User requirements to enable passengers of automated passenger services (APS) to perform journey tasks during emergencies

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This report has been prepared by **Lacuna Agency**, a strategic insights agency serving clients in public sector, automotive, luxury, and sport. We combine scientific techniques with evidence-based practices to design innovative research for hard-to-reach or difficult to-study audiences. Our work also extends to the broader mobility and transport sectors, where we assist governments, manufacturers and network providers in planning for emerging transport needs.

Executive Summary

Background to the project

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 & 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. The complexity of these tasks may vary based on individual passenger needs, capabilities, and age.

The Equality Act 2010[1] 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.[2]
- 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.

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 recognizing 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

[1] https://www.legislation.gov.uk/ukpga/2010/15/contents

[2] While primarily relevant to employment contexts, this protected characteristic was included in the research just in case it held any significance.

automated systems, traditional support tasks, like boarding and exiting, would need to be automated to ensure accessibility (Low, 2020; Millonig & Fröhlich, 2018).

In traditional taxis, human drivers may address specific requirements for individuals with certain protected characteristics during emergencies, such as assisting passengers with mobility impairments, ensuring safe evacuation for wheelchair users, or supporting pregnant passengers. For older adults, a taxi driver may provide reassurance or additional physical assistance, or 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.

In the context of self-driving taxis, the absence of a driver raises critical questions about how the needs of individuals with protected characteristics will be met. The potential for discrimination, whether through inaccessible design or failure to account for diverse requirements, must be carefully evaluated. The absence of a driver increases users' vulnerability, especially during emergencies, raising concerns about manual controls, emergency stop features, and communication with remote authorities (Pigeon, 2021). The combined effects of multiple protected characteristics, such as physical disability with age-related mobility issues, exacerbate challenges and make transportation even more difficult for affected individuals (DfT, 2020b). As self-driving technology develops, it is essential to integrate the Act's principles to meet the needs of diverse user groups, particularly those with protected characteristics. These legal protections offer a framework for designing and deploying self-driving taxis that are safe, accessible, and equitable for all.

While there is some knowledge about general user interactions with APS, a critical gap remains in the development of established guidance to inform vehicle and service design for scenarios involving emergencies during the use of these services. This project seeks to fill these knowledge gaps through a human factors and ergonomics approach to investigate user tasks and vehicle interactions during emergency scenarios and their associated requirements. This 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.

Brief and project aims

This project aimed to explore how users' protected characteristics, as defined by the Equality Act 2010, influence passenger experiences during emergencies, and identify diverse user needs to support passenger safety in emergency situations.
Findings from this work will help the Department for Transport (DfT) and CCAV to understand under what circumstances users of APS are most likely to need support to perform tasks that are required in the event of an emergency, which will help with decisions over the level of support that will be mandatory for APS operators to provide.

The objectives of this project were designed to guide the understanding and resolution of the key challenges faced by end-users, particularly those with protected characteristics, in emergency scenarios. These objectives were:

- to identify tasks that may have to be performed by users during emergencies and consider their needs for performing these tasks,

- to conduct a task analysis of what tasks might be involved in this process, to identify where responsibilities lie and, where relevant, the interfaces which will facilitate these processes, and
- to develop qualitative understanding of diverse user experiences (cognitive, behavioural, emotional responses) during these tasks.

To achieve these objectives, Lacuna Agency worked in partnership with Loughborough University, combining expertise in Human Factors research and virtual reality (VR) simulations. The project used a VR approach to closely replicate real-life emergency scenarios in a self-driving taxi to prompt diverse participants to consider what tasks they would need to do and their needs for achieving them. This collaboration, together with DfT and CCAV aimed to provide evidence-based insights to inform emergency accessibility protocols whilst also contributing to a framework of differentiated support mechanisms for users with different abilities and journey purposes. This project represents a novel methodology in the field of transport research, leveraging advanced VR simulations to generate user insights in an innovative and highly immersive way.

Method

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 participants 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.

