Autonomous Vehicles: Capturing In-Vehicle Experience and Focus Group Follow-up with Persons with Autism and Other Disabilities at the 2019 Princeton University SmartDrivingCar Summit

FINAL REPORT
October 2020

Submitted by:

Cecilia Feeley, Ph.D.[1]
Transportation Autism Project Manager

Andrea Lubin[2]
Senior Research Specialist

Alain Kornhauser, Ph.D.[3]
Professor, Operations Research & Financial Engineering

Brian Tobin[1]
Engineering Research Project Manager

Jinuk Hwang[4]
Ph.D. Student

[1] Center for Advanced Infrastructure and Transportation
Rutgers, The State University of New Jersey
100 Brett Road, Piscataway, NJ 08854-8014
[2] Edward J. Bloustein School of Planning and Public Policy
Rutgers, The State University of New Jersey
33 Livingston Avenue, New Brunswick, NJ 08901
[3] Princeton University
229 Sherrerd Hall, Princeton University, Princeton, NJ
[4]Texas A&M
3137 TAMU, College Station, TX

External Project Manager
Mary Ameen, Executive Director
North Jersey Transportation Planning Authority
One Newark Center, 17th Floor, Newark, NJ 07102

In cooperation with

Rutgers, The State University of New Jersey
And
U.S. Department of Transportation
Federal Highway Administration

Disclaimer Statement

The Center for Advanced Infrastructure and Transportation (CAIT) is a Regional UTC Consortium led by Rutgers, The State University. Members of the consortium are Atlantic Cape Community College, Columbia University, Cornell University, New Jersey Institute of Technology, Polytechnic University of Puerto Rico, Princeton University, Rowan University, SUNY - Farmingdale State College, and SUNY - University at Buffalo. The Center is funded by the U.S. Department of Transportation.

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
CAIT-UTC-REG21		

4. Title and Subtitle	5. Report Date
Autonomous Vehicles: Capturing In-Vehicle Experience & Focus Group Follow-up with Persons with Autism and Other Disabilities at the 2019 Princeton University SmartDrivingCar Summit.	April 2020
	6. Performing Organization Code Rutgers CAIT/Princeton

7. Author(s)	8. Performing Organization Report No.
Cecilia Feeley, Ph.D. https://orcid.org/0000-0003-1926-8616 Andrea Lubin https://orcid.org/0000-0002-6258-0464 Jinuk Hwang https://orcid/0000-0001-6566-3401 Brian Tobin https://orcid/0000-0001-8402-0882	CAIT-UTC-REG21

9. Performing Organization Name and Address	10. Work Unit No.
Rutgers CAIT 100 Brett Road, Piscataway, NJ 08854-8014 Rutgers VTC 33 Livingston Avenue, New Brunswick, NJ 08901 Princeton University 229 Sherrerd Hall, Princeton University, Princeton, NJ	11. Contract or Grant No. 69A3551847102

12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
Center for Advanced Infrastructure and Transportation Rutgers, The State University of New Jersey 100 Brett Road Piscataway, NJ 08854	Final Report October 2020 5/7/19 – 9/30/20
	14. Sponsoring Agency Code

15. Supplementary Notes
U.S. Department of Transportation/OST-R
1200 New Jersey Avenue, SE
Washington, DC 20590-0001

16. Abstract
As autonomous vehicle (AV) innovation continues to gain worldwide momentum and with it the potential for expanded mobility, it is vital to consider how this technology can contribute to improved access for persons with disabilities, who represent one in four U.S. adults, or over 60 million persons. To date, there has been limited research focused on investigating strategies for designing and deploying self-driving vehicles so they can best accommodate the often-diverse needs of persons living with one or more disabilities. This research discusses findings from a series of four autonomous shuttle rides followed by focus group sessions convened with adults with disabilities to document their direct experience as passengers during Princeton University's 2019 SmartDrivingCar Summit. A core intent of this research was to gather feedback and recommendations on AV from persons with disabilities who had acquired a level of familiarity with the technology through a direct vehicle encounter, transcending their knowledge of AV solely as an abstract concept. Ultimately, the research team captured invaluable information on participant initial impressions of AV; their in-vehicle trip experience; interest in utilizing AV in the future; and AV-related concerns. Findings demonstrate that the majority of participants had both positive initial and post-trip impressions of AV and were extremely interested in utilizing AV to meet their current trip needs. Participants also offered insightful recommendations that can contribute to continued development of AV technology so that it can more fully accommodate the travel needs of persons with diverse disabilities.

17. Key Words	18. Distribution Statement
autonomous vehicle, self-driving car, accessibility, disability, equity	

19. Security Classification (of this report)	20. Security Classification (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	22	

Acknowledgments

The authors thank Princeton University and the SmartDrivingCar Summit for providing the opportunity, location, and the vehicle necessary for this study and Rutgers CAIT for financial support of the Rutgers team to conduct the research. We also thank the individuals with disabilities who graciously volunteered their time to participate in this research, and the many family members who enabled participation by providing participant transportation to the study site.

Table of Contents

List of Tables

DESCRIPTION OF THE PROBLEM

Access to transportation is essential for people to become integrated and productive members of society. For persons with disability (PWD), relying on public transit and other non-driving options can be necessary to achieve inclusion and meet trip needs. Non-driving options are especially essential for persons whose disability precludes them from operating a vehicle, even with current vehicle accessibility modifications available on the market.

