policy discriminates against their interest. Federal policy interventions, as we review in the following, can serve as a useful mechanism for solving this problem by elevating minimal standards related to accessibility.

4.3 Federal Policy

Federal efforts to support and incentivize FAV development are ongoing. 2017's **Safely Ensuring Lives Future Deployment and Research in Vehicle Evolution (SELF DRIVE)** Act sought to establish the Highly Automated Vehicle Advisory Council within the NHTSA to, among other efforts, advance "…mobility access for the disabled community with respect to the deployment of automated driving systems to ensure awareness of the needs of the disability community as these vehicles are being designed for distribution in commerce" [Latta 2017]. Unfortunately, although the SELF DRIVE Act passed unanimously in the 115th Congress's House of Representatives, it stalled in the Senate. On September 23rd, 2020 the SELF DRIVE Act was reintroduced in the 116th Congress as H.R.8350 [Latta 2020]. Notably, the revised bill retains language for promoting mobility access, while also adding language with regard to discriminatory state laws: "A State may not issue a motor vehicle operator's license for the operation or use of a dedicated highly automated vehicle in a manner that discriminates on the basis of disability (as defined in section 3 of the Americans with

Disabilities Act of 1990)". Although this bill would do much to ameliorate concerns surrounding existing state laws that effectively prevent BVI people from operating an FAV, to date, the bill has only recently been introduced in the House and its prospects of passing are low according to its sponsors given current congressional gridlock [Miller 2020]. Lacking congressional agreement, the executive branch has tasked itself in recent years with providing guidance for the development of FAVs through the DOT and the NHTSA. Most relevant to the current discussion includes the NHTSA's **Vehicle Performance Guidance for Automated Vehicles (VPGAV)** and the DOT's series of *Automated Vehicles* reports.

The VPGAV was first issued in September of 2016 as part of the Obama administration's Federal Automated Vehicles Policy [DOT 2016]. The VPGAV included an enforceable 15-point assessment specifically intended for use with FAVs, with failure to comply resulting in potential recall for both in-development and consumer-ready vehicles. The assessment included several relevant points for promoting accessibility: a "human machine interface to fully accommodate people with disabilities (e.g., through visual, auditory, and haptic displays)," an "accessible, clear, meaningful data privacy and security notice/agreement," and "measures to maintain the accuracy of personal data and permit vehicle operators and owners to review and correct such information when it is collected in a way that directly or reasonably links the data to a specific vehicle or person" [DOT 2016]. Unfortunately, as stated previously, the VPGAV was replaced in 2017 by the new administration's *Automated Vehicles 2.0* guidance [DOT 2017], which eliminated VPGAV's enforceable assessment in favor of voluntary guidance. This new guidance failed to include incentives or requirements for accessible **Human Machine Interfaces (HMIs)** or related technology for increasing mobility among people with disabilities.

The legacy of *Automated Vehicles 2.0* has continued in each annual iteration of the DOT's *Automated Vehicles* reports by prioritizing a laissez-faire approach to FAV development where standards for supporting access among people with disabilities remained completely voluntary. Some efforts, however, should be applauded. 2018's *Automated Vehicles 3.0* established "…expanding access to safe and independent mobility for people with disabilities" as one of the DOT's Automation Principles and also established incentives to support accessibility research through the Accessible Transportation Technologies Research Initiative [DOT 2018]. Further efforts to incentivize accessibility research in 2020's *Automated Vehicles 4.0* have been substantial through its commitment to $40 Million for a Complete Trip Deployment Solicitation, $5 million in cash prizes for the Inclusive Design Challenge, and a notice of Funding Opportunity for the Federal Transit Administration's FY 2020 Mobility for All Pilot Program [DOT 2020a]. While we would be remiss not to recognize the importance of these research incentives for accessibility, we argue that without the "teeth" of a clear piece of legislation or enforceable regulation, these incentives from the executive branch (i.e., from the DOT) will be outweighed by state laws that preclude people with visual impairments from operating FAVs. To buck this trend, the following section offers a road ahead by recommending adaptations to existing language in the ADA and by reinstating enforceable standards informed by the emerging corpus of BVI FAV research.

