Enhancing Inclusivity and Safety in Self-Driving Taxis

Clare Mutzenich[1], Emily Stobbs[1], Ahmed Ehab Abdelsalam[2] & Gary Burnett[2]

[1]Lacuna Agency, [2]Loughborough University

SUMMARY

This study explored the challenges individuals with protected characteristics face during emergencies in self-driving taxis and how inclusive design can enhance safety. Automated Passenger Services (APS) offer significant mobility benefits, but the absence of a driver shifts safety responsibilities to passengers and automated systems. Key emergency tasks—such as contacting emergency services, making evacuation decisions, and interacting with transport operators—vary in complexity depending on passengers' physical, cognitive, and sensory abilities. A qualitative research approach, including focus groups and VR simulations, was used to understand the actions passengers must take during emergencies and the system features required to support them. The study identified that users with disabilities, older adults, and younger passengers face significant barriers in these situations, while personal safety concerns related to gender, race, religion, or sexual orientation influence decision-making. Findings indicated that APS must integrate adaptive human-machine interfaces (HMIs), real-time operator support, and tailored accessibility features to ensure safety for diverse users. Recommendations include manual door overrides, multimodal alerts, and AI-driven emergency assistance. As the APS sector evolves under the Automated Vehicle Act 2024, collaboration with industry stakeholders will be essential. Engaging user groups, transport operators, and technology providers will help integrate inclusivity into self-driving taxi services, improving safety and accessibility while setting a new standard for user-centred innovation.

KEYWORDS

Inclusivity, Emergency Design, Self-Driving Vehicles, Virtual Reality, Protected Characteristics

Introduction

The increasing development and deployment of Automated Passenger Services (APS), such as self-driving taxis, presents significant opportunities for enhancing mobility, accessibility, and safety. In April 2023, the Centre for Connected and Autonomous Vehicles (CCAV) identified a lack of established guidance relating to how different user groups interact with self-driving transport systems across a variety of tasks, such as booking, payment, and wayfinding. As the deployment of APS expands, it is essential to consider not just how users interact with the system under normal conditions, but also how they will navigate unforeseen situations, particularly in emergencies. Emergency situations within APS present unique challenges, particularly due to the absence of a driver, which places greater responsibility on users. Key user tasks during emergencies may include contacting emergency services, communicating with the transport operator, and making evacuation decisions. Emergencies, such as vehicle collisions, floods, or medical crises, present significant challenges, particularly for vulnerable populations. The complexity of these tasks may vary based on individual passenger needs, capabilities, and age. Historically, transport systems have

overlooked diverse user needs—for example, crash test dummies were primarily modelled on male bodies, neglecting women, children, and people with disabilities (Schiebinger, 2014).

The rise of self-driving taxis heralds a new era in personal mobility, promising increased accessibility and convenience (Department for Transport, 2019). However, these benefits are contingent on their ability to accommodate all users, including those with protected characteristics under the Equality Act 2010 (Equality Act, 2010). The Act mandates that public services, including transport, provide equitable access and support to individuals with diverse needs. The Act identifies nine specific characteristics that are legally protected from discrimination, harassment, and victimisation, referred to in this report as protected characteristics. These are:

- **Age:** Covers people of all age groups, ensuring protection against age-related discrimination.
- **Disability:** Includes physical and mental impairments that have a substantial and long-term impact on an individual's ability to carry out daily activities.
- **Gender Reassignment:** Protects those who are undergoing, have undergone, or are considering a process to reassign their gender.
- **Marriage and Civil Partnership:** Protects against discrimination based on marital status or civil partnership, but only in employment contexts.
- **Pregnancy and Maternity:** Protects individuals from discrimination during pregnancy and up to 26 weeks after giving birth, including breastfeeding.
- **Race:** Encompasses colour, nationality, and ethnic or national origins.
- **Religion or Belief:** Protects people with religious beliefs, non-religious beliefs (e.g., atheism), or philosophical beliefs (e.g., environmentalism), provided they are worthy of respect in a democratic society.
- **Sex:** Protects individuals from discrimination based on being male or female.
- **Sexual Orientation:** Covers heterosexual, homosexual, and bisexual orientations.