Since the late 2000s, the transportation system has been disrupted with the advent of new and transformative technologies including ride-hailing services and shared vehicles. An even more disruptive phase is anticipated for the transport cycle as autonomous vehicle (AV) innovations continue to gain worldwide momentum. Accompanying these AV innovations is the potential for expanded mobility. It is therefore vital to consider how this technology can contribute to improved mobility access for persons with disabilities, who represent one in four U.S. adults, or over 60 million persons (1).

Persons with disabilities are generally considered one of three transportation disadvantaged populations, sometimes referred to as transportation challenged persons; the other two groups are older adults and low-income populations. These targeted populations also have lower vehicle ownership rates and often rely on non-driving options for mobility (2).

The autonomous vehicle market is expected to transform public transit services as society has come to know such services (3). For example, a transformation in current individual auto ownership trends and public conception of shared vehicles and shared rides is anticipated (3). These changes will most likely have a significant impact on persons with disability, who often rely on these services. However, to date, there has been limited research focused on investigating strategies for designing and deploying AV (otherwise known as self-driving vehicles) so they can best accommodate the often-diverse needs of persons living with one or more disabilities (4).

This paper imparts findings collected and analyzed from a series of vehicle rides taken by persons with disabilities on an autonomous shuttle and subsequent focus groups convened with these individuals. The intent of the research was to gather information on AV from persons with disabilities who had been exposed to a self-driving vehicle, in an effort to influence and help define the continuing development of AV technology in a manner that accommodates the needs of persons with diverse disability. Innovative and unique to this research was the team's decision to have the focus group participants first ride the autonomous shuttle in small groups on the Princeton University campus during the 2019 SmartDrivingCar Summit prior to their engagement in the focus group discussions (5-7). This approach allowed study participants to acquire first-hand experience with an autonomous vehicle in action prior to sharing their opinions and feedback. The research team used Local Motors Olli AV shuttle for the vehicle trips in part because Olli does not appear to be a conventional vehicle, as there is no steering wheel onboard or dedicated seat for a vehicle operator. Olli is a 3D-printed autonomous electric vehicle that is accessible, as it includes a retractable wheelchair ramp, as well as other accessibility features (8).

Background

The burgeoning and dynamic field of autonomous vehicle technology is poised to dramatically alter the landscape of modern mobility. As presented by the Society of Automotive Engineers International and adopted by the US Department of Transportation (USDOT), there are six levels of driving automation (zero to five), with level zero representing no automation and level five representing full automation (9, 10). Today, many semi-autonomous vehicle features are already commercially available, such as collision avoidance and adaptive cruise control, and numerous vehicle manufacturers and technology firms are actively engaged in developing AV technology including Waymo, Uber, Apple, Toyota, Mercedes-Benz, Volvo, General Motors, Baidu, and NVidia (11, 12). Private sector interest in AV is not surprising, especially given projections estimating the global autonomous vehicle market will yield more than 500 billion dollars by 2026 (13).

AV innovation and proliferation is international in scope. The Bloomberg Aspen Institute Initiative on cities and autonomous vehicles offers the first inventory tracking cities globally that are undertaking efforts to prepare for AV, with 128 cities included in the Atlas as of July 2019, the majority of which are located in North America, Europe, and East Asia (14). The type of efforts documented via the Atlas include city AV pilots and cities that are developing AV policies and related plans. Some specific examples of international AV activity include the technology start-up nuTonomy launching the first driverless taxi pilot in Singapore in 2016 (4); the city of Helsinki's automated bus pilots (14); and a variety of AV pilots underway in London, Paris, and Dubai (14).

Regarding AV innovation and adoption in the U.S., both the USDOT and National Highway Traffic Safety Administration (NHTSA) have been supportive of AV technology development, primarily because of the assumed role AV will have in increasing traffic safety, as research demonstrates that 94 percent of vehicle crashes are caused by human error (15).

While federal legislation on AV remains absent, many states are moving forward in exploring and adopting AV related legislation and policies. Specifically, as per the National Conference of State Legislatures, to date, 29 states and the District of Columbia have enacted legislation related to AV and 11 state governors have issued AV related executive orders (16).

Also, according to a 2018 report by the National League of Cities, over half of US cities are preparing for AV in their long-range transportation plans, with many cities conducting AV pilots including Boston, MA; Pittsburgh, PA; Arlington, TX; Phoenix, AZ, and San Jose, CA (17). Google's former self-driving car project – now the self-driving technology company Waymo – announced in 2018 that their autonomous cars had logged ten million miles operating in six states (18). Other examples of stateside AV pilots include the driverless shuttle being tested by the U.S. Army at Fort Bragg to help wounded soldiers access the on-site medical clinic (4); the soon to be implemented AV shuttle Optimus Ride will operate at the Brooklyn Navy Yard as well as at a private California older adult retirement community (19); and the Voyage Auto self-driving taxi pilot covering a 700 plus mile service area in The Villages retirement community of Central Florida (20).

APPROACH

AV Benefits and Persons with Disability

Much discussion surrounding AV focuses on the potentially broad benefits being associated with the technology that focus on improved safety, mobility, and productivity, as well as contributing to various environmental and efficiency goals (3, 4, 11, 21-22). As Fagnant and Kockelman discuss, AV technology may also yield benefits related to reduced congestion and fuel consumption and improved freight transport (11).