5 POLICY AND DESIGN RECOMMENDATIONS

5.1 Eliminate Discriminatory State Laws

The position of our research group is that for the social and economic/workforce benefits of FAV transportation to be fully realized, the mobility afforded by FAV systems should be guaranteed to those who cannot drive and consequently do not hold driver's licenses, including many people with visual impairments. Our first recommendation calls for BVI stakeholders to advocate for passing the provision in the SELF DRIVE Act that eliminates states' ability to issue FAV laws that

discriminate on the basis of disability. Passing this law would respond effectively to Brinkley et al.'s [2020] finding that the vast majority of BVI respondents were concerned about discriminatory laws that would limit people with visual impairments from operating self-driving vehicles. A proactive solution that emerged in this research was the concept of an FAV operator's license, as opposed to a driver's license, which would eliminate processes that discriminate based on disability (e.g., traditional driving tests and vision tests), while retaining age requirements. The operator's license would be available to those who are unable to pass traditional driver's tests but would still like to be able to use FAVs. We argue that a federal law that not only supersedes discriminatory state laws, but also establishes this new conceptualization of an operator's license would do much to assuage BVI people's concerns, while also providing a sensical path for state FAV licensure processes separate from the traditional driver's license, which is no longer necessary with FAVs.

5.2 Extend ADA Driver Requirements to FAV AI Requirements

Our next set of recommendations concern enforceable policy regulations. Unfortunately, accessibility must often be mandated to ensure the needs and safety of all users, as was the case with many transportation requirements enacted in the ADA. ADA transportation rules detailed in Part 37 require that all transit provide adequate information in accessible formats; for BVI people, ADA compliance includes braille alternatives, large print formats, and/or electronic screen reading equipment and related software. ADA compliance also requires operator training to ensure that the operator is knowledgeable about providing adequate information for people with disabilities, including stop announcements and destination and route information [ADA §37.1 – 37.215 1990]. While ADA requirements serve as a useful guide for future FAV policy, the act needs to be updated for the 21st century, as FAVs will employ a new suite of technologies not considered in ADA guidelines as they are presently composed (e.g., touchscreen interfaces and AI drivers). These technological advances, combined with predictions that FAVs are expected to operate both as privately owned passenger vehicles and as a rideshare service [Narayanan et al. 2020], cast uncertainly as to whether the ADA, as it is currently constructed, will apply seamlessly to FAVs. The ongoing legal battle between disability advocates and rideshare services provides discouraging insight, having initially resulted in split decisions favoring Uber and Lyft's arguments that, as private peer-to-peer technology providers, they are not subject to ADA liability, instead offering their own disability policies [Columbia University 2020].

Much like Brewer and Ellison's [2020] research with rideshare drivers revealed the utility of ridesharing as a proxy for FAVs, we can use ridesharing as a proxy to demonstrate the need for expanded FAV accessibility policy. In order for FAV services to avoid the legal gray area surrounding ridesharing accessibility, a pragmatic policy approach is to update, adapt, and extend existing language in the ADA to FAVs. Given that FAVs inherently lack a human operator, the information provisions and training that is currently required by the ADA of bus, shuttle, and taxi drivers can be translated into requirements for 'training' the AI at the wheel of autonomous vehicles. For example, in line with Brinkley et al.'s [2020] finding that BVI people desire features for verifying correct arrival destinations, AIs of FAVs should be programmed to grant passengers this information, in multiple formats. The ADA offers language in this regard, as transit operators are already required to provide orientation information to passengers upon arrival (such as signs and announcements to relay that "the destination is…" or "…doors will open on the right side"). ADA requirements should also be updated to include responsiveness to self-disclosed information concerning a person's disability. Much like the ADA requires bus and taxi drivers to receive and provide information in a respectful, courteous way, FAVs should be required to be responsive to self-disclosed disability information and handle this information appropriately. For example, FAV services could respond to a user disability profile by prioritizing vehicles with sufficient cargo

space (e.g., an SUV) for passengers whose profile indicates a service dog. This provision would be in line with Brewer and Ellison's [2020] discussion regarding the importance of self-disclosure of disability in FAV apps and would do much to provide a responsive and accessible user experience for BVI people.