Set up and procedure

The qualitative testing for this study took place in the User-Centred Design (UCD) Lab at Loughborough University. This lab was equipped to facilitate both in-person and VR sessions, where participants could share a virtual self-driving taxi experience and then discuss their reactions in a focus group. The aim was to combine immersive VR experiences with traditional group discussions to gather insights into participants' responses to emergency scenarios in self-driving vehicles.

Each participant was assigned a seat in the physical environment, and the seating was clearly marked with mats corresponding to their avatar colours in the virtual environment (red, green, blue, purple). The moderator’s chair was positioned outside the virtual ‘car’ setup to mirror their virtual avatar’s location seated inside the vehicle. The moderator was present in both the physical and virtual world to guide participants through the experience and facilitate the discussions afterward.

For social VR sessions, four participants were present in the room at once. Each participant had a dedicated "guardian square" to keep them within the designated safe area during the VR experience. Research assistants helped participants with headset preparation and left the room once participants were set up, to allow participants to engage in the experience without distraction. In solo sessions, only the participant and the moderator were present.

Participants then went through a brief VR practice session to familiarise themselves with the controls and environment. Each participant experienced three emergency scenarios in the virtual self-driving taxi, lasting 10-15 seconds. They were encouraged to vocalise their thoughts and actions as they engaged with the VR environment. The scenarios were repeated to ensure participants had sufficient time to engage fully

During the VR experience, the moderator prompted participants to reflect on their actions and decisions, encouraging them to consider how their protected characteristics influenced their responses. If any participant experienced discomfort, they were given the option to switch to a television screen instead of the headset or to end the study early while still receiving full payment.

After the VR simulation, participants engaged in a post-VR discussion, either in focus groups (social VR) or with the moderator individually (solo VR). The group discussions allowed participants to share their reactions and provide insights on how they interacted with the technology. In the social VR setup, participants were encouraged to respond to each other's comments, offering a deeper understanding of the diverse needs and experiences of different users. The moderator also prompted participants to consider how the absence of a driver affected their ability to manage emergencies and the types of features they would expect from self-driving taxi services.

Results and analysis

Each of the six emergency scenarios was individually examined through task analysis, focusing on the series of actions, thoughts, and system interactions required by passengers during emergencies in self-driving taxis. Whether participants could complete these tasks independently or if additional features were needed to support them was investigated. The data gathered from interviews and focus groups highlighted key emotional, cognitive, and behavioural responses, providing insights into the challenges passengers face in such situations. The analysis also explored how individual protected characteristics, such as age, disability, and cognitive impairments, influence the ability to manage tasks during emergencies in the absence of a driver. Some challenges were common across all users and scenarios, while others were specific to certain emergency situations. The report also examined how multiple protected characteristics intersect to create unique barriers for users.

A master task framework was developed that outlines the key tasks that users must perform during emergencies in self-driving taxis, where the absence of a driver fundamentally shifts responsibilities to automated systems and the passengers themselves. The key stages of emergency interaction were:

#1 Awareness and recognition: The first stage focuses on users' ability to detect and understand potential issues. In traditional taxis, passengers rely on the driver's judgment to recognise and respond to emergencies. The driver is responsible for assessing the situation, deciding whether to contact emergency services, and taking any necessary actions, such as pulling over to a safe location or providing reassurance to passengers. Emergency alerts, such as flashing lights, sirens, or verbal cues, are typically provided by the driver, and the passenger's role is often passive. In the absence of a driver, passengers must rely entirely on system-provided alerts, such as audio cues, visual notifications, or other sensory signals, to identify risks. Automated systems play a crucial role in providing clear, timely, and accessible notifications to all users, ensuring that those with sensory impairments or cognitive challenges can understand the situation.

#2 Assess the situation: The second stage involves evaluating the severity of the issue and identifying immediate risks to safety. In traditional taxis, the driver is responsible for quickly assessing the situation during an emergency, whether it involves calling emergency services, taking immediate action to avoid further harm, or providing guidance and reassurance to passengers. For example, in a medical emergency, the taxi driver would assess the severity of the situation and respond accordingly, either by calling emergency services or ensuring that the passenger remains calm until help arrives.