Potential benefits of AV are also being discussed related to persons with disabilities and other transportation disadvantaged populations, including older adults (3, 4, 22-24). These potential benefits focus primarily on increased mobility, as research historically demonstrates transportation's vital role overall for person with disabilities in facilitating access to both needed and desired services, such as employment, healthcare, and recreation, as well as in achieving community integration goals (25-28).

As evidenced in data analyzed from the 2017 National Household Travel Survey, many persons with disability struggle greatly with transportation issues. More than 25 million Americans age five and older have self-reported travel-limiting disabilities; these persons with disability have lower levels of vehicle ownership and vehicle access compared to persons without disability; and they make fewer trips per day on average than people without disabilities (29). It is within this context that disability advocates and policymakers are eager to harness the potential of AV technology as a means to advance improved mobility access, decrease isolation, and facilitate fuller economic and social inclusion of persons with disability (23, 30).

While the universe of potential benefits this targeted population may experience with the advent of AV are indeed promising, barriers to successful use of this technology by persons with disabilities must first be explored, documented, and subsequently addressed by manufacturers and technologists as they continue to design and refine AVs. Those potential barriers include, but are not limited to how persons with disabilities can successfully access both the physical equipment related to an AV as well as the vehicle's communication interfaces (31). Determining any distinct needs and/or challenges in using AV among persons with differing disabilities (e.g. cognitive/developmental, sensory, physical) must also be investigated and resolved in order to achieve universal AV access.

METHODOLOGY

The research study reported on in this paper was a joint initiative between Rutgers, The State University of New Jersey and Princeton University. Rutgers served as the IRB of record and the research was conducted on the Princeton University Campus during the 2019 SmartDrivingCar Summit. A total of 21 adults with disabilities participated in the study, which encompassed four focus group sessions facilitated over a two-day period. Due to limited seating on the Olli shuttle, each session had a maximum of seven participants.

Some of the participants were recruited for the study through a New Jersey disability-focused organization, while others volunteered to participate through an email announcement sent to individuals registered with the Rutgers Transportation Autism Project database. Participants did not receive any cash incentives and were not provided with transportation to attend. One session was comprised of persons who were blind and/or visually impaired (N = 5) and the other three sessions encompassed persons with autism and/or related developmental disabilities (N = 16). None of the participants reported a co-morbid physical disability, which would have required a ramp, wheelchair, or other mobility device.

Each of the four sessions began with a review of the study consent forms, a project overview, and a request for participants to complete a brief demographic questionnaire. Although participants were adults, most traveled to the study site in the company of a parent/family member, who remained with their adult relative with disability through the session introductory remarks. Family members in attendance did not participate in the vehicle ride nor were they present during the focus group discussion.

Following staff and participant self-introductions, two brief introductory videos available free on YouTube about autonomous vehicles were shown to the group. One video was entitled "Autonomous Car/Self-Driving Car - How it works!" and the second was entitled "James Corden Rides Olli (AV Shuttle)." After the videos concluded, participants were guided outdoors, where they were introduced to the Olli vehicle and boarded for a group ride within the Princeton University football stadium field. Immediately following the ride, they went to a nearby classroom for the focus group discussion.

At least one member of the research team was on-board the vehicle for each of the four trips and confirmed the recorded observations indicating that limited participant conversation occurred during the trip. Instead, participants appeared to have their attention focused on the experience and/or their surroundings. To meet the Rutgers IRB requirement that the vehicle rides occur in a safe and controlled environment that secured each participant's privacy and anonymity, all trips were conducted in the Princeton football stadium, Powers Field. Additionally, the football stadium facility offered the necessary meeting rooms, theater, and restroom facilities to successfully conduct the focus groups. It must also be noted that since each shuttle ride took place on the artificial football field turf surface, an operator was on board to ensure safety and control of the vehicle for all trips.

Each of the four in-vehicle trips and focus group sessions were audio and video recorded. As mentioned, there was limited conversation during the vehicle rides and video footage demonstrates that many instead focused their attention on the ride or the vehicle itself. The focus groups on the other hand generated spirited and lively discussions surrounding participants' primarily enjoyable experiences on the AV, especially compared to their current transportation mode(s).

As noted previously, the study was composed of 21 participants in four different sessions. Study inclusion criteria was for adults with disability between the ages of 18 to 64 who were able to maneuver themselves in/out of the vehicle independently with ability to participate in a 45-

minute to one-hour focus group session. Many individuals expressed interest in participating, but ultimately those who met the inclusion criteria and were able to make the scheduled dates were selected. The researchers met the target participant levels of between five to seven persons per session, with three sessions of five participants and the last with six.

As shown in Table 1, the majority of participants were males in the age range of 22 to 29 years old and resided with their parents. There was significant racial diversity among participants, with 33% identifying as white not Hispanic, 29% as white Hispanic, and 14% as Asian. The sample also demonstrated a range in educational levels attained, from high school without a degree to possessing a graduate level degree. All study participants were medically diagnosed with a disability.