In traditional taxis, human drivers may address specific requirements during emergencies, such as assisting passengers with mobility impairments, ensuring safe evacuation for wheelchair users, or supporting pregnant passengers. For older adults, drivers may provide reassurance or additional physical assistance, and for passengers with sensory impairments, clear verbal communication is often essential. These practices align with the Equality Act by ensuring that individuals with protected characteristics are not disadvantaged in emergencies.

Research has highlighted several key challenges faced by individuals with protected characteristics in transport systems. Individuals with mobility and cognitive impairments often struggle with tasks like recognising hazards, securing seatbelts, and stowing luggage, requiring additional assistance (Schräder, 2019; Millonig & Fröhlich, 2018). Anxiety, lack of confidence, and mental health conditions (e.g., depression, agoraphobia) can limit travel frequency and independence, particularly for those with cognitive and behavioural impairments (Mackett, 2017). Visually impaired passengers may face difficulties navigating vehicles and rely heavily on digital tools for journey planning. In automated systems, traditional support tasks, like boarding and exiting, would need to be automated to ensure accessibility (Low, 2020; Millonig & Fröhlich, 2018).

This project seeks to fill knowledge gaps through a human factors and ergonomics approach to investigate user tasks and vehicle interactions during emergency scenarios and their associated requirements. Lacuna Agency worked in partnership with Loughborough University, combining expertise in Human Factors research and VR simulations. This collaboration, together with DfT and CCAV aimed to provide evidence-based insights to inform emergency accessibility protocols. The research was commissioned to explore the needs of diverse populations using APS, focusing on inclusivity and accessibility, as well as the requirements for managing tasks during emergency

situations. Particular attention was given to the experiences of users with protected characteristics as defined under the Equality Act 2010. This study leverages VR technology to simulate emergencies and gather insights into user behaviours, perceptions, and needs. By focusing on inclusivity and safety, the research aligns with the conference theme of enhancing human performance through the integration of technology and human-centred design.

Methodology

This study used a qualitative research approach, incorporating focus groups and VR simulated self-driving taxi experiences to investigate user needs and behaviours during emergency scenarios. A quota sampling strategy was employed to ensure diverse participant demographics, with particular attention to individuals falling under the protected characteristics defined by the Equality Act 2010. To ensure that systems effectively support user needs, task analysis was applied to identify the cognitive and physical actions participants reported they would need to perform in these emergencies.

A total of 91 participants were recruited for this study, including 10 children (aged 8-17yrs old) who participated with their parents. The sample were recruited from cities and towns located in the Midlands region of England, UK (Leicester, Nottingham, Loughborough, and Birmingham), reflecting both urban and rural areas. To qualify, all participants were required to be able to use public transport independently and 80% of participants needed to use a taxi service more than twice a month, with more flexibility allowed for accessibility groups.

Participants were recruited to reflect a broad range of protected characteristics under the Equality Act 2010, ensuring representation across various age groups, genders, ethnicities, and social grades. Recruitment methods prioritised intersectionality, aiming for participants with two or more protected characteristics where possible, to provide nuanced insights into diverse user needs. The protected characteristic of disability was split into categories to represent distinct user groups to understand specific accessibility needs in this group: physical impairment, hearing impairment, vision impairment, and neurodivergent (Autism Spectrum Disorder - ASD, Dyslexia, Dyspraxia, Attention deficit disorder - ADD). The study was conducted in adherence to the ethical standards set by Loughborough University Ethics Committee to ensure participant safety, inclusivity, and data privacy.

Participants could participate in either “solo” sessions in which they participated alone, or “social” sessions in which they participated alongside three others (total of four participants). Participants under the ages of 18 years old were only permitted to take part in social sessions with their parents for safeguarding reasons. The inclusion of both solo and social VR sessions in this study was designed to reflect the varied contexts in which passengers might experience emergencies in self-driving taxis. These scenarios aimed to capture the diverse psychological, behavioural, and emotional responses that could arise depending on whether a passenger is alone or accompanied.