5.3 Revise and Reinstate the VPGAV

When considering interaction modalities for accessible FAVs, the VPGAV provides a useful starting point in its call for an HMI to fully accommodate people with disabilities (e.g., through visual, auditory, and haptic displays). However, in the years since the VPGAV's inaction (and subsequent replacement), FAV research with BVI people has revealed several specific points that should be included in an enforceable update. First, a readily available FAV integration with users' existing smartphones would enable BVI people to rely on the native accessibility features they are already accustomed to, especially considering that touchscreen-based smart device usage among the visually impaired population has increased dramatically over the last decade, from 12% in 2009 to 88% in 2017 [WebAim 2017]. Results from Brinkley et al.'s [2020] study support that FAV smartphone-based integrations should enable both dictation and touchscreen-based interaction modalities. Indeed, the multimodal nature of smartphones can be leveraged to open new doors for research and access in FAVs. For instance, touchscreens designed to appropriately utilize vibro-audio feedback have been demonstrated to be highly effective in rendering previously inaccessible visual content for spatial navigation information that would be relevant to FAV travel (e.g., route mapping) [Giudice et al. 2020]. Using haptic feedback in this way would align well with Brewer and Kameswaran's [2018] suggestion that tactile solutions may be preferred for understanding, reflecting on, and changing plans in dynamic driving environments. The inclusion of smartphone-based integration is also supported by Brewer et al.'s [2019] discussion of app-based passenger profiles that include disability information. Policy supporting smartphone-based integrations in FAVs would therefore promote BVI users in selectively disclosing their disability to receive additional supports from the vehicle, while also enhancing usability through multimodal interactions that have relevance throughout the complete trip. When taken as a whole, the small but growing body of BVI research in relation to FAVs has revealed that each stage of the trip (i.e., route planning, locating a vehicle, entering, operating, exiting, and arriving at the destination) all present needs that should be considered in policy to promote accessible vehicle design. By guiding the design of FAVs to include multimodal tools for route planning, vehicle location, entry/exit process, and information access/control during the trip, a new regulatory framework for the future of FAVs would do much to assuage BVI stakeholder concerns in the near-term, while promoting usability for all during widespread implementation.

Ultimately, in order to promote a future that includes fair, accountable, and transparent mobility for all transportation populations, FAV stakeholders would be wise to prioritize policy that obliges diverse AI interaction modalities that are accessible to all, instead of adopting one-size-fits all approaches. Multimodal interfaces that leverage haptic vibration and audio in combination with visual displays will not only promote inclusion, but also convenience for all users across the complete trip. One way to achieve this outcome is by prioritizing inclusive and universal design in native FAV interfaces, whereby features such as hearing assistance, screen readers utilizing text-to-speech, full haptic vibration support, and visual enhancements (e.g., magnification, reverse polarity or contrast, enlarged buttons) are included as available utilities during every interaction. By legislating these requirements through the SELF DRIVE Act, the ADA, and the VPGAV, and by prioritizing universal design principles, FAVs and related AIs will be poised to reach their full potential by providing access to people with visual impairments, as well as people across the spectrum of ability — sensory, motor, cognitive, or otherwise.

6 DISCUSSION

Fully autonomous vehicles represent an enormous potential to mitigate existing travel barriers experienced by many people with disabilities. By situating our findings in the current political landscape, we argue in the following discussion that the time is now for researchers, designers, and BVI stakeholders to advocate for substantive policy reform. We also expand on this theme to discuss the advantages of smartphone-based HMI integrations, as well as the ways in which legal challenges to ride-hailing services offer insight into important updates to the ADA. We conclude the discussion by contrasting our recommendations with concerning trends related to consumer trust and acceptance of FAVs at large.

6.1 Legal Necessity

The current status of the SELF DRIVE Act (as discussed in Section 4.3), coupled with state laws emphasizing licensure requirements (as discussed in Section 4.2), suggest that new policy is necessary to satisfy concerns among BVI people related to discriminatory state laws (i.e., those that require driver's licenses and/or the ability for manual takeover) [Brinkley et al. 2020], and those related to distrust in FAV policy makers [Bennett et al. 2020]. As congressional gridlock continues to entrust state legislatures as the de facto governing body for FAV development and testing, a new presidential administration represents a chance to usher in executive branch reforms and priorities for accessible autonomous transportation. We argue that although bottom-up advocacy by BVI researchers and advocacy groups have done much to illuminate the needs of BVI people in FAVs, the unfortunate reality is that these insights have not been prioritized through the voluntary guidance emphasized in Automated Vehicles 2.0-4.0. While on-going efforts by the DOT to fund research for accessible FAV development is a step in the right direction, these efforts are undoubtedly less impactful in terms of public perception than enforceable mandates for accessible FAV design, as would have been the result of implementation of regulatory tools included in 2016's VPGAV. In other words, should the laissez-faire regulatory approach from the federal government continue, it is likely that so too will the status quo with regard to BVI skepticism and related distrust in FAVs working for those without vision. This skepticism and distrust not only presents a concerning scenario in which BVI people are less likely to adopt FAV technology when it becomes available to consumers, it also suggests the very real possibility that these concerns are grounded in a fundamental truth: that FAV technology is in fact *not* being designed with the needs of BVI people in mind, despite the many life-changing benefits that this technology promises for this demographic. While Waymo's presentation of an accessible smartphone-based app assisting BVI people throughout the complete journey at 2020's Sight Tech Global [*Accessibility from the Wheels Up* 2020] suggested an alternative, resulting in cautious optimism, future research is needed to determine if the majority of major auto manufacturers are heeding insights revealed by ongoing BVI FAV research efforts.