TABLE 1 Participant Demographics

Characteristics	Respondents	Percent
Gender		
Male	14	67%
Female	3	14%
No Answer/Not Disclosed	4	19%
Race		
White not Hispanic	7	33%
Black not Hispanic	1	5%
White Hispanic	4	19%
Black Hispanic	0	0%
Asian	3	14%
Native American	0	0%
Hawaiian/Pacific Islander	0	0%
Other	0	0%
No Answer/Not disclosed	6	29%
Age		
18-21	3	14%
22-29	11	52%
30-39	3	14%
40-49	0	0%
50-64	2	10%
65+	0	0%
No Answer/Not Disclosed	2	10%
Education		
High School No Degree	2	10%
High School Degree	5	24%
Some College No Degree	4	19%
Associated Degree	2	10%
Bachelor's Degree	0	0%
Graduate Degree	1	5%
No Answer/Not Disclosed	7	33%
Living Arrangement		
With Parents	14	67%
With Spouse/Partner	2	10%
Group Home	1	5%
No Answer/Not Disclosed	4	19%

Finally, several study limitations should be noted, beyond the small sample size of participants. Specifically, the travel time on-board Olli was approximately five minutes. Due to

both state legal restrictions and IRB constraints, the vehicle was limited to operating on the Princeton University campus football field instead of on local roadways. Also, as previously mentioned, due to the unique conditions of the testing environment, an operator was onboard for the trip. However, owing to Olli's design, the operational interface was very discrete and the vehicle was navigated using a small joystick and computer screen.

FINDINGS

Post-Autonomous Vehicle Ride: Focus Group Findings

As noted, three focus group sessions were primarily composed of adults who identified as having a developmental disability(s) and one was composed of persons with visual impairments. Each discussion was initiated directly following participant experience riding as a passenger in the Olli vehicle, with the intent of capturing immediate feedback related to the encounter. It should be noted that one of the 21 participants did not take the trip on Olli due to last minute parental concerns; however, that individual did observe the vehicle trip and participated in the focus group discussion, responding to relevant questions.

The same topic guide was utilized by the two research team co-moderators to facilitate each of the four sessions. Key questions and prompts are presented in Table 2. The questions focused on capturing information on the full experience the participant encountered with the Olli – from their first exposure to the vehicle; to entering the vehicle; to riding in the vehicle on the campus stadium field; to exiting the vehicle post trip.

TABLE 2 Focus Group Discussion Guide – Key Questions & Prompts

Question Type	Purpose	Question
Introduction	To Begin Discussion	- Have you heard of self-driving or autonomous vehicles before today?
		- How do you usually get to where you need to go? *(prompts: work, shopping, medical, social trips, etc.)*
Key Questions	Olli Vehicle: Initial Impressions	- How did you feel when you first saw the self-driving vehicle known as Olli today? - How was the experience getting in to and out of the self-driving vehicle? *(prompts included: easy or difficult?)* - How did you feel when you first sat in the self-driving vehicle? *(prompts included: comfortable or uncomfortable?)*
	Olli Vehicle: On-board Experience	- How did you feel during the trip in the self-driving vehicle? *(prompts included: positives and negatives)*
	Self-driving Vehicles: Interest as Mode Choice & Related Concerns and Recommendations	- Would you want to ride in a self-driving vehicle following today's experience? - Would you want to use a self-driving vehicle instead of or in addition to the current way(s) you travel? - What types of places would you seek to travel to in a self-driving vehicle? - What concerns or worries, if any, do you have about self-driving vehicles? *(prompts: none, cost or fare, safety, accessibility, familiarity, other passengers, etc.)* - Do you receive assistance from a driver or vehicle operator when you travel now? Would you need assistance if using a self-driving vehicle?
	Conclusion	- Do you have any ideas not already shared today for improving self-driving vehicles so that persons with disabilities can use them safely?

Discussion at each session was undertaken for approximately 45 minutes. Most feedback communicated during the sessions did not differ based on participant disability type (DD or visual disability), with several exceptions noted. The majority of participants reported being aware of self-driving or autonomous vehicles prior to their exposure at the Summit; however, most possessed extremely limited information on the technology. Current transportation modes utilized by participants varied – especially among the group with visual impairments – and included fixed-route public transit, ADA complementary paratransit, ride-hailing (e.g. Lyft), school transport, and self-driving. The travel mode reported by the vast majority of participants with DD was passenger in a vehicle driven by family or friends.

Initial Impressions

Participants were asked to recall their initial impressions upon seeing the Olli vehicle in-person. Notably, the feedback communicated by all was overwhelmingly positive. Regarding vehicle appearance, comments shared included "it looks cool," "its' amazing," and "it looks so futuristic." One participant even explained that the vehicle design was "cute" and made her feel "happy."

A few reported feeling nervous when they first saw Olli, as they realized they would soon be taking a ride in an AV and they had no prior experience doing so. However, the majority explained that the dominant sentiment they had when first seeing Olli was excitement for their pending trip.

All participants reported that the experience in both entering and exiting Olli was "easy" and "smooth." Participants who were visually impaired specifically remarked that they appreciated that the step between the ground and the floor of the AV was low. They added that the handrail on the step up was also helpful in entering/exiting the vehicle. One visually impaired participant explained that he was able to orient himself to Olli easily because the design reminded him of airport shuttles that he had familiarity using.

On-board Experience

Participants also engaged in a substantial discussion on their overall Olli trip experience. Once all boarded and were seated, the attendant welcomed them. Shortly after, the vehicle was engaged and the trip began, lasting approximately five minutes. Participant feedback on the trip was positive, with all indicating they enjoyed the short journey. Words frequently used to describe the trip experience included "comfortable," "smooth," "quiet," and "slow." One participant described the trip experience as "successful" and another noted that the trip was so relaxing that he could imagine bringing a book or portable gaming system onboard to occupy him during a longer trip. Several noted that they appreciated the vehicle's slow travel speed, as that helped ease concerns related to vehicle safety.