The emergency scenarios for the VR simulations were developed in collaboration with CCAV through a workshop involving key stakeholders from transport charities and organisations. The workshop helped to prioritise the types of emergencies to focus on, selecting those deemed the most common in transport situations, likely to occur, or of significant concern to potential future users of APS. This research prioritised the inclusion of voices from groups often underrepresented in transport research, with a focus on ensuring there were no barriers for people with disabilities or other protected characteristics to participate. Several measures were implemented throughout the study to support participants. For those with sensory issues or neurodivergence, such as ADD, regular breaks were provided to reduce fatigue and prevent cognitive overload. A designated “chill-out” area was set up for participants to rest if needed. Sensory adjustments included dimming the

lighting and reducing the number of researchers in the room, allowing participants to engage more comfortably. These steps ensured participants were able to engage without feeling overwhelmed.

Carers and support staff were encouraged to accompany participants, particularly those with mobility impairments or cognitive disabilities, to ensure they could fully engage with the study. Carers could either stay in the room to support participants directly or remain in the designated chill-out area for additional assistance. The venue was made fully accessible, with lift access and adjustments to the physical setup, allowing participants in wheelchairs to remain seated throughout the study without needing to transfer. To address transportation challenges, detailed instructions, including maps and parking information, and a dedicated host were provided in advance to ensure participants with mobility impairments or cognitive challenges could navigate the venue easily. For pregnant participants or those with young children, flexible scheduling allowed for more frequent breaks and timing adjustments to meet their needs. These efforts along with others were put in place to ensure that participants, regardless of their background or needs, could fully engage in the study without facing unnecessary barriers. This approach reflects the research team's commitment to inclusivity and accessibility, ensuring that all users could participate meaningfully.

Emergency scenarios

The study focused on six carefully crafted emergency scenarios, each representing a distinct type of emergency, including internal incidents (e.g., medical emergencies), external threats (e.g., vehicle collisions), environmental hazards (e.g., flooding), and interpersonal situations (e.g., passenger altercations). The six scenarios were:

- **Pedestrian interaction:** A pedestrian attempts to open the taxi door while the vehicle is stopped at a red light.
- **Medical emergency:** Participants share the self-driving taxi with an unfamiliar passenger (a VR avatar) who becomes unwell during the journey.
- **Incorrect stopping point:** Participants are travelling to the library but the self-driving taxi misses the designated stop and attempts to drop them off further away.
- **Road closure due to flooding:** The taxi is caught in bad weather, where heavy flooding and a barricade force the vehicle to stop.
- **Fire or smoke emergency with door malfunction:** The vehicle catches fire while the participants are on their way home, producing smoke and flames, while the doors fail to open despite the vehicle stopping.
- **Vehicle collision:** The self-driving taxi is hit from behind by another vehicle while stopped at a red light.

Participants experienced three out of the six scenarios, selected randomly, to provide diverse exposure while avoiding cognitive or physical strain from time spent wearing the VR headset. By immersing participants in these VR simulations, the study gathered detailed qualitative feedback on the necessary user actions and cognitive processes, the system features needed to support users, and, if relevant, the protected characteristic considerations related to that step. This innovative approach generated rich qualitative data, offering valuable insights into how to design inclusive and effective emergency protocols for self-driving taxis.

Results

Each of the six emergency scenarios was analysed through task analysis, examining the actions, thoughts, and system interactions required by passengers in self-driving taxis. The study assessed whether passengers could manage these tasks independently or needed additional support. Insights from interviews and focus groups highlighted key emotional, cognitive, and behavioural challenges. The analysis also explored how protected characteristics, such as age, disability, and cognitive

impairments, affected passengers' ability to handle emergencies without a driver. Some issues were universal, while others were specific to particular emergency scenarios. The intersection of multiple protected characteristics was also examined to identify unique barriers.

A master task framework was developed to outline the key emergency tasks required of passengers, given the absence of a driver, shifting responsibility to automated systems and the users.