6.2 Smartphone-based App Integrations

Our findings through a deep-dive into the BVI FAV user research and current policy landscape suggest that smartphone-based app integrations, such as Waymo's example, should be included in a revised version of the VPGAVs requirements for accessible FAV HMIs. This approach would not only enable the audio and haptic interaction capabilities that existing research has already revealed are ideal for completing various tasks related to autonomous mobility [Brewer et al. 2019; Brewer & Kameswaran 2018; Brinkley et al. 2020], but would also fit well into the critical need for broadening applications of information access technologies at large. We argue that a holistic, integrative approach that cuts across disciplines is necessary to solve accessibility challenges in areas of emerging and disruptive technology, such as FAV development. By leveraging existing

development efforts to apply evidence-based outcomes from research related to accessible input/output devices, designers would be equipped to quickly respond to the accessibility needs in FAVs without the need to completely reinvent the wheel.

Of particular interest are the opportunities afforded by touchscreen-based smart devices, which employ a host of multisensory features in their native user interface. In addition to auditory and enhanced visual interactions, a growing body of research has shown that the embedded vibration motors and haptic engines used to provide alerts, solicit attention, and enhance the visual experience in these commercial devices can also serve as a primary channel of haptic interaction. This newest class of information-access technology, called a **vibro-audio interface (VAI)** [Giudice et al. 2012], is particularly adroit at conveying spatial information, such as graphical content and non-textual information, which is inaccessible to current screen readers but highly relevant to the graphical user interfaces employed in FAV applications. Research has demonstrated the efficacy of using touchscreens with the VAI for accessing many types of content, including (1) recognizing different polygons [Giudice et al. 2012], as might be extended to icon recognition during FAV operation, (2) for learning maps [Giudice et al. 2020], as could be used to indicate FAVs driving routes, and (3) to indicate movement direction [Grussenmeyer et al. 2016], as may be used to indicate actions about the vehicle's immediate path of travel. Importantly, a significant body of research assessing the best psychophysical and usability parameters has already been conducted with BVI users using the vibro-audio interface with different touchscreens. This work has led to a clear set of perceptually-motivated and empirically-validated design guidelines [Palani et al. 2020; Gorlewicz et al. 2020], which are readily extendable to use with FAVs, whether it be through a dedicated smartphone app or via the vehicle's touchscreen-based control center. In addition to providing guidance on maximizing the multisensory usability of touchscreens, this work also provides guidelines for schematizing traditionally visually-based graphical content for non-visual access using the VAI. This research provides an important resource for OEMs and third-party developers interested in increasing FAV accessibility and enhancing BVI control and spatial understanding during FAV transportation. Given that the user research has clearly revealed that many BVI people desire touchscreens as a backup form of interaction in FAVs, but were skeptical given experiences with inaccessible touchscreens [Brinkley et al. 2020], and guidance that tactile information should be used to augment understanding and control in dynamic driving environments [Brewer & Kameswaran 2018], the emerging research employing haptic interactions using commercially-available vibration actuators in conjunction with existing touchscreens provide an obvious and empirically-validated solution that could result in the implementation of low-cost, transformative accessibility features in FAVs.

The near ubiquitous penetration of smartphone technology in the BVI market means that including policy requirements for accessible FAV integrations with existing mobile devices would also reduce the learning curve, cost, and OEM hardware adaptations associated with making FAVs fully BVI accessible. Furthermore, smartphone-based app integrations would do much to enable users to self-disclose their disability and enable FAV AI understanding of the accessibility features that users already use, as discussed in Brewer and colleague's research [Brewer et al. 2019]. By enabling human-AI information exchange in this way, FAVs AIs would be better equipped to respond effectively to user ability information, as we suggest a reimagined ADA should require.

6.3 Inadequacy of Ride-hailing as a Legal Proxy

Just as research utilizing ride-hailing serves as a useful proxy for understanding the ways in which BVI people will experience FAVs, lessons learned from legal challenges to these services can inform improvements to FAV policy. Our review of the literature revealed that drivers of ride-hailing services may still have the opportunity to discriminate against people with disabilities

[Brewer et al. 2019], despite earlier settlements such as that awarded to the National Federation of the Blind's members in a class-action lawsuit against Uber in 2016 [*National Federation of the Blind of California, et al. v. Uber Technologies, Inc., et al.* 2016]. Our research group has personal experience with this unfortunate reality, as a rideshare trip to the local airport by the corresponding author of this paper was denied because of his guide dog, resulting in a missed flight. Coupled with evidence of the inapplicability of the ADA to ride-hailing services [Columbia University 2020], a new regulatory framework that updates the ADA to extend requirements to FAV AIs would guarantee BVI people (and their guide dogs) access to transformative mobility.