The research team specifically discussed the topic of on-board sound/noises, as persons with developmental disabilities, including Autism, often experience auditory sensitivities. When asked about the presence of any distributing or distracting noises or sounds onboard, only one participant reported hearing a low, "creaking sound" with vehicle turning movements. All others shared that the ride was very quiet, which several remarked would make it easier to converse with fellow passengers.

Other facets of the trip experience discussed by participants focused on positive feedback related to the vehicle's large windows. They explained that the windows afforded substantial natural light onboard, while also offering a clear view of their exterior surroundings. Others shared that the large windows made the vehicle feel "very open," which they appreciated. Many participants also reported that they liked that the vehicle included on-board video monitoring screens visible to passengers. The rear facing monitor provided 360° images of the vehicle surroundings, while the front facing monitor showed a series of static images, including the Olli

logo. Several noted that the presence of onboard video monitoring screens made them feel "more secure" during the trip.

Interest in using self-driving vehicles

Seventeen of the 21 study participants, the overwhelming majority, reported they were interested in traveling again in an AV, based on their positive Olli trip encounter. The four individuals reporting disinterest in utilizing an AV again had difficulty communicating the factor(s) contributing to their sentiment in this regard. However, one shared that he preferred getting rides from his family as he enjoyed traveling with his parents.

Commentary from the 17 participants interested in being a passenger again in an AV focused on the opinion that availability of an AV travel option would facilitate much needed travel freedom and increased independence, especially because so many participants discussed the challenges of being dependent on parents/family for transportation. As one participant noted, "my parents don't have the time to take me where I want to go."

Notably, several participants who were dependent on family for transportation discussed not only the personal limitations they experienced from this arrangement, but also highlighted the difficulties their respective family members encountered in providing transport for their adult child. One stated that "mom could do more if she didn't have to drive me places." Others similarly acknowledged that the availability of other travel options, like AV, would decrease the responsibility their family members currently incur in providing transportation.

Many of the participants communicated that availability and usage of AV would also help to decrease feelings of "isolation," "depression," and even "jealousy" that they often feel when they cannot access a ride to a desired or needed destination. In discussing AV in comparison to other modes they currently utilize, participant support and preference for AV was clear. For example, the few participants who reported driving discussed that riding in an AV would be less stressful overall compared to driving themselves, especially when traveling in unfamiliar locales. Others noted they preferred AV travel to the community transit options and ADA complementary paratransit they have utilized, mainly because they envision the former as a more on-demand, user friendly travel option.

Several suggested that autonomous vehicles, like Olli, would be ideal shuttle systems in urban environments and even as circulators on university campuses. Others added the benefits of employing AV shuttles as transportation for large-scale events. One participant opined that widespread availability and public usage of AV shuttles/buses would also contribute to more rapid AV sector development and public acceptance of and confidence in AV technology.

Focus group participants were also extremely eager to share the multitude of destinations/trip types they would seek to access utilizing an autonomous vehicle. Common responses included employment, college or other continuing education opportunity, and daily living trips (e.g. shopping). Several participants also mentioned they would seek to access public transit stations using AV.

Notably, participants in each of the three sessions were most excited to discuss the plethora of social/recreational places of interest they would seek to access using AV, which included movie theaters, music concerts, book stores, beaches, parks, sightseeing trips, and homes of friends. One participant noted several times that he would love to attend anime conventions traveling in an AV.

The authors must acknowledge that the overwhelming group interest and enthusiasm in detailing destinations they would seek to access using an AV highlights not only their interest in the travel opportunities potentially available via AV, but likely also reflects their current universe of limited transportation options. As one participant shared, "I would like to travel anywhere – using Olli would let you leave the house by yourself."

A final topic discussed related to participant interest in utilizing self-driving vehicles was desire and/or need for personal assistance as an AV passenger with tasks including vehicle boarding/alighting and/or carrying packages. The majority reported they do not typically utilize such assistance with their current mode(s) and would not need or want such assistance when traveling on an AV, at least not in the long term. One passenger noted it would be "embarrassing" to have an on-board assistant and another explained "it defeats the point of AV to have help on-board."

Several participants with DD did indicate however that they would like the option of a family member accompanying them on AV trips until they felt comfortable traveling as an independent passenger on this new transport mode. One participant with DD also commented that it would be helpful to have assistance in securing his seatbelt. Several participants with visual impairments shared that it would be helpful if assistance was available to open and close vehicle doors; provide guidance to available seats; help with passenger bags; and secure wheelchairs and/or other mobility devices. Notably, one participant remarked that while she did not anticipate needing personal assistance in using an AV, it would be beneficial to have an on-board attendant in case of vehicle malfunction and/or other emergency situation.

Concerns with self-driving vehicles & participant recommendations

A variety of specific concerns with self-driving vehicles as well as recommendations were communicated in each focus group session, with core issues focused on the topics of accessibility, vehicle safety, communication interface, comfort and design, cost, and availability. While some concerns were specifically related to the Olli vehicle, most applied to AV in general.

Almost all participants stressed that AV should be designed fully accessible, facilitating usage among persons with disabilities. For example, accessibility components, including the kneeling feature and wheelchair lifts, should be standard on AV shuttles and buses. Also, all AV, including personal vehicles, should have on-board audio capability to announce vehicle arrival at destinations and to provide guidance and information on safe boarding, seat belt usage, and other vehicle-related details that could be helpful to passengers.

Safety-related concerns related to AV were the most discussed issues among participants in each focus group session and numerous recommendations to ensure optimum safety were

suggested, including usage of on-board cameras to capture safety-related incidents, as well as audio and visual sensors that can assist the AV in identifying and responding appropriately to approaching emergency vehicles. A few participants questioned if the technology being employed on AV (e.g. GPS, radar, LIDAR) was adequate to ensure safety, with one recommending that AV manufacturers should invest resources in exploring strategies to improve radar reliability in inclement weather conditions, such as fog. One participant even recommended that an international governmental safety regulatory body on AV should be established, similar to the Federal Aviation Administration, that would be responsible for vehicle oversight, recalls, and other safety concerns.

There was substantial discussion on the safety implications of both external (e.g. vehicular crash) and internal (e.g. AV technology malfunction, passenger becomes ill on board) incidents. Participants expressed concern that if either type of incident occurred, they could be stranded without assistance. Recommendations to address this concern focused on presence of an on-board attendant with a valid driver's license and vehicle mechanical expertise so he/she could at a minimum troubleshoot, if not resolve, any technical malfunctions and secure emergency personnel assistance if needed.

Two safety-related topics discussed specifically on the Olli vehicle included desired modifications to the current Olli seat belt configuration and maximum speed capability. Regarding the former, several participants reported difficulty using the vehicle's lap belts. Some noted the belts were easily entangled, while others explained they had difficulty determining how to secure the belt's closure. Overall, participants expressed preference for a three-point seatbelt configuration as opposed to a lap belt. Regarding the latter issue, participants expressed concern with Olli's current maximum speed capability of 25 miles per hour, noting this limitation would hinder usage of Olli beyond local roadways. As several stated, vehicle ability to maintain speed with the flow of traffic on all roadways was critical to ensure passenger safety and widespread vehicle usage.

Also related to safety was a discussion on the vehicle communication interface. Participants shared many questions related to the AV interface, primarily focused on how passengers were supposed to indicate their desired destination and schedule their trip. They wanted to know if they would be able to do so using the GPS technology on their cellular smart phones – which most indicated would be ideal – or if they would instead need to indicate their destination upon boarding the vehicle. Some were interested in better understanding the capabilities of the on-board interface in terms of engaging in a 'conversation' with Olli on various topics (e.g. weather), while others wanted to know if they could secure needed assistance while traveling via the interface. Several recommended that the on-board interface should permit passengers to access a call center to secure live operator assistance if needed, especially vital in the event of an emergency.

Vehicle design was another area of concern where participants shared recommendations. Participants with visual impairments noted that several design features should be incorporated that would aid in promoting passenger safety and orientation in an AV similar to Olli's shuttle

configuration including utilization of contrast texture and color on any vehicle steps; installation of a hand rail on the vehicle exterior near the entrance; and utilization of a non-slip finish on the vehicle step(s) and flooring.

Many participants also discussed the need to redesign the current Olli seat configuration, allowing for more generously sized seats. Others noted that additional seats should be added to increase vehicle passenger capacity. The importance of all vehicles being climate-controlled to ensure passenger comfort in all seasons was also stressed. One participant suggested and several voiced support for the placement of DVD players onboard, as a means to provide passenger entertainment. Lastly, one passenger explained that he would prefer that Olli be re-designed as a "normal sedan," with the reasoning that he did not want to call attention to himself by traveling in a vehicle that differs in appearance from other "standard" vehicles.

Finally, vehicle availability and cost factors were discussed as concerns. Regarding the former, participants emphasized that they were eager for AV to function as an "on-demand' transport mode, similar to ride-hailing options, in that usage would not require advanced reservations. Comments on this topic included "I want the vehicle available on my command" and "I want to be able to go when I want to go." Also, on the topic of availability, interestingly, many conveyed contradictory sentiments regarding a desire for widespread availability of AV shuttles, but preference to travel via AV alone, not sharing their ride with other passengers. Some even acknowledged this conflicting sentiment by indicating that while their preference is to travel alone, they understand they may have to share rides. In one session, three participants were particularly adamant in their desire to travel "privately" in an AV, with two of the three reporting they would choose a private AV trip instead of a shared AV ride, even if the former option was costlier.

Participant discussion on cost concerns assumed they would be paying for passenger trips on an AV, as opposed to purchasing an AV for personal use. Many noted that affordability is a paramount concern and would ultimately be a main determinant in AV usage. The question of how cost/fares would compare to other on-demand transport modes, such as the ride-hailing options offered by Lyft or Uber was also mentioned. Still others questioned the likely fare payment mechanism and stressed that access would be expanded – including among the unbanked – if several payment methods were available to passengers, including cash, smart card, and payment via smartphone applications.

CONCLUSIONS

The findings from the four focus group sessions convened with persons with disabilities at the 2019 Princeton SmartDrivingCar Summit presented in this paper yielded valuable primary data from adults with disabilities on perceptions, concerns, and recommendations related to AV. Utilizing a qualitative research approach for this study enabled the authors to explore facets of AV technology first-hand with a segment of the population whose transportation needs are too

often not considered. Findings demonstrate the potential value of AV for transportation disadvantaged populations and strong interest in this technology among persons with disability.

Each of the four focus group discussions was undertaken post participant experience as a passenger in the Olli autonomous vehicle. Initial impressions related to Olli were extremely positive, with most participants reporting feelings of eagerness for their AV trip and only a few indicating some concern for the pending trip experience. All shared that they encountered no difficulty either entering or exiting Olli, with several participants with visual impairments explaining that vehicle features including interior handrails and low flooring were especially helpful in navigating the onboarding/alighting process.

Similarly, very positive feedback was shared on the actual trip experience, with participants using adjectives including "comfortable," "smooth," and "quiet" to describe their trip and noting they enjoyed the openness and natural sunlight afforded passengers through the vehicle's large windows. Based on their positive trip encounter, almost all (81%) of participants expressed interested in using an AV in the future, explaining that an AV travel option would facilitate increased transportation independence and reduce isolation. This sentiment was strongly communicated among the participants with DD who reported their dependence on parents/family for transportation. In total, all participants enthusiastically discussed a multitude of destinations/trip types they could envision accessing with AV, including but not limited to employment, continuing education, daily living trips, and social/recreational opportunities.

It must also be noted that most participants reported not anticipating the need for any specific personal assistance (e.g. entering/exiting vehicle, carry shopping bags) in using an AV – at least not after acquiring familiarity with the vehicle – as they do not typically use such assistance with their current mode(s). However, follow-up research on the topic of personal on-board AV assistance should be pursued as related to other transportation disadvantaged populations, specifically older adults and persons with physical disabilities, as these cohorts may have differing needs in this regard.

Concerns and recommendations related to AV expressed by participants focused primarily on the topics of vehicle accessibility, safety, communication interface, design, cost, and availability. While some comments were targeted specifically to Olli, most were generalizable to all AV.

The importance of AV accessibility was emphasized, with several specifying that design features including non-slip flooring, vehicle entrance hand rails, and contrast texture and color on steps should be included in AV shuttles/buses. The topic of AV availability and trip scheduling was also discussed by many participants, with most desiring AV to function as an "on-demand' transport mode, similar to ride-hailing options. Participants expressed mixed opinions on shared-rides, with many indicating their preference to travel alone. Cost issues were also discussed, primarily in terms of assumed passenger fees as opposed to vehicle purchase costs. Affordability was repeatedly cited as a critical determinant of likely AV usage, as was provider utilization of a fare payment mechanism permitting several payment methods.

The main concerns expressed by participants related to AV safety, with some reporting that their safety concerns were due to lack of familiarity with AV technology. Concerns with safety events both internal and external to the vehicle were mentioned, with many suggesting that an on-board attendant would be able to help address many of those concerns. The importance of including a two-way, on-board communication interface that would enable passenger contact with live operator support assistance was also discussed as a valuable AV safety component.

RECOMMENDATIONS

Looking ahead to next steps, it is clear that additional research must be performed with persons with disability to ensure their diverse needs are documented and considered as AV technology continues to advance. Such research will contribute immensely to efforts to ensuring this technology can offer a viable travel option to all persons.

The authors specifically seek to convene additional focus groups nationwide with diverse populations with disability who are given the opportunity to directly experience travel in an AV and subsequently share direct feedback on their encounter. Focus groups should also be convened with family members, caregivers, and informal and formal support personnel to help document and better understand the varied needs of populations with disability. Gathering information from caregivers is especially valuable if the persons with disability they support are unable to directly communicate their needs and potential barriers related to AV. It is fully anticipated that the primary data collected from such research – especially participant expressed concerns and recommendations – will be extremely instrumental to the motor vehicle industry and technologists, who can foster trust and a better understanding of AV among regulators and the general public by acknowledging and responding to identified safety-related and others concerns. This primary data will also be valuable to transportation and disability stakeholders in assisting to advance the critical conversation on how AV technology can and should be designed and deployed to best serve transportation disadvantaged populations and contribute to universal transportation equity goals.

REFERENCES

1. Okoro, C.A., Hollis, N.D., Cyrus, A.C., & S. Griffin-Blake. Prevalence of Disabilities and Health Care Access by Disability Status and Type Among Adults – United States 2016. Morbidity and Mortality Weekly Report, 2018. 67: 882-887. DOI: http://dx.doi.org/10.15586/mmwr.mm6732a3
2. Zhao, Fang, and Thomas Gustafson. *Transportation Needs of Disadvantaged Populations: Where, When, and How?* FTA Report No. 0030. United States. Federal Transit Administration, 2013.