1. **Awareness and recognition** – Passengers must detect and understand potential risks. Unlike traditional taxis, where drivers provide verbal warnings and alerts, self-driving taxis rely on system notifications (audio, visual, or sensory cues). These alerts must be clear and accessible to all passengers, particularly those with sensory or cognitive impairments.
2. **Assessing the situation** – Passengers must evaluate the severity of the emergency and potential risks. In traditional taxis, drivers assess the situation and take appropriate action. In self-driving taxis, passengers rely on system-provided information to determine their next steps, such as recognising hazards like fire, flooding, or an unwell co-passenger.
3. **Decision making** – Without a driver to make emergency decisions, passengers must act independently or with system guidance. Features such as emergency stop buttons, door overrides, and clear exit instructions can support users. Ensuring that these systems are intuitive and accessible is essential for a diverse range of passengers.
4. **System interaction** – Passengers must engage with system controls to execute their emergency response. Traditional taxis require little direct system interaction, as drivers manage vehicle functions. In self-driving taxis, passengers may need to activate emergency stop mechanisms, issue voice commands, or override door locks. Interfaces must be user-friendly and adaptable for individuals with different abilities.
5. **Communication** – Passengers must contact external parties, such as operators, emergency services, or other passengers. Traditional taxis rely on drivers to handle communication. In self-driving taxis, passengers will need robust communication tools, such as intercoms, pre-recorded emergency messages, or live operator support. Multilingual and accessibility features will enhance inclusivity.
6. **Post-incident actions** – Passengers must manage the aftermath of an emergency, such as arranging alternative transport or seeking further assistance. Traditional taxi drivers help facilitate these steps. In self-driving taxis, automated assistance, live operator support, and accessible travel updates will be crucial for ensuring passengers feel supported post-incident. These findings underscore the importance of inclusive safety features and tailored emergency protocols that address the diverse needs of passengers, ensuring self-driving taxis are safe and equitable for all users.

Key passenger needs during emergencies in self-driving taxis include clear and accessible alerts, such as audio-visual notifications, to ensure all users can recognise potential dangers. Safe and accessible exit options, including emergency stop buttons, door overrides, and ramps, are essential for a quick and efficient evacuation. Passengers also require guidance on how to interact with external parties, such as emergency services or operators, through intercoms and emergency contact systems. Emotional reassurance is another critical factor, with structured system messages or live operator support helping to reduce anxiety and improve decision-making under stress.

To facilitate effective incident reporting and help-seeking, systems should include voice assistance and subtitles, ensuring accessibility for all users. Real-time alternative travel arrangements and accessible navigation tools will support passengers after an incident, helping them continue their journey safely. Proactive hazard detection, such as fire, flooding, and collision sensors, can further enhance passenger safety by enabling early intervention. Additionally, emergency protocols must be culturally and religiously sensitive, incorporating multilingual support and gender-sensitive communication to accommodate diverse user needs. These findings underscore the importance of

inclusive emergency protocols in self-driving taxis. Accessibility considerations are particularly crucial for passengers with sensory, physical, or cognitive challenges, ensuring that all users can effectively respond to emergencies without the presence of a driver.

Discussion

This research contributes to the broader discourse on enhancing human performance by addressing inclusivity in autonomous transport design. By focusing on protected characteristics, it ensures that self-driving taxis accommodate diverse user needs during emergencies. The findings highlight the intersectionality of characteristics, such as disability and gender, in shaping perceptions of safety and usability. The findings offer crucial insights into the challenges passengers face during emergencies in self-driving taxis, particularly those from groups more likely to experience vulnerability or exclusion. Without a driver to provide guidance, mediate interactions, or offer physical support, passengers must rely entirely on automated systems and interfaces. This shift introduces unique difficulties, particularly for individuals with disabilities, older adults, and younger passengers, who may encounter barriers due to physical, cognitive, or sensory limitations. Beyond practical challenges, personal safety concerns—shaped by factors such as race, religious beliefs, gender, or sexual orientation—also influence how individuals perceive and respond to emergencies. Barriers experienced by different user groups included:

Disability: The absence of a driver removes an essential source of immediate assistance for passengers with disabilities. Physical impairments make features such as automated door unlocking, reliable ramps, and clear evacuation paths critical for ensuring accessibility without human intervention. Vision-impaired users, who might typically rely on a driver for situational context, require voice-guided navigation and audible alerts. Hearing-impaired passengers, unable to engage in verbal communication, depend on visual aids and real-time updates. Neurodivergent users, who may benefit from the calming presence of a driver, require structured and intuitive systems to minimise overstimulation and distress.

Sex: The lack of a driver increases feelings of vulnerability, particularly among female and non-binary passengers. Automated safety features such as panic buttons, alternative exits, and live operator support could help replace the protective presence of a human driver. For male passengers, the absence of a driver who might otherwise mediate interactions raised concerns about accountability. Transparent monitoring systems, including CCTV and audio recording, were seen as necessary to ensure fair treatment and prevent misinterpretation during emergencies.

Sexual orientation: LGBTQIA+ passengers expressed concern about the absence of a driver to deter potential harassment or discrimination. High-quality CCTV and live operator support were identified as essential for ensuring safety in high-risk situations. Automated systems that detect and mitigate discriminatory behaviour could provide reassurance, replacing the role a driver might play in preventing or intervening in incidents of bias.

Religion: For passengers from religious backgrounds, visible safety features such as CCTV were regarded as important deterrents against prejudice. The lack of a driver to offer situational clarity in emergencies underscored the need for alternative exits and culturally sensitive communication systems to accommodate diverse needs.

Age: Younger and older passengers were particularly affected by the absence of a driver. Younger passengers (8–17 years), who might typically look to a driver for reassurance or authority, require structured guidance and live operator support. Older passengers (65+ years), who may rely on drivers for physical assistance, need accessible features such as low-threshold doors, wide ramps, and tailored medical alerts. Middle-aged passengers benefit from clear, step-by-step system guidance to navigate emergencies effectively.

Pregnancy and maternity: Pregnant passengers highlighted the absence of a driver as a key factor in their sense of vulnerability during emergencies. Features such as automated door unlocking, low-threshold doors, and ramps were seen as essential for safe evacuation without physical assistance. Live operator connections could replicate the reassurance a driver might provide, while integrated medical response systems could replace the driver's role in assisting with health concerns.

Race One participant expressed heightened anxiety about the risk of misjudgement or prejudice in the absence of a driver to mediate interactions. Real-time video and audio monitoring were considered crucial for ensuring fairness and accountability. Automated alerts and impartial instructions could help reduce bias in high-pressure scenarios.

Gender reassignment: For transgender passengers, the absence of a driver removed an important layer of security. Real-time video monitoring and live operator support could offer reassurance and accountability. The use of pre-filled diversity profiles might allow emergency responders to access sensitive information in a way that ensures appropriate and respectful assistance.

Marriage and civil partnership: This characteristic did not significantly influence user needs, as the absence of a driver did not intersect meaningfully with participants' experiences.

Digital exclusion: Passengers with limited digital literacy faced additional challenges due to the reliance on automated systems. Manual buttons, physical intercoms, and simple navigation tools could provide essential support for these users. Live operator connections and non-digital options are key to ensuring effective access to emergency assistance.

Limitations of the study

While the study provided valuable insights into how protected characteristics shape passengers' experiences in self-driving taxis, several limitations should be acknowledged. One challenge was the reliance on individual perspectives to represent broader demographic groups. For instance, the study included only one transgender participant, making it difficult to generalise findings across the wider transgender community. Future research should seek a more diverse participant base to capture a broader range of experiences, potentially by offering home-based sessions to improve accessibility.

Participants were also limited to experiencing only three of the six VR scenarios to minimise fatigue. While this approach helped maintain engagement, it may have restricted the relevance of the scenarios to certain participants' protected characteristics. Future studies could explore longer or staggered sessions to ensure all relevant challenges are captured. Additionally, participants often made assumptions about scenario elements, which may have influenced their responses. For example, in the pedestrian interaction scenario, many assumed the VR pedestrian was male, despite it being designed as gender-neutral. This highlights the importance of designing avatars with explicitly diverse identities in future studies.

Another key finding was that participants sometimes spoke on behalf of others rather than reflecting on their own experiences. Many described how an older or pregnant person might feel in a situation, rather than focusing on how their own protected characteristics influenced their response. While this approach highlights a positive consideration for inclusivity, it also obscured some of the unique challenges individuals faced. Future research could provide clearer instructions to encourage self-reflection. A final challenge was the overrepresentation of older participants, who were often more vocal in their feedback. While their insights were valuable, they may have overshadowed the experiences of younger participants. Ensuring balanced representation across age groups in future studies could help address this.

Recommendations for future self-driving taxi design

The absence of a human driver places new responsibilities on both passengers and automated systems, particularly in emergency situations where passengers must now perform tasks traditionally handled by a driver. The findings highlight that these challenges are both practical—relating to physical, sensory, or cognitive barriers—and psychological, influenced by concerns around safety, trust, and bias. To address these challenges, future automated passenger service (APS) designs should prioritise the following:

- **Accessible vehicle design**: Features such as manual door overrides, weather-resistant ramps, and ergonomic seating would help ensure all passengers can evacuate safely in an emergency.
- **Multimodal communication systems**: Voice, text, and visual instructions should be used to accommodate sensory and cognitive differences, with universally recognisable icons to aid decision-making under stress.
- **Personalised safety features**: Passengers should be able to pre-fill accessibility and safety preferences during booking, allowing the system to provide tailored guidance in emergencies.
- **Proactive emergency planning**: Embedded medical tools, AI-powered evacuation plans, and live operator connections could compensate for the lack of human intervention.
- **Enhanced security and monitoring**: Real-time video and audio monitoring, along with automated alerts, would provide reassurance to passengers concerned about personal safety.
- **Cultural and religious sensitivity**: Systems should be designed to accommodate diverse backgrounds, offering multilingual support and culturally appropriate communication methods.

Conclusion

This study highlights the unique challenges individuals with protected characteristics—such as disabilities, gender, age, and cultural or religious identities—face during emergencies in self-driving taxis. These challenges present opportunities to innovate and collaborate with industry to ensure APS are safe, inclusive, and adaptable to diverse user needs. The study aimed to identify emergency tasks passengers may need to perform, determine when support is most needed, and propose inclusive design considerations. Findings suggest that adaptive HMIs, robust communication systems, and proactive emergency planning can enhance safety and trust in APS. Without a driver, the responsibility for safety shifts to passengers and automated systems, requiring user-centred solutions.

This shift creates an opportunity to rethink how support is provided. Automated systems must take on a more proactive role, ensuring equitable responses to physical, cognitive, and emotional challenges. As the APS sector evolves under the Automated Vehicle Act 2024, collaboration with industry stakeholders will be essential. Engaging user groups, transport operators, and technology providers will help integrate inclusivity into self-driving taxi services, improving safety and accessibility while setting a new standard for user-centred innovation. Using VR simulations, this study explored emergency scenarios in a controlled yet realistic setting, identifying safety and accessibility needs before widespread deployment. By incorporating voices often overlooked in transport planning—such as those of disabled, neurodivergent, and faith-based users—the study underscores the importance of inclusive design. These insights provide a foundation for refining APS development, ensuring self-driving taxis are equitable, trusted, and responsive to the needs of all passengers.

References

Department for Transport. (2019). The Inclusive Transport Strategy: Achieving Equal Access for Disabled People. Retrieved from https://www.gov.uk/government/publications/inclusive-transport-strategy/the-inclusive-transport-strategy-achieving-equal-access-for-disabled-people

Equality Act. (2010). Available at: https://www.legislation.gov.uk/ukpga/2010/15/contents

Low, R. (2020). Barriers and enablers for visually impaired passengers in transportation systems. Disability and Society Journal, 35(4), 510–525.

Mackett, R. (2017). Travel challenges faced by individuals with cognitive and behavioural impairments. Journal of Transport Accessibility, 29(1), 15–32.

Millonig, A., & Fröhlich, P. (2018). Addressing accessibility challenges in autonomous transport systems. Transportation Research Part A, 113, 20–33.

Schräder, F. (2019). The role of dependents in autonomous vehicle interactions. Journal of Transportation and Dependents, 10(4), 250–270.

Schiebinger, L. (2014). *Gendered Innovations: How Gender Analysis Contributes to Research*. Stanford University Press.