6.4 The Paradox of FAV Information Access

The proliferation of smart devices in the last decade has resulted in increased usage and acceptance of technologies that rely on access to sensitive user information. From Fitbits to Apple Health to in-home AI-based assistants such as Amazon's Alexa, it is tempting to assume that people are becoming increasingly comfortable with disclosing their information, disability, accessibility, or otherwise, to the technology of the future. However, this trend has been complicated by an increased emphasis on data privacy, both as a result of new technology requiring more sensitive human data, and privacy violations at the hands of social media conglomerates and governmental organizations. As designers intend to increase user satisfaction and trust by making AI-enabled technology more personalized and responsive to humans, there is a paradox in that these information-rich approaches can actually decrease trust and comfort with technology through the information collection processes.

In the context of autonomous transportation, we refer to this phenomenon as the paradox of FAV human information access, where users might distrust information sharing yet continue seeking technology that works best with user specific information. This paradox is critical to consider in any conversation involving increasing AI awareness of human data as a means to improve the user experience. Given the policy recommendations that we advocate in this paper to furnish FAV AIs with access to users' smartphones and self-disclosed disability information, we would be remiss not to mention that the AAA Foundation reports that over 70% of people in the U.S. distrust self-driving cars, even when considering the benefits to safety and efficiency the technology represents [AAA Foundation 2019]. Therefore, we acknowledge that, in tandem with our proposed policy and design recommendations, further investigation of the ways in which FAV AIs collect, monitor, and utilize user information is necessary should autonomous driving technology prove palatable, not only for transportation-limited populations but for widespread consumer acceptance. An important consideration is the degree to which users understand, have access to, and control over the data they share with their vehicle. We predict that by increasing user control over FAV data usage, through a combination of policy and technology design that promotes transparent and accessible formats, the human trust problem currently plaguing FAVs will gradually give way to cautious optimism that promotes the technology's further implementation as an everyday mode of transportation. By so doing, FAVs will be enabled to yield their full potential towards mediating the adverse circumstances experienced by many individuals who currently face transportation limitations, while drastically improving these individuals' mobility, independence, and quality of life.

7 CONCLUSION

This paper reveals the ways in which FAV research with people who are blind and visually impaired, representing a large and growing demographic of our society, should inform policy for the road beyond 2020. Results demonstrate that although people with visual impairments are by in large excited for the mobility and independence afforded by FAVs, additional advocacy is

necessary to ensure that federal and state policy encourages accessible FAV development. A meaningful contribution of this work is elucidating the areas in which the research to policy pipeline in the FAV domain should be strengthened to include smartphone-based accessibility integrations and new multimodal tools for navigation across the complete journey of driving.

7.1 Limitations

The primary limitation of this work derives from the fast-moving FAV research and policy landscape. The user research and policies reviewed here only pertain to those available prior to January 1st, 2021. It is important to note that given the intense research, development, and political interest in FAVs, stakeholders must stay apprised of rapid changes in this domain in order to most effectively advance new policy and legislation.

7.2 Future Work

Future work motivated by the results of this paper could include both user research and policy development. Further examination of the ways in which smartphone-based accessibility solutions can integrate with FAV technology and infrastructure is necessary to understand how existing accessibility tools can support FAV travel among BVI people. New multimodal techniques to support information access and dynamic spatial understanding in FAVs is also of interest. Emerging research from DOT supported projects, such as the Inclusive Design Challenge, presents a significant opportunity to consider how these research efforts and others relating to underserved transportation communities can inform proactive and transformative policy.

APPENDIX

A ACRONYMS

Acronym	Term
BVI	Blind and Visually Impaired
FAVs	Fully Autonomous Vehicles
AI	Artificial Intelligence
AVs	Autonomous Vehicles
OEM	Original Equipment Manufacturers
MaaS	Mobility-as-a-Service
DOT	Department of Transportation
NHTSA	National Highway Transportation Safety Administration
VPGAV	Vehicle Performance Guidance for Automated Vehicles
ADA	Americans with Disabilities Act
SELF DRIVE	Safely Ensuring Lives Future Deployment and Research in Vehicle Evolution
HMI	Human Machine Interface
VAI	Vibro-audio Interface

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