In a self-driving taxi, this responsibility shifts to the user. Without a driver to interpret the environment or guide passengers, users depend on the system's ability to provide contextual guidance. For example, passengers may need to assess hazards like fire, flooding, or external threats based on system notifications. This stage is critical for determining the urgency of the situation and deciding on appropriate next steps.

#3 Decision making: In the decision-making stage, users must choose how to respond to the emergency. In traditional taxis, passengers generally defer to the driver’s expertise when deciding how to respond in an emergency. The driver makes critical decisions, such as whether to pull over, how to communicate with emergency services, and whether the passenger should stay in the vehicle or evacuate. Passengers are often passive participants in these decisions, following the driver's instructions.

In a self-driving taxi, passengers must make these decisions independently or with support from the vehicle’s system. System features that help passengers make informed decisions could be introduced: for instance, emergency stop buttons (E-Stop), door overrides, and clear exit strategies could guide users during emergencies. This presents an opportunity to explore how adaptive controls, and accessible interfaces can be integrated to assist passengers with varying levels of ability and experience. As these technologies develop, there is an opportunity to fine-tune the interaction between the system and passengers, ensuring that decision-making is as intuitive and supportive as possible for a diverse range of users.

#4 System interaction: This stage highlights the need for passengers to engage with system features to execute their decisions. In traditional taxis, passengers rarely need to interact with the vehicle’s systems during an emergency. The driver typically manages all aspects of the situation, including controlling the vehicle, accessing communication tools, and activating emergency features such as door locks or stop buttons.

In self-driving taxis, however, users will be responsible for interacting with the system directly to manage the emergency. This could include tasks such as activating emergency stop buttons, using voice commands, or accessing manual overrides for doors and other systems. System interfaces could be made user-friendly and adaptable to ensure that all passengers can interact with the system easily, regardless of their abilities. This could involve developing adaptive controls, such as voice-activated systems or tactile feedback for users with mobility or sensory impairments. As the technology matures, these system interfaces can be tested and refined to improve accessibility and usability for a broader range of passengers.

#5 Communication: Communication is another critical stage, where users must inform relevant parties—such as operators, pedestrians, or emergency services—about the situation. In traditional taxis, the driver acts as the intermediary between passengers and external parties. In an emergency, the driver typically makes the call to emergency services and communicates with others, either verbally or through gestures. The driver may also reassure the passenger, offering support and guidance throughout the process.

In self-driving taxis, the communication responsibilities shift to the user, who may need to interact directly with emergency services, other passengers, or external parties. Robust communication tools, such as intercoms, pre-recorded messages, or operator support systems, will be required to ensure passengers can effectively communicate during emergencies. Multilingual options and accessibility features could be added to enhance the inclusivity of communication systems. These features compensate for the absence of a driver, who would typically facilitate such interactions but could also represent an enhancement in the taxi service for many users, making it a more appealing option than a traditional taxi service. This is an area where further development and testing are needed to ensure that communication systems can be made flexible and adaptive to the needs of all passengers, providing an effective means of interaction in a variety of emergency scenarios.

#6 Post-incident actions: Finally, the post-incident actions stage focuses on how passengers manage the aftermath of an emergency. After an emergency, traditional taxi passengers typically rely on the driver to manage follow-up actions, such as arranging alternative transport, contacting insurance, or receiving post-incident support. The driver may also provide emotional support, ensuring that passengers feel reassured and supported during the aftermath of the emergency.

In a self-driving taxi, however, users will need to manage these post-incident actions on their own or with support from the system. Tasks such as continuing the journey, arranging alternative transport, or accessing follow-up support require seamless system integration. Features like live operator assistance and automated tools would help users navigate these processes, ensuring that they feel supported even after the immediate emergency is resolved. As the technology develops, there is potential for more dynamic solutions to be integrated into self-driving systems, offering tailored assistance to passengers based on their individual needs. For example, real-time updates could be delivered in a format most accessible to the user, such as voice-guided systems for visually impaired users or simple text updates for users with cognitive impairments.

The study also identified several critical needs for passengers during emergencies in self-driving taxis, ranked below based on their importance across different protected characteristics. The most common needs included:

- Clear and accessible communication of the emergency situation, such as audio-visual alerts and structured interface messages.
- Safe and accessible methods for exiting the vehicle, such as emergency stop buttons, manual door overrides, and ramps.
- Guidance on interacting with external parties, such as pedestrians and emergency services, using intercoms or pre-recorded messages.
- Emotional support through calm, structured notifications and access to live operators.
- Accessible systems for reporting incidents and seeking help, including intercom systems with subtitles or voice-based assistance.
- Real-time updates on onward travel or alternative transport options, with accessible navigation apps.
- Proactive hazard detection and mitigation systems, such as fire, flooding, and collision sensors, which initiate safety protocols.
- Cultural or religious sensitivity in emergency protocols, ensuring that communication is tailored to diverse needs, including multilingual support and gender-sensitive communication.

These needs reflect a broad range of requirements to ensure safety and inclusivity during emergencies in self-driving taxis, with particular attention given to accessibility for users with sensory impairments, physical disabilities, and cognitive or emotional challenges.

Key findings

The findings provide valuable insights into the barriers faced by users during emergencies, particularly those from groups more likely to experience vulnerability or exclusion. The absence of a driver in self-driving taxi services creates unique challenges for users related to their protected characteristics if there is an emergency during the journey. Without a driver to provide guidance, mediate interactions, or offer physical support, passengers must rely entirely on automated systems and interfaces. A key observation is that individuals with disabilities, older adults, and younger passengers are most likely to face significant challenges in completing emergency tasks due to physical, cognitive, or sensory limitations. However, feelings of personal safety, shaped by factors such as race, religious beliefs, gender, or sexual orientation, also play a critical role in how individuals perceive and approach emergency situations. For example, fears of prejudice or misjudgement may interfere with some users' willingness to seek help or take necessary actions.

The overall goal of this study was to identify tasks that passengers may need to perform during emergencies and consider their needs for accomplishing these tasks related to their protected characteristics. The findings suggest that inclusive design—through personalised, adaptive HMIs, robust communication systems, and proactive emergency planning—offers significant opportunities to improve passenger safety and trust. Specific findings related to the individual protected characteristics across all the scenarios included:

Disability: The absence of a driver removes the immediate assistance often required by users with disabilities. Physical impairments necessitate automated door unlocking, reliable ramps, and clear evacuation paths to compensate for the lack of human intervention during emergencies. Vision-impaired users, who might rely on a driver for situational context, require voice-guided navigation and audible alerts. Hearing-impaired users, without the option of verbal interaction, depend on visual aids and real-time updates. For neurodivergent passengers, the lack of a driver to provide calming guidance intensifies the need for structured, intuitive systems that minimise overstimulation.

Sex: The lack of a driver heightens feelings of vulnerability, particularly for female and non-binary passengers. Automated systems could replace the protective presence of a human driver through features such as panic buttons, alternative exits, and live operator support. Male passengers, who might otherwise rely on a driver to mediate interactions, highlighted the need for transparent monitoring systems, like CCTV and audio recording, to ensure accountability and avoid misinterpretation during interactions.

Sexual orientation: For LGBTQIA+ passengers, the absence of a driver to deter harassment or bias increases reliance on high-quality CCTV and live operator support to ensure safety in high-risk scenarios. Automated systems that detect and mitigate discriminatory behaviour could be used to replace the reassurance a driver might provide, ensuring fair treatment and equitable emergency responses.

Religion: Without a driver to mediate or support passengers in emergencies, visible safety features like CCTV become critical for deterring prejudice and ensuring accountability, particularly for individuals with identifiable religious markers. In faith-based contexts, the lack of a driver to offer situational clarity emphasises the importance of alternative exits and culturally sensitive communication systems.

Age: The absence of a driver impacted younger and older passengers most significantly. Younger passengers (8–17 years), who might look to a driver for reassurance or authority, require live operator connections and structured guidance to fill this gap. Older passengers (65+ years), who may depend on drivers for physical assistance, require accessible features like low-threshold doors, wide ramps, and tailored medical alerts to ensure safety without human support. Middle-aged passengers rely on clear, step-by-step system guidance to navigate emergencies effectively in the absence of a driver.

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

Race: Without a driver to mediate interactions, one passenger expressed increased anxiety about misjudgement or prejudice during emergencies. Real-time video and audio monitoring are essential for promoting fairness and accountability. Automated alerts and impartial instructions could take the place of driver intervention, ensuring inclusivity and reducing bias in high-pressure scenarios.

Gender reassignment: For transgender passengers, the absence of a driver removes a layer of safety that could deter harmful behaviours. Real-time video monitoring and live operator support could replace this protective role, offering reassurance and accountability. Pre-filled diversity profiles might be a way to provide responders with sensitive and tailored information to address emergencies appropriately, compensating for the lack of human understanding in self-driving taxis.

Marriage and civil partnership: This characteristic did not influence user needs directly, as the absence of a driver did not intersect meaningfully with this group's responses.

Digital exclusion: The absence of a driver amplified the challenges faced by digitally excluded passengers, who rely on traditional methods of communication and support. Manual buttons, physical intercoms, and simple navigation tools should compensate for the lack of human guidance. Live operator connections and non-digital options ensure these passengers can access help effectively during emergencies.

Conclusion

The absence of a human driver in self-driving taxis introduces unique challenges for users, particularly in emergencies where tasks typically managed by a driver must now be performed by the passengers themselves. The findings highlight that barriers faced during such scenarios are not only practical—rooted in physical, sensory, or cognitive limitations—but also shaped by passengers' perceptions of safety, often influenced by their protected characteristics. Individuals with disabilities, older adults, and younger passengers are most likely to encounter significant obstacles, while factors such as race, religious beliefs, gender, or sexual orientation can impact users' willingness to seek help or perform necessary actions.

The absence of a driver provides a distinctive opportunity to reimagine how support is offered during emergencies. Without the presence of a human figure to provide guidance or mediate interactions, automated systems will be required to take on a more proactive and dynamic role in addressing users' needs. This shift encourages a deeper exploration of how technology can create equitable and reliable systems that respond to physical, cognitive, and emotional challenges.

As the APS sector evolves and the implementation of the Automated Vehicle Act 2024 progresses, collaboration with industry stakeholders is crucial. By engaging with user groups, transport operators, and technology providers, these insights can inform the design of systems that integrate inclusivity into the core of self-driving taxi services. This approach not only enhances safety and accessibility but also sets a standard for user-centred innovation in emerging transport technologies.

By aligning design and service provision with the specific needs of diverse users, APS systems can ensure that all passengers, regardless of their characteristics or vulnerabilities, can navigate emergencies with confidence. This study provides a foundation for further collaboration with industry stakeholders to refine processes, develop innovative solutions, and embed inclusivity into the core of APS design and implementation.

This study employed an innovative approach using virtual reality (VR) simulations to examine emergency scenarios in the context of a newly emerging transport technology. By leveraging VR, it was possible to study self-driving taxi systems in a controlled yet realistic environment, enabling the identification of safety and accessibility needs ahead of widespread rollout. This method ensured that potential challenges could be addressed proactively, promoting systems that meet the needs of all passengers, including those with protected characteristics.

The inclusion of voices often overlooked in transport planning, such as those of individuals with disabilities, neurodivergent conditions, and gender or faith-based concerns, underscores the transport industry's commitment to inclusivity. This approach not only provided richer insights into user needs but also highlighted the importance of designing transport systems that consider the full diversity of their users. By integrating these perspectives, the study lays the groundwork for self-driving taxis to become a truly equitable and trusted mode of transport.

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Glossary of terms

Automated Passenger Service (APS)	A transportation service in which a vehicle operates independently, without the need for human control or monitoring during the journey. The vehicle's operation, including navigation and decision-making, is fully managed by its onboard systems. Crucially, APS applies to public transport or taxi services, where the user does not own the vehicle but uses it as part of a shared or on-demand mobility system. (Adapted from *Written Evidence Submitted by the Society of Motor Manufacturers and Traders (SMMT)*, 2018)
B-call	In the context of this study, an emergency button in the vehicle designed to call for roadside assistance in the event of a breakdown
Centre for Connected & Autonomous Vehicles (CCAV)	A joint government body shaping the safe and secure introduction of self-driving vehicles and services on UK roads
Department for Transport (DfT)	Oversees transportation policies and infrastructure in the UK.
E-call	In the context of this study, an emergency button in the vehicle designed to call 999 in the event of an emergency
E-stop	In the context of this study, the emergency button in the vehicle is designed to stop its operation immediately
Virtual Reality (VR)	A computer-generated simulation that immerses users in a three-dimensional environment, allowing them to interact with it as if it were real (Kardong-Edgren et al., 2019)

1. Introduction

1.1 Background to the project

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 & 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 passengers. Key tasks during emergencies may include contacting emergency services, communicating with the transport operator, and making evacuation decisions. The complexity of these tasks may vary based on individual passenger needs, capabilities, and age.

The Equality Act 2010[3] 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.
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- **Marriage and Civil Partnership**: Protects against discrimination based on marital status or civil partnership, but only in employment contexts.[4]
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- **Race**: Encompasses colour, nationality, and ethnic or national origins.

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- **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.

In the context of self-driving taxis, the absence of a driver raises critical questions about how the needs of individuals with protected characteristics will be met. The potential for discrimination, whether through inaccessible design or failure to account for diverse requirements, must be carefully evaluated. As self-driving technology develops, it is essential to integrate the Act's principles to meet the needs of diverse user groups, particularly those with protected characteristics. These legal protections offer a framework for designing and deploying self-driving taxis that are safe, accessible, and equitable for all.

While there is some knowledge about general user interactions with APS, a critical gap remains in the development of established guidance to inform vehicle and service design for scenarios involving emergencies during the use of these services. This project seeks to fill these knowledge gaps through a human factors and ergonomics approach to investigate user tasks and vehicle interactions during emergency scenarios and their associated requirements. This 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.

Summary

- The development of Automated Passenger Services (APS), such as self-driving taxi-like services, offers significant potential to improve mobility, accessibility, and safety, but inclusivity and emergency readiness remain underexplored areas.
- Emergency situations in APS shift responsibility to passengers as there is no human driver, requiring them to perform complex tasks such as contacting emergency services, communicating with operators, and making evacuation decisions—tasks influenced by individual capabilities and needs.

1.2 Definitions of automated vehicles

Automated vehicles (AVs) are classified by the Society of Automotive Engineers (SAE) into six levels, ranging from Level 0 (no automation) to Level 5 (full automation) (SAE

International, 2016). Levels 0 to 2 involves the driver's continuous control, with some assistance from advanced safety systems such as automatic braking. At SAE Levels 3-5, the autonomy increases gradually, with the vehicle capable of handling driving activities for brief periods at Level 3 to being capable of fulfilling all driving tasks at Level 5. The 'levels' of automation quickly became shorthand to communicate the shift from human driver to system control but lacked legal clarity.

In 2022, the Law Commission of England and Wales and the Scottish Law Commission released a report proposing a significant revision to the legal framework governing automated vehicles (The Law Commissions, 2022). The Department for Transport (DfT) and the Centre for Connected & Autonomous Vehicles (CCAV) no longer refer to 'levels' of self-driving, instead using the Law Commissions' definition of automation[5]. The joint report conducted a comprehensive review of the regulatory structure for automated vehicles on public roads and highways and introduced new legal entities and actors; the Authorised Self Driving Entity (ASDE), the No-User-in Charge (NUiC) and the No-User-in Charge Operator (NUiCO).

An ASDE is an organisation that puts the vehicle with self-driving (SD) features forward for authorisation (Law Commissions, 2022). The ASDE responsible for submitting an automated vehicle (AV) for authorisation with SD capabilities varies. It could be the vehicle manufacturer (for example Mercedes-Benz), a software designer (such as NVDIA), or a collaboration between both entities such as in the case of all automated driving functions in future Mercedes-Benz cars will be powered by NVIDIA's next generation DRIVE platform[6].

Certain SD vehicles may be approved for operation with what is referred to as "No User-In-Charge" (NUiC) capabilities. An example is an Automated Passenger Service (APS), also referred to as a self-driving taxi service (or in popular media 'robo-taxis'), which are able to complete entire journeys without human intervention, treating the human occupant purely as a user. These vehicles currently operate at high levels of automation within specific conditions or geofenced areas, equivalent to SAE Level 4 or above (HM Government, 2022). APS rely on advanced technologies, including artificial intelligence, machine learning, sensors, and real-time data processing, to navigate and perform driving tasks. In the UK, the Automated Vehicles Act 2024 provides a legal framework for APS, defining them as services that consist of carrying passengers in road vehicles designed or adapted to travel without a human driver, or used for trials aimed at developing such vehicles (Automated Vehicles Act, 2024).

When a NUiC feature is activated, the Law Commissions recommend that oversight of the vehicle be managed by a licensed NUiC Operator (NUiCO), which is typically an organisation rather than an individual (Law Commission of England and Wales & Scottish Law Commission, 2022b). An example of such an entity would be Waymo, which operates automated taxi services in the United States (see section 1.3).

The NUiCO is responsible for responding to vehicle alerts, maintaining and insuring the vehicle, ensuring safe operation, and managing other tasks like toll payments. The NUiCO may also need to liaise with law enforcement or emergency services as necessary (Law

[5] This report will exclusively use the Law Commission's definition but will refer to the equivalent SAE level in parentheses.

[6] https://group.mercedes-benz.com/innovation/product-innovation/autonomous-driving/mercedes-benz-and-nvidia-plan-cooperation.html

Commissions, 2022). The Joint Report (2022) highlights that during the activation of a NUiC feature, the NUiCO must maintain vigilance over the vehicle and be prepared to respond to alerts as needed. In the case of a self-driving taxi journey, a licensed NUiCO, should have general responsibility for the detection of, and response to, problems arising during the journey with oversight by an operator (Automated Vehicles Act, 2024).

Summary

- Vehicles are classified into six levels (0-5), with increasing autonomy from human driver control (Levels 0-2) to full automation (Level 5) ((SAE international, 2016).
- In 2022, the Law Commissions proposed replacing SAE levels with a new legal framework, defining key roles like ASDE, NUiC, and NUiCO (Law Commission, 2022).
- Automated Passenger Services (APS) operate without human drivers in geofenced areas, relying on advanced technologies and governed by the Automated Vehicles Act (2024).
- No-User-in-Charge Operators (NUiCOs) oversee vehicle alerts, maintenance, safety, and legal compliance during NUiC operation. In emergencies, an operator must be available to respond and ensure safety.

1.3 State of the art of Automated Passenger Services (APS)

The development of self-driving taxis has progressed significantly over the past decade, driven by advancements in artificial intelligence, sensor technologies, and regulatory frameworks. As of December 2024, several companies have initiated commercial deployments of self-driving taxis in the US and internationally:

- **Waymo**: Companies like Waymo, a subsidiary of Alphabet Inc., have been at the forefront of deploying Level 4 automated taxis (Lindzon, 2024). In 2023, Waymo expanded its operational territory in Phoenix, Arizona, claiming it as the world's largest fully automated service area. By 2024, Waymo extended its services to Los Angeles, covering areas from Santa Monica to downtown, excluding highways. Users can hail these automated vehicles via the Waymo app, with plans to introduce the service in Austin by 2025. The company reports an 85% reduction in injury-causing crashes over 7 million miles compared to traditional vehicles, highlighting the potential safety benefits of autonomous taxis. (Lindzon, 2024).
- **Cruise**: A subsidiary of General Motors, Cruise has been testing automated vehicles in San Francisco. However, the company faced setbacks, including a suspension of its operating permit following incidents involving its self-driving taxis. As of December 2024, Cruise announced that they would stop funding for their automated taxi services and focus its attention on personal passenger vehicles, citing the competitive market as its reason (Hoskins & Jamali, 2024).
- **Tesla**: Elon Musk unveiled the "Cybercab," a self-driving taxi without a steering wheel or pedals, with production expected to begin in 2026. This vehicle is projected to cost less than $30,000 and aims to operate both for private use and as part of a shared automated fