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Automated mobility for elderly and people with disability

Somayah Mohammed Asiri[1], Erik van Vulpen[2], Huawei Tu[1]

[1]Department of Computer Science and Information Technology, La Trobe University, Melbourne, VIC, Australia

[2] Centre for Technology Infusion, La Trobe University, Melbourne, VIC, Australia

s.asiri, e.vanvulpen, h.tu@latrobe.edu.au

Abstract

In order to improve the accessibility of autonomous vehicle (AV) technology for individuals with disabilities, this paper examines the incorporation of co-creation approaches in the development process of mobile techniques. We investigate the particular difficulties this group has using conventional public transportation systems and how AVs can help to address these problems. We report on a new application that enables end users' direct control over many autonomous shuttle tasks, including door operations, destination settings, and vehicle hailing, via a mobile application. In order to guarantee accessibility, this program, which was created using a great deal of user-centered design research, has voice activation, screen reading capabilities, and high contrast visual interfaces. The study highlights how crucial it is to include people with disabilities (PWD) in the design phase in order to provide practical, easy-to-use transportation options that promote increased independence and safety.

1 Introduction

Autonomous shuttles represent a significant technological evolution in public transportation, providing enhanced mobility options for People with Disabilities (PWD). Nevertheless, these advances also introduce novel challenges that need careful consideration to ensure accessibility and usability. Documented challenges by the Department of Infrastructure, Transport, Regional Development, Communications, and the Arts (DITRDC) highlight issues such as the interaction complexities PWD face with these systems.

In response, the Centre for Technology Infusion (CTI), leveraging advancements in Human-Machine Interface (HMI) technologies, initiated the development of a specialized smartphone application. This app aims to facilitate PWD interactions with autonomous shuttles, ensuring ease of access, safety during boarding, and secure seating without the need for driver assistance.

This paper outlines the development and evaluation processes of this smartphone application, conducted through collaborative efforts with the Australian Federation of Disability Organizations (AFDO). The evaluation involved focus groups which helped refine the app, followed by a live trial at Sydney Olympic Park. The insights gained from this project are aimed at enhancing the overall accessibility of autonomous shuttles and providing PWD with the necessary tools to navigate these new systems independently.

2 Background

Autonomous vehicles present a transformative potential for public transportation, particularly for individuals with disabilities. The spectrum of automation in AVs ranges from no automation to full automation, with highly autonomous vehicles (HAVs) at level 4 offering significant safety, societal, and environmental benefits (Leal Rocha et al., 2015). Automobile manufacturers are

actively investing in research and development to bring these self-driving cars to fruition in the near future. The advantages of AVs extend beyond enhanced safety; they reduce congestion, improve urban infrastructure utilization, optimize fuel savings, and crucially, provide opportunities for safe and independent travel for persons with impairments (Lewandowski, 2018).

Despite the projected benefits, the actual perceptions of PWD regarding AVs remain underexplored. While studies have acknowledged the importance of autonomous mobility services for PWD, efforts to gauge their acceptance are scant (Baccarella et al., 2021).Furthermore, the literature suggests that AVs could significantly enhance the quality of life for PWD , potentially improving road safety for all pedestrians, including those with disabilities (Salonen and Haavisto, 2019);(Sundararajan et al., 2019).

However, the inclusion of PWD in studies concerning AVs is notably lacking, with their perspectives often absent or underreported (Gudlavalleti et al., 2014). This is in contrast to numerous studies focused on the general public's views of AVs, which predominantly address the technology's automation aspects without considering the unique needs related to disability accessibility (Asgari et al., 2018) (Rahimi et al., 2020). This oversight underscores the need for a focused exploration of the mobility issues faced by PWDs and capturing their perceptions of AVs as a viable transportation option.

Involving users, particularly persons with disabilities, in the design and evaluation of AV technologies is paramount. Sivakanthan et al. (2023) emphasize that active engagement of end-users in the development process ensures that AV technologies accommodate diverse accessibility needs effectively. Additionally, involving older users in technology design has shown that user insights can significantly enhance the quality of technology outcomes (Booth et al., 2022). This highlights the necessity of incorporating PWD in the AV design process to ensure that their specific needs and concerns are effectively addressed.

The current body of research on autonomous vehicles has mostly concentrated on technical progress and broader societal issues (Sundararajan et al., 2019, Asha et al., 2021, Nanchen et al., 2022, Hwang et al., 2020). However, there is a significant absence of qualitative analytic frameworks that are especially designed to examine the perceptions of persons with disabilities about these developments and their possible effects on mobility choices and user experience. Recent research has highlighted the importance of including inclusive design norms in Human-Machine Interaction and User Experience HMI/UX for Autonomous Vehicles (Hwang et al., 2020; Bastola et al., 2024; Nanchen et al., 2022). In order to address this gap, it is important to use qualitative research methods to capture the intricate experiences and perspectives of persons with disabilities PWD on autonomous vehicle (AV) technology. The approaches of co-design studies, user interviews, and surveys have been shown to be successful in collecting detailed and descriptive data that illustrate the distinct difficulties and preferences of this particular group (Nanchen et al., 2022, Brewer and Kameswaran, 2018). As an example, the study by (Asha et al., 2021) used a remote co-design approach that included powered wheelchair users. This approach effectively generated interface design concepts with the goal of enhancing the interactions between motorized wheelchair users and autonomous cars. This research highlights the capacity of inclusive design methods to provide transportation experiences that are both safer and more inclusive.

Moreover, iterative design methods that include input from persons with disabilities at every stage of the development lifecycle are essential. Optimizing autonomous vehicle interfaces to be both functional and intuitively tailored to the specific requirements and preferences of its users may greatly improve the overall user experience and accessibility. The integration of immersive and interactive design components, such as virtual reality simulations and participatory design experiments, has become a potent instrument in comprehending the practical consequences of autonomous vehicle technology for those with impairments. These methodologies enable cooperative generation of ideas to tackle particular mobility issues (Nanchen et al., 2022).

The significance of using inclusive design concepts in the development of AV HMI/UX cannot be exaggerated. Participatory design, the systematic involvement of persons with particular

impairments in the design process, has been shown to be successful in developing accessible interfaces that give priority to user requirements (Huff Jr et al., 2020). The knowledge acquired from these endeavors has resulted in the development of prototypes for novel interfaces that improve the safety and usability of autonomous vehicles for persons with disabilities. An essential aspect of developing fair transportation solutions for everyone, including those with disabilities, is the implementation of a comprehensive design framework that incorporates a wide range of user experiences throughout the autonomous vehicle development process (Bastola et al., 2024). This highlights the importance of involving PWD in the autonomous vehicle design process to ensure their specific needs and concerns are effectively addressed. Our study advances this field by employing co-creation methods, directly engaging with PWD to shape AV technologies and address significant gaps in current research.

3 Navigating challenges and implementing solutions in autonomous shuttle accessibility

Autonomous shuttles represent an opportunity for PWD, but also introduce new challenges. These challenges have been documented in a report for the Department of Infrastructure, Transport, Regional Development, Communications, and the Arts (DITRDC, 2002).

These challenges include not being able to rely on things a good bus driver normally look after, for instance,

- ensuring that the bus stops at the bus stop,
- keeping the doors open so passengers can get on and off the shuttle safely
- only start driving once a frail person is properly seated
- providing assistance in a variety of situations

The other challenge is that automated shuttles rely on a touch screen for the human machine interaction, which cannot be used by many people with disability. To mitigate these issues, we developed and deployed an application that gives some of the controls of the shuttle to the end user. Our application is deployed as a phone app, bus stand screen and in-shuttle screen, so end users could choose the most practical way to interact with the shuttle. Enabling interaction with the shuttle before entering the shuttle at the bus stop or with a phone, was designed to take the stress away for people who would otherwise be nervous having to set destination in the shuttle. The phone app only worked in the vicinity of the bus-stop when connected with a beacon.

4 Co-creation

4.1 Co-Creation workshops

Co-creation workshops were integral to the development phase of the smartphone app, conducted via Zoom video conferencing over three days from 8/9/22 to 12/9/22. Initially, participants were briefed on the research goals and shared their disability types, assistive devices, and smartphone usage, which helped tailor the app's design. They were then shown PowerPoint slides of proposed app screens, derived from research, standards, and existing technologies, and provided feedback. Six one-hour focus groups were held, with four to seven participants each, facilitated by CTI and organized by AFDO. Participants also discussed their likes and dislikes about the app screens and a demonstration of the app's voiceover feature, initially recorded and later replayed. The sessions were recorded and transcribed by The Captioning Studio, and feedback was analyzed using qualitative thematic analysis to identify common themes, which were then ranked based on consensus across disability groups.

4.2 Overview of app functionality in prototype testing

Figure 1 presents an operational example of the app during the focus group sessions. Initially, participants were introduced to the interface via a screenshot of the home screen (Figure 1a).

Subsequently, the facilitator CTI demonstrated key functionalities including the 'hail bus' feature, which allows users to summon a bus to a nearby stop, the 'voice mode' for toggling voice commands on and off, and the 'trip enquiry' to connect with a remote operator. Specifically, activating the ‘hail bus’ function transitions the screen to 'set destination' (Figure 1b), where users select their stop (Figure 1c). Notifications alert users when the bus approaches (Figure 1d). Upon bus arrival and door opening, the app offers the option to delay the closing of the doors by 60-second increments (Figures 1e and 1f), a feature that recurs at each stop.

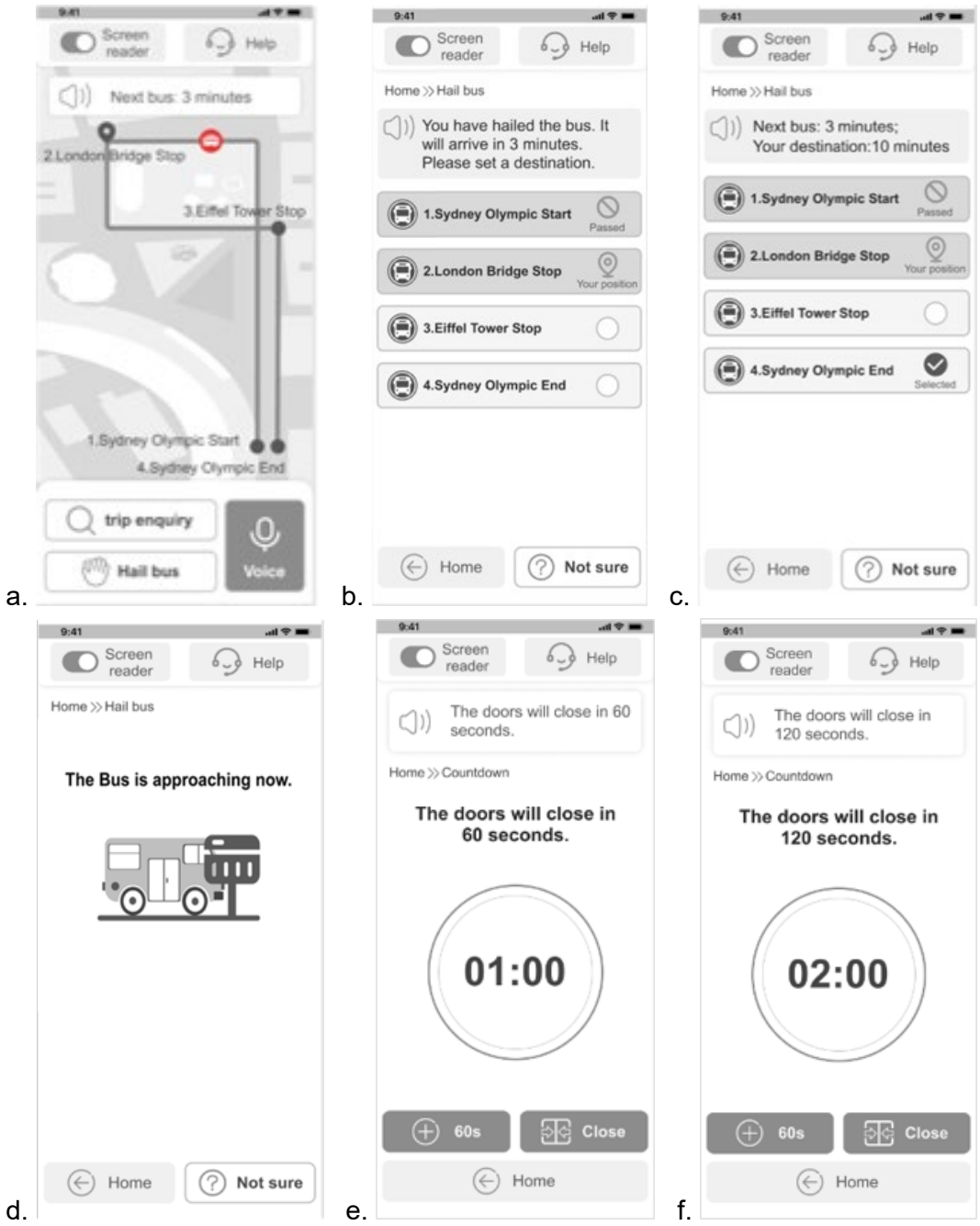

Figure 1: a. Home-screen, b. Select stop, c. Stop selected, d. Bus approaching, e. Countdown one minute, f. Countdown two minutes.

4.3 Result analysis and discussion

4.3.1 Thematic analysis overview

A thematic analysis was used to systematically analyze the feedback gathered from the co-creation workshops and focus groups. This approach utilizes the six stages of coding and analysis as proposed by Braun and Clarke (2006), enabling themes to naturally emerge from the data, rather than being influenced by pre-existing theories. The process started by fully familiarizing with the data. The transcripts from the co-creation workshops and focus groups were thoroughly examined to develop a comprehensive understanding of the participants' experiences with the autonomous shuttle service and the smartphone application. During the initial phase, it was essential to identify initial patterns and potential areas of interest. These findings were then further developed into more structured codes.

In the coding phase, the data were well-organized by tagging special characteristics and addressing the concerns raised by the participants. As an example, specific codes were assigned to challenges like screen readability issues, voice command functionality difficulties, and the ease of using haptic feedback. The codes formed the basis for identifying overarching themes, reflecting significant concerns about accessibility.

After generating the basic codes, the subsequent step was to organize these codes into more comprehensive topics. Recurring problems relating to visual engagement with the app were identified via investigation and categorized under the subject "Visual Accessibility." Furthermore, other topics such as "Interaction Methods" and "Auditory Accessibility" surfaced, including several facets of the participants' encounters with the user interface and control systems of the shuttle. The topics were not predetermined but arose naturally from the data, reflecting the fundamental issues and requirements articulated by the participants.

The themes that were identified underwent an extensive evaluation to ensure their accuracy in reflecting the data. The review process was a collaborative effort, with multiple discussions held to enhance the themes and ensure their clarity and uniqueness. For example, the theme "Interaction Methods" started out as a broad concept, covering different types of user interaction. After engaging in thorough discussions, it became distinct that further clarification was necessary to accurately encompass the wide range of interactions reported by participants. Through refinement, "Interaction Methods" now include various specific aspects, such as voice commands, haptic feedback, and hands-free control options. These distinct interaction modes have a significant impact on enhancing the user experience. All uncertainties or inconsistencies were addressed by reviewing the original data and codes.

Once the themes were refined, each one was given a clear and descriptive name that captured its main focus. "Visual Accessibility," for instance, encompassed various aspects concerning the visual design of the app, such as screen contrast, readability, and overall visual presentation. This phase was crucial in ensuring that each theme was directly connected to the broader goals of enhancing accessibility for People with Disabilities.

Finally, the themes were synthesized into a coherent narrative that effectively highlighted the accessibility challenges identified through the analysis. Each theme was thoroughly detailed in the next section, for instance, under the theme of "Auditory Accessibility," participants emphasized the critical need for clear and customizable voice interactions, especially for users with visual impairments.

The thematic analysis revealed four primary themes: Visual Accessibility, Interaction Methods, Auditory Accessibility, and Other Challenges. These themes are summarized in Table 1, providing a comprehensive overview of the key findings from the analysis.

Theme	Description
Visual Accessibility	Issues related to screen contrast, readability, and overall visual design.
Interaction Methods	Functionality of features like haptic feedback, voice commands, and hands-free interaction.
Auditory Accessibility	Clarity and customization of voiceover features.
Other Challenges	Additional concerns such as conflicting commands, user accents, and caregiver interactions.

Table 1: Themes identified from thematic analysis

4.3.2 *Utilization of mobile devices and applications*

During the focus group discussions, all participants reported having access to and using a smartphone, though their app usage and ability to use phones independently varied. Vision-impaired participants frequently used accessibility settings or specialized apps like Lazarillo, Bindi Maps, and JAWS to navigate. While the app was demonstrated on an Android device, nearly half of the vision-impaired participants (4 out of 9) indicated a preference for Apple devices, expressing concerns about compatibility with features like dark mode and screen magnification on Android. Table 2 summarizes the key findings regarding participants' use of mobile devices and applications:

Device/Application	Usage
Smartphone	All participants used smartphones, with varying degrees of app usage and independence.
Accessibility Apps	Vision-impaired users commonly used Lazarillo, Bindi Maps, and JAWS for navigation.
Device Preference	Forty-four percent of vision-impaired participants preferred Apple devices, citing better accessibility features.
Compatibility Concerns	Concerns were raised about the app’s compatibility with Apple features like dark mode and magnification.

Table 2: summarizes key findings on participants' mobile device and app usage.

4.3.3 Co-creation: Functionality

Feedback from focus groups revealed that participants appreciated the app’s functionality and the control it provided over the shuttle. However, some users experienced stress due to the increased responsibility, particularly with features like the 60-second door delay, which caused anxiety for some. To address these concerns, the app has undergone several enhancements, focusing on improving Customizability and Simplicity. These improvements aim to better meet user needs and reduce stress during use.

4.3.3.1 Stop list with ETA

Improvements were made to communicate the estimated time of arrival (ETA) more clearly, addressing the need for better timing information. Participants expressed concerns about the unclear stop sequence and lack of time indications, suggesting that adding estimated timeframes next to each stop would enhance usability.

4.3.3.2 Door control time intervals

The original door control feature, allowing a 60-second extension, was replaced with a simpler 'pause' and 'go' button due to user feedback. Participants suggested shorter or customizable time intervals, with many preferring a 30-second option instead of the standard 60 seconds.

4.3.4 Co-creation findings: Accessibility

The initial low-fidelity prototype of the app was positively received, praised for its pleasant and straightforward design. The black and white color scheme was effective, though there were suggestions to increase contrast and utilize more icons instead of text to enhance usability. Participants with disabilities unanimously emphasized the need for customizable app features to accommodate their individual needs:

- Participants on the autism spectrum (ASD) preferred an option to disable frequent notifications, which they found anxiety-inducing.
- Participants with mobility impairments, such as wheelchair users or those using walkers, recommended the addition of a 'Handsfree mode'.
- Participants with vision impairments suggested increasing the contrast on the home screen and speeding up voice feedback.
- Participants with hearing impairments requested closed captioning for audio announcements to make the app more accessible.

In terms of simplifying the app, vision-impaired participants advocated for fewer commands and the ability to set preferences in advance. Compatibility with existing phone technologies and default accessibility settings, like zoom and voiceover, was also highlighted as crucial.

Table 3 provides a summary of these recommendations from the focus groups aimed at refining the app for the subsequent testing phase.

Visual	**Interaction**
• Increase contrast. • Dark mode/invert colors • Picture of stops/landmarks • Captions on screen	• Haptic vibrations on countdown • Simplifying voice commands • Bypassing menu • Handsfree interaction • Accessibility on iPhone • Works with peripheral devices • Overuse of “stop”
Auditory	Other
• Increase voiceover speed. • Options to change speaker. • Improve voice clarity.	• Conflicting commands • User accents • Carer using phone. • Wrong bus alerts

Table 3: Accessibility Improvements Overview

5 Develop and test our application

We developed our application in Android Studio and deployed it on an AV. Testing was conducted at Sydney Olympic Park with 27 participants from previous co-creation groups, including 15 females and 9 males, aged 18 to over 50, and representing various impairments (9 vision-impaired, 12 physically impaired, 5 with other impairments). Participants were from New South Wales and Victoria, with no hearing-impaired individuals. Testing was organized in two daily sessions, with 6 participants each. Initially, groups were briefed together, but individual briefings were later adopted to streamline the process. Participants completed a preliminary survey, received a briefing on shuttle functionalities, and took a supervised 10-minute journey through four stops. An experienced operator ensured safety during the sessions. A post-test survey using the System Usability Scale measured app usability, with testing times ranging from 1 to 1.5 hours per participant. Before testing, the shuttle and app underwent thorough safety checks. This involved verifying that the app's commands, such as

starting or stopping the shuttle, were executed reliably and safely. Pre-trial tests ensured that the app posed no risks to users, creating a secure environment for the trial.

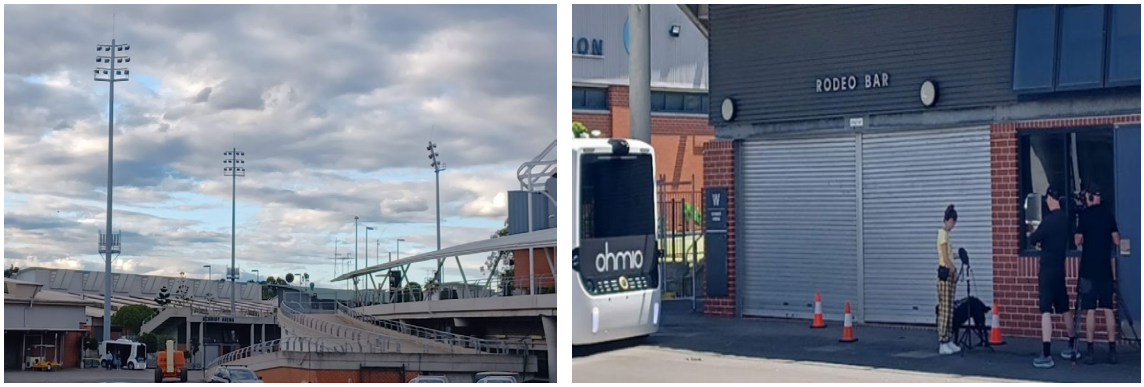

Figure 2: Test location

5.1 Technical set up

We simulated a bus stop scenario with four stops, allowing users to control the shuttle via a UI app available on their smartphone, bus stop touchscreen, or in-shuttle screen. The app enabled users to set destinations, open and close doors, and perform other essential functions. Commands were transmitted over the Internet to the HMI app on the shuttle's management computer, with middleware developed to manage these commands effectively. The UI app's home screen, shown in Figure 3, displayed key functionalities such as help options, estimated shuttle arrival times, route information, and trip inquiries. The HMI app executed these commands, monitored shuttle status (e.g., speed, position, door states), and provided user feedback through voice, vibration, and visual cues.

5.2 App interfaces

To enhance clarity and streamline the presentation, the app interfaces on the smartphone are summarized below, categorized by their respective functions. Each function is briefly explained to provide an understanding of its operation, as illustrated in Figure 3.

- **Hail bus function:**
  - Begin the process by tapping the "Hail bus" button on the homepage.
  - Confirm your choice by tapping the "Yes" button.
  - Select your desired destination from the options displayed.
- **Trip enquiry function:**
  - Access trip information by clicking the "Trip enquiry" button on the homepage.
  - Choose the start and end stops.
  - View the trip details.
- **Voice activation:**
  - Activate the voice mode by saying "Hi HMI" to the app.
- **Pause and go functions:**
  - Use the "Pause" button to hold the door.
  - Click "Start" to resume the bus's movement.
- **Help function:**
  - Contact remote staff for assistance by clicking the "Help" button.

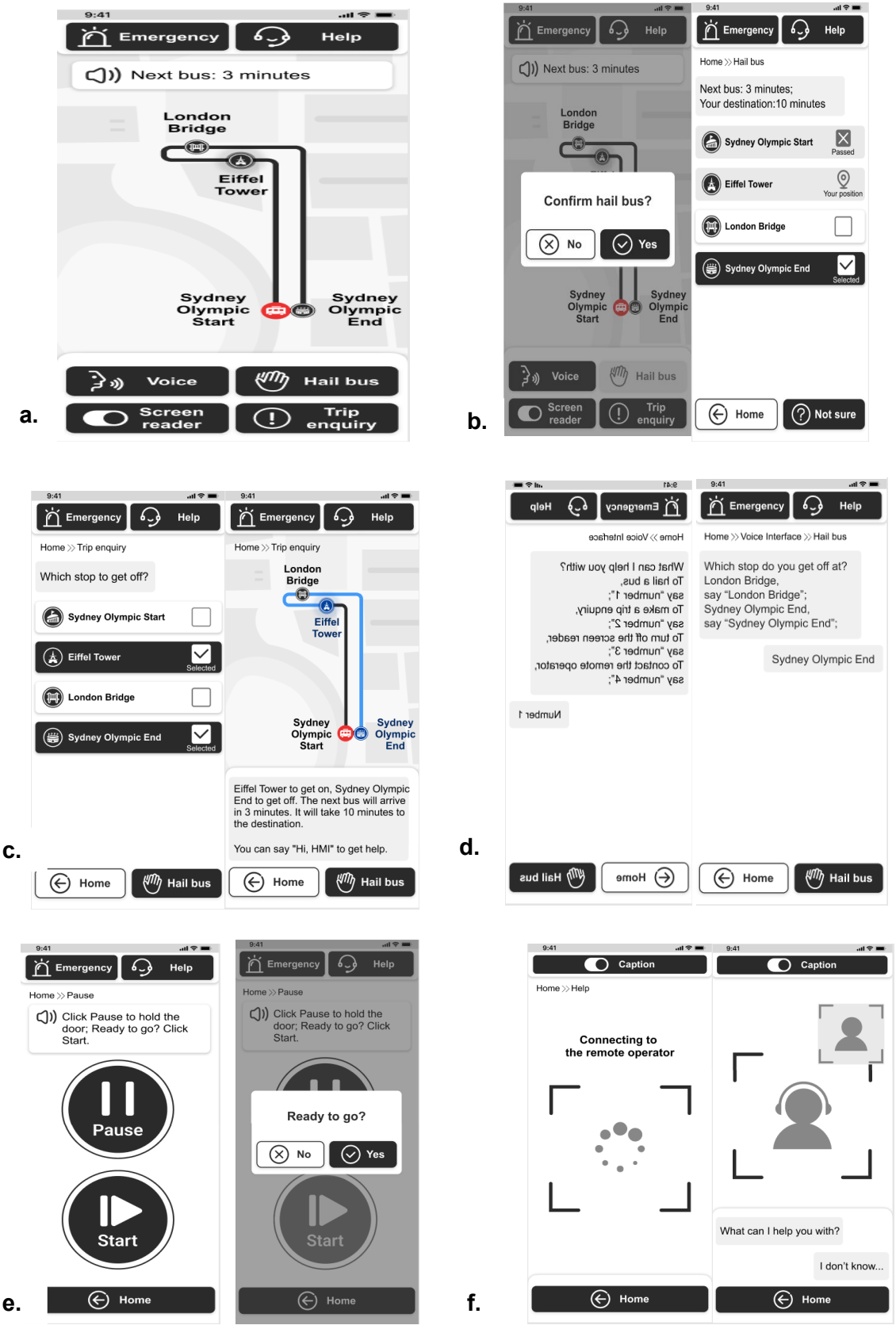

Figure 3: (a) UI App Home Screen Interface Overview, (b) Hail Bus Function, (c) Trip Enquiry Function, (d) Voice Function, (e) Pause and Go Functions, and (f) Help Functions.

6 Result

6.1 User feedback

The thematic analysis of the feedback obtained from participants revealed significant insights into the user experience and satisfaction with the autonomous shuttle service facilitated by the newly developed app. A comprehensive evaluation showed that 93% of participants found that the app significantly enhanced their travel experience by simplifying interactions with the autonomous shuttle. This ease of use was crucial in alleviating initial apprehensions associated with the adoption of autonomous vehicle technology.

Participants reported a marked improvement in their ability to independently operate and interact with the shuttle service. The feedback highlighted that the app effectively addressed common concerns among PWD, such as safety, reliability, and accessibility. The detailed analysis also uncovered a substantial increase in participants' willingness to use such technology in the future, reflecting a successful mitigation of fears related to the absence of a human driver. Notably, the thematic analysis also pointed out areas for further enhancement, particularly in voice command responsiveness and the physical layout of in-app controls, which some users found challenging to navigate.

Figure 4, appended below, visually represents the shift in participants' perceptions before and after using the app, indicating a significant reduction in concerns and an increase in comfort levels with autonomous shuttle technology.

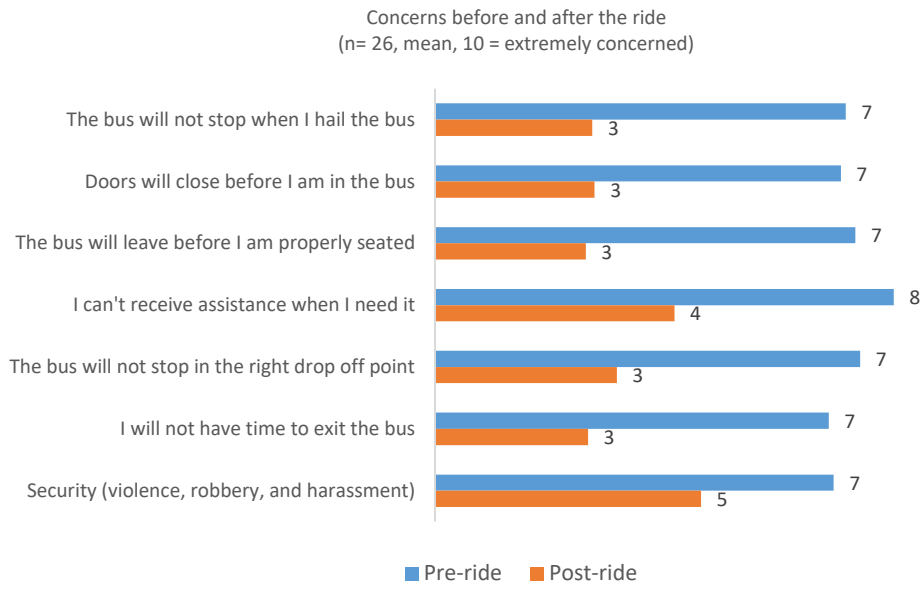

Figure 4. Concerns pre and post ride

6.1.1 Functionality and accessibility of the app

Participants rated their experience with using the app favorably. To control the shuttle, 89% of participants reported using the phone app (n = 25), while other reported using the screen in the bus (n = 2, 7%) and the bus stop app (n = 1, 4%) (Figure 5). The majority (n = 25, 93%) indicated that the functionality of the app made the journey easier.

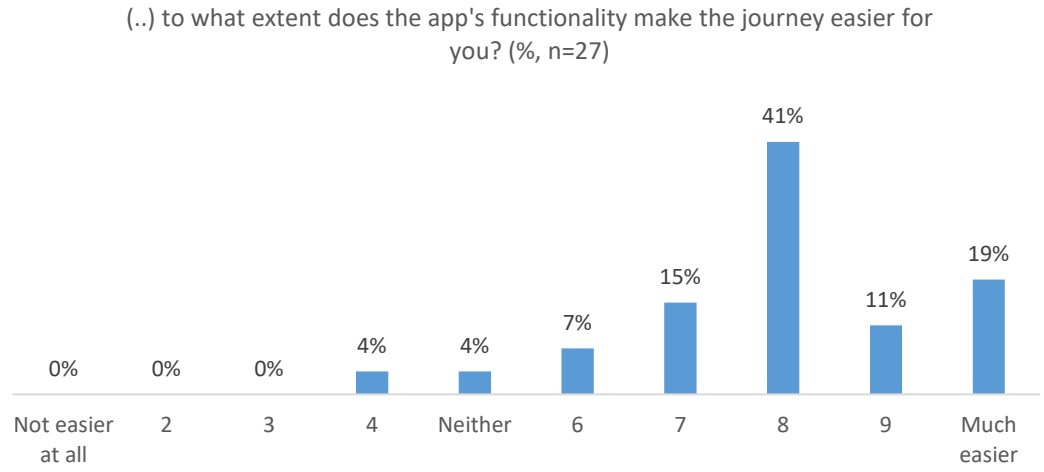

Figure 5. App's functionality

When asked about their experiences with using the app, participants indicated the app was easy to use (n = 17, 63%), not cumbersome (n = 21, 78%), and that they would like to use the app more frequently (n = 24, 89%). Responses to the usability questionnaire items are displayed below, note that some questions are negatively worded (Figure 6).

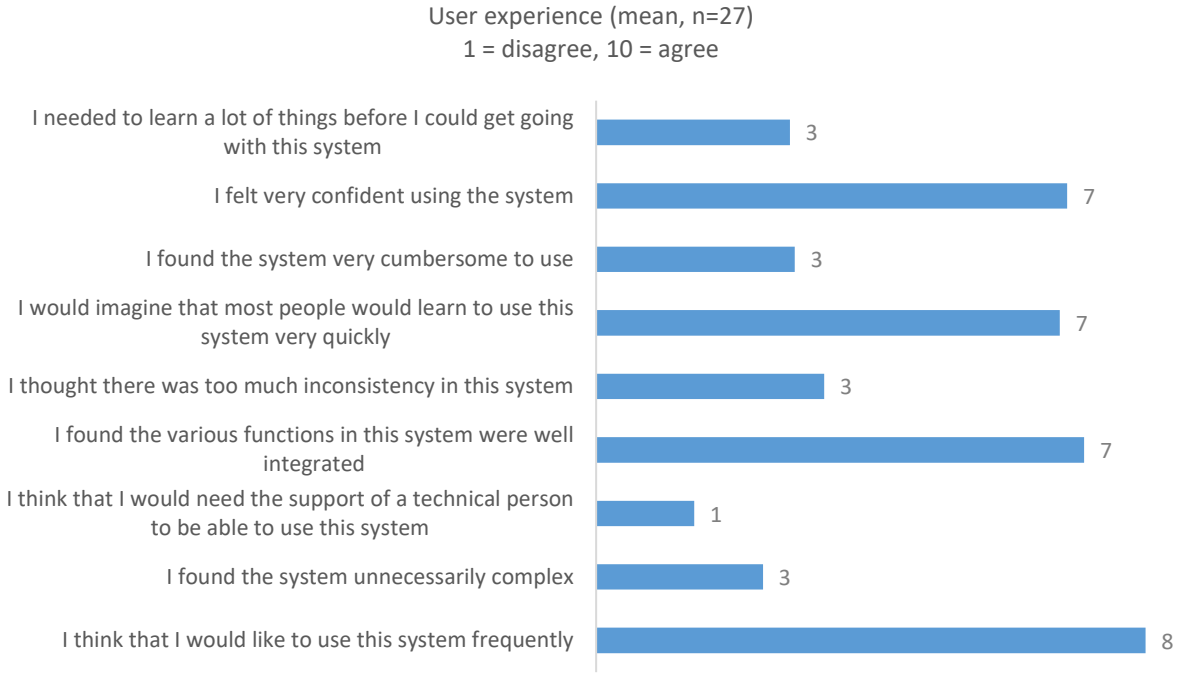

Figure 6. Users experience evaluation.

Participants also responded favorably to open-ended questions about the app, indicating the ability to choose between different accessibility options enabled them to decide for themselves how to operate the shuttle. For example:

> *"And I would just click it, so it will be totally switched to stress free. The app with knowing that it has screen reader on it will benefit me because it will take away all the stress and be stress free."*
>
> *"You can have the voiceover or the screen reader on the app, which is both beneficial sometimes."*
>
> *"So having control gives me like a sense of security because it yes, I do not have to rush... I can take my time and not feel panicked or stressed."*

6.1.2 Suggested improvements of the app

While many commented on how easy it was to use, e.g., *"It was very simple"* there was definitely room for improvement. The speed of navigating the app were the most common recommendations. Participants indicated that the app performance was lacking, particularly with the speed of navigating the map, *"Tiny bit glitches bit slow."* and *"It kept freezing."* Others indicated they had to press the buttons a few times, or when they pressed "pause" the bus did not wait, "*I had pressed go then someone needed to get off and I pressed pause and it did not work."*

Improving the voice interaction was another improvement suggested by participants:

> *The voice needs improvement you need to wait for all the options may be a setting to turn off hints or may be just like Siri and screen reader you can turn off hints quickly in settings.*

Correcting user error and improving user interaction with the app were other suggestions:

> *Route entered was not retained, frustrated that it lost route information due to door being opened longer, said it exited screen reader mode which was concerning as not sure whether it did, could not hear help phone ringing it was silent, some Inaccuracies in announcement information.*
>
> *Have to press same button a few times, wording on some features could be more obvious.*

5.2 App enhancements

Following the co-creation workshops and subsequent testing phases, a series of targeted enhancements were implemented to refine the smartphone app, addressing the specific feedback provided by People with Disabilities (PWD). These enhancements were aimed at increasing the app's usability, safety, and overall accessibility: Emergency Assistance Button: In response to concerns about safety and the need for quick emergency responses, an easily accessible emergency assistance button was added to the app's interface. This allows users to alert support services with minimal effort, providing an immediate sense of security.

Enhanced Voice Control Features: The voice control functionality was significantly enhanced to support a wider range of commands and improve recognition accuracy. This development was particularly beneficial for users with visual and physical impairments, enabling them to operate the app hands-free and ensuring a more inclusive user experience.

Adaptive Text Size and Contrast Settings: To accommodate users with varying visual abilities, the app was updated to include customizable text size and contrast settings. This feature allows users to adjust the display according to their personal needs, making the app more accessible to individuals with different degrees of visual impairment. These modifications not only improved the functional aspects of the app but also enhanced the overall user experience by making the technology more adaptable to the diverse needs of PWD. Table 5 give Improvements Overview visually summarizes these enhancements, illustrating the direct correlation between user feedback and the specific changes made to the app. This figure provides a clear depiction of how the app has evolved to better meet the needs of its users, underscoring the practical impact of the feedback received during the co-creation process.

7 Discussion

7.1 Key outcomes and design implications

The smartphone application for autonomous shuttles led to significant positive outcomes, reinforcing the importance of user-centered design in accessible technology. 93% of participants reported enhanced travel experiences, and 85% of visually impaired users found the adaptive features, like voice control and adjustable text sizes, improved their interaction with the shuttle. These findings emphasize several design implications:

- User-Centered Design: High user satisfaction confirms the need for involving PWD in the design process to create effective and user-friendly solutions.

- Adaptive Features: Customizable options should remain a priority to meet diverse user needs and improve accessibility.

- Safety Enhancements: Addressing safety concerns, such as navigation speed and voice command responsiveness, is crucial. The addition of an emergency assistance button further increased usability and safety.

- Usability Issues: Early identification and resolution of usability issues are vital for ensuring a smooth user experience.

- Scalability: With 90% of participants satisfied, there is strong potential for integrating similar technologies into public transport systems to enhance accessibility which explain in more detail in next section

7.2 Integration of findings with existing literature

The empirical results from this study underscore the efficacy of participatory design in creating technological solutions tailored for PWD. This approach aligns well with existing literature that emphasizes the need for user-centered design processes in the development of accessible technologies (Zachäus et al., 2024). These studies argue that directly engaging users, particularly those with disabilities, leads to higher functionality and user satisfaction due to the adaptation of technology to real-world needs and conditions. The positive impact of the enhanced features of the smartphone application, such as voice control and adaptive text sizes, on the user experience of autonomous shuttles demonstrates that these enhancements also contribute to increased safety perceptions among users, a crucial factor in the adoption of new transportation technologies. Building on these results, there is strong potential to integrate these features into existing public transport systems:

Enhancing Accessibility: Future study should investigate the integration of adaptive functionalities, such as voice command, customizable font sizes, and high-contrast visual interfaces, into current public transit applications. These improvements have the potential to greatly boost accessibility for visually impaired users, therefore improving the accessibility of key travel information such as route data and service updates. Furthermore, the development of navigation aid systems that provide detailed instructions at transportation hubs and on moving vehicles would be especially advantageous for those with limited mobility.

- Seamless Integration: The seamless integration of the smartphone application with both traditional and autonomous transport systems is an interesting subject for future research. Potential research may concentrate on the app's ability to synchronize timetables across different transit modes, while offering real-time updates and personalized recommendations. The integration would provide PWD with a uniform and easily accessible interface, therefore simplifying the process of planning and carrying out trips that include various modes of transportation.

- Data-Driven Optimization: Further research could leverage the app’s ability to gather and analyze real-time user feedback to optimize public transport services. By focusing on data-driven approaches, future studies could identify key areas for infrastructure improvements and service modifications based on the specific needs and preferences of PWD. This approach would ensure that public transport systems evolve to be more responsive to the users they serve.

7.3 Future research directions: Long-term usability and scalability

Our scalable software shows potential implications for autonomous shuttle systems and other smart transportation options. As cities progress toward integrated and smart transportation networks, the initiative offers a method to create more inclusive and user-friendly systems by incorporating accessibility from the start. The application's iterative design approach, based on PWD input, keeps it adaptive and sustainable as user requirements change. This strategy encourages innovation and improves technology's long-term usage, keeping it current and

effective. Post-trial participant acceptance and desire to utilize autonomous shuttles suggest market readiness for such technologies, especially when user-centered design is employed.

The scalability and usability of these applications could be further improved by future research that investigates advanced adaptive technologies. For example, machine learning algorithms that continuously learn from user interactions could allow the application to offer increasingly personalized experiences. Predictive models could be created to dynamically modify interfaces in accordance with user behavior, thereby reducing cognitive burden for PWD and enhancing the intuitiveness of the application. In addition, the application's scalability could be further optimized by examining the potential of containerized deployments (e.g., Kubernetes) to improve efficiency and adaptability. Additionally, the seamless interoperability and adaptation to a variety of urban environments could be achieved by integrating RESTful APIs with existing public transportation systems. Additionally, the utilization of natural language processing (NLP) techniques could facilitate the analysis of ongoing user feedback, thereby enabling more pertinent and timely updates. This would not only enhance usability but also promote greater user engagement and contentment in the long term.

while our application is already positioned as a scalable and adaptable solution, future studies could explore these advanced techniques and technologies to further expand its applicability and effectiveness in various domains, ensuring it continues to meet the evolving needs of PWD and other users in diverse contexts.

8 Conclusion

This study underscores the significant benefits of integrating smart technology with public transportation, particularly for PWD. Through a participatory design approach, we developed an app that allowed PWD to have greater control over autonomous shuttles, addressing many of the accessibility challenges traditionally associated with public transit. The feedback from the co-creation sessions and subsequent trials confirms that such technological interventions can substantially enhance the user experience, making travel more accessible and less daunting for PWD. The app's features, particularly those allowing for the control of shuttle operations, were well-received, highlighting the importance of user-centric design in technological development. This project illustrates a broader application potential, suggesting that similar approaches could be beneficial across various facets of public transport, making them more inclusive and responsive to the needs of all users.

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References

<Maximizing-Benefits-Self-Driving-Vehicles.pdf>.

ASGARI, H., JIN, X. & CORKERY, T. 2018. A stated preference survey approach to understanding mobility choices in light of shared mobility services and automated vehicle technologies in the US. *Transportation Research Record,* 2672**,** 12-22.

ASHA, A. Z., SMITH, C., FREEMAN, G., CRUMP, S., SOMANATH, S., OEHLBERG, L. & SHARLIN, E. Co-designing interactions between pedestrians in wheelchairs and autonomous vehicles. Proceedings of the 2021 ACM Designing Interactive Systems Conference, 2021. 339-351.

BACCARELLA, C. V., WAGNER, T. F., SCHEINER, C. W., MAIER, L. & VOIGT, K.-I. 2021. Investigating consumer acceptance of autonomous technologies: the case of self-driving automobiles. *European Journal of Innovation Management,* 24**,** 1210-1232.

BASTOLA, A., BRINKLEY, J., WANG, H. & RAZI, A. 2024. Driving towards inclusion: Revisiting in-vehicle interaction in autonomous vehicles. *arXiv preprint arXiv:2401.14571*.

BRAUN, V. & CLARKE, V. 2006. Using thematic analysis in psychology. *Qualitative research in psychology,* 3**,** 77-101.

BREWER, R. N. & KAMESWARAN, V. Understanding the power of control in autonomous vehicles for people with vision impairment. Proceedings of the 20th International ACM SIGACCESS Conference on Computers and Accessibility, 2018. 185-197.

GUDLAVALLETI, M. V. S., JOHN, N., ALLAGH, K., SAGAR, J., KAMALAKANNAN, S., RAMACHANDRA, S. S. & GROUP, S. I. D. E. S. 2014. Access to health care and employment status of people with disabilities in South India, the SIDE (South India Disability Evidence) study. *BMC public health,* 14**,** 1-8.

HUFF JR, E. W., LUCAITES, K. M., ROBERTS, A. & BRINKLEY, J. Participatory design in the classroom: exploring the design of an autonomous vehicle human-machine interface with a visually impaired co-designer. Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 2020. SAGE Publications Sage CA: Los Angeles, CA, 1921-1925.

HWANG, J., LI, W., STOUGH, L., LEE, C. & TURNBULL, K. 2020. A focus group study on the potential of autonomous vehicles as a viable transportation option: Perspectives from people with disabilities and public transit agencies. *Transportation research part F: traffic psychology and behaviour,* 70**,** 260-274.

LEAL ROCHA, L., VIEIRA DE LIMA SAINTRAIN, M. & PIMENTEL GOMES FERNANDES VIEIRA-MEYER, A. 2015. Access to dental public services by disabled persons. *BMC oral health,* 15**,** 1-9.

LEWANDOWSKI, S. 2018. Inclusion and personalization for autonomous mobility [master thesis]. *MFA Interaction Design: College for Creative Studies, Detroit*.

NANCHEN, B., RAMSEYER, R., GRÈZES, S., WYER, M., GERVAIX, A., JUON, D. & FRAGNIÈRE, E. 2022. Perceptions of people with special needs regarding autonomous vehicles and implication on the design of mobility as a service to foster social inclusion. *Frontiers in human dynamics,* 3**,** 751258.

RAHIMI, A., AZIMI, G. & JIN, X. 2020. Examining human attitudes toward shared mobility options and autonomous vehicles. *Transportation research part F: traffic psychology and behaviour,* 72**,** 133-154.

SALONEN, A. O. & HAAVISTO, N. 2019. Towards autonomous transportation. Passengers' experiences, perceptions and feelings in a driverless shuttle bus in Finland. *Sustainability,* 11**,** 588.

SUNDARARAJAN, S., YOUSUF, M., OMAY, M., STEINFELD, A. & OWENS, J. M. Automated vehicles (AVs) for people with disabilities. Road vehicle automation 5, 2019. Springer, 85-90.