3. Lutin, J. M., Kornhauser, A. L. & E. Lerner-Lam. The Revolutionary Development of Self-driving Vehicles and Implications for the Transportation Engineering Profession. *Institute of Transportation Engineers ITE Journal*, 2013. 83: 28-32.
4. Claypool, H., Bin-Nun, A., and J. Gerlach. *Self-driving Cars: The Impact on People with Disabilities*. Ruderman Family Foundation, Boston, Massachusetts, 2017.
5. Politis, I. Designing Autonomy in Cars: A survey and Two Focus Groups on Driving Habits of an Inclusive User Group, and Group Attitudes Towards Autonomous Cars. *International Conference on Applied Human Factors and Ergonomics*. Springer, Cham, Los Angeles, CA. July 17-21, 2017.
6. Bennett, R., Vijaygopal, R., & Kottasz, R. Willingness of People with Mental Health Disabilities to Travel in Driverless Vehicles. *Journal of Transport & Health*, 2019. *12*: 1-12.
7. Tremoulet, P.D., Seacrist, T., Ward McIntosh, C., Loeb, H., DiPietro, A., & S. Tushak. Transporting Unaccompanied Minors in Autonomous Vehicles: Results from Driving Simulator Exposure and Focus Groups. Automated Vehicle Symposium. Orlando, FL. July 16, 2019.
8. Fox Ruben, B. This Self-Driving Shuttle Puts Accessibility First: Accessible Olli was deigned from the ground up to help people with disabilities get where they need to go. CNET. January 26, 2018. https://www.cnet.com/news/accessible-olli-local-motors-ibm-self-driving-shuttle-bus-accessibility/ Accessed July 29, 2019.
9. Shuttleworth, J. *SAE J3016 Levels of Driving Automation Graphic*. Society of Automotive Engineers International. January 7, 2019. https://www.sae.org/news/2019/01/sae-updates-j3016-automated-driving-graphic. Accessed July 1, 2019.
10. Thorn, E., Kimmel, S. C., Chaka, M., and B.A. Hamilton. *A Framework for Automated Driving System Testable Cases and Scenarios.* No. DOT HS 812 623. U.S. Department of Transportation, National Highway Traffic Safety Administration, 2018.
11. Fagnant, D. J., & K. Kockelman. Preparing a Nation for Autonomous Vehicles: Opportunities, Barriers and Policy Recommendations. *Transportation Research Part A: Policy and Practice*, 2015. 77: 167-181.
12. Mercer, C. and T. Macaulay. *Which Companies Are Making Driverless Cars?* Techworld. June 27, 2019. https://www.techworld.com/picture-gallery/data/-companies-working-on-driverless-cars-3641537/. Accessed July 3, 2019.
13. Kumar, R. and Richa. *Global Autonomous Vehicle Market by Level of Automation, Component, and Application: Global Opportunity Analysis and Industry Forecast, 2019-2026.* Allied Market Research, Portland, Oregon, May 2018.
14. Bloomberg Aspen Initiative on Cities and Autonomous Vehicles Atlas. https://avsincities.bloomberg.org/. Accessed July 8, 2019.
15. Singh, S. *Critical Reasons for Crashes Investigated in the National Motor Vehicle Crash Causation Survey*. No. DOT HS 812 115. U.S. Department of Transportation, National Highway Traffic Safety Administration, 2015.
16. National Conference of State Legislatures. *Self-driving Vehicle Enacted Legislation.* March 19, 2019. http://www.ncsl.org/research/transportation/autonomous-vehicles-self-driving-vehicles-enacted-legislation.aspx. Accessed July 8, 2019.

17. Perkins, L., Dupuis, N., and B. Rainwater. *Autonomous Vehicle Pilots Across America*. National League of Cities, Washington, D.C., 2018.
18. Hu, J.C. *Waymo's Driverless Cars Have Logged 10 Million Miles on Public Roads*. Quartz. October 10, 2018. https://qz.com/1419747/waymos-self-driving-cars-have-logged-10-million-miles/. Accessed July 7, 2019.
19. Optimus Ride. Optimus Ride Announces Self-Driving Vehicle Deployments at the Brooklyn Navy Yard and Paradise Valley Estates. Press release. March 20, 2019. https://www.optimusride.com/press/optimus-ride-announces-new-deployments-at-the-brooklyn-navy-yard-and-paradise-valley-estates. Accessed June 17, 2019.
20. Voyage. *The Villages Florida*. https://voyage.auto/community/the-villages-florida/. Accessed June 20, 2019.
21. Bagloee, S. A., Tavana, M., Asadi, M., and T. Oliver. Autonomous Vehicles: Challenges, Opportunities, and Future Implications for Transportation Policies. *Journal of Modern Transportation*, 2016. 24(4): 284-303.
22. Sperling, D., *Three Revolutions: Steering Automated, Shared, and Electric Vehicles to a Better Future*. Island Press, Washington, D.C., 2018.
23. Henderson, S., and M. Golden. *Self-Driving Cars: Mapping Access to a Technology Revolution*. National Council on Disability, Washington, D.C., 2015.
24. Grantmakers in Aging. *Mobility & Aging in Rural America: The Role for Innovation.* Arlington, VA, 2018.
25. Loprest, P., and E. Maag. *Barriers to and Supports for Work Among Adults with Disabilities: Results from the NHIS-D*. The Urban Institute, Washington, D.C., 2001.
26. Lubin, A., and C. Feeley. Transportation Issues of Adults on the Autism Spectrum: Findings from Focus Group Discussions. *Transportation Research Record: Journal of the Transportation Research Board*, 2016. 2542(1): 1-8.
27. Rosenbloom, S. G. Transportation Patterns and Problems of People with Disabilities. In *The Future of Disability in America* (M.J. Field and A.M. Jette, eds.), National Academies Press, Washington, D.C., 2007, pp. 519-560.
28. Amado, A. N., Stancliffe, R. J., McCarron, M., and P. McCallion. Social Inclusion and Community Participation of Individuals with Intellectual/Developmental Disabilities. *Intellectual and Developmental Disabilities*, 2013. 51(5): 360-375.
29. Brumbaugh, Stephen. *Travel Patterns of American Adults with Disabilities*. Bureau of Transportation Statistics, U.S. Department of Transportation, 2018.
30. Office of Disability Employment Policy. *Autonomous Vehicles: Driving Employment for People with Disabilities, Information-Gathering Session Report.* U.S. Department of Labor, 2018.
31. National Center for Mobility Management. *Autonomous Vehicles: Considerations for People with Disabilities and Older Adults*. Washington, D.C., 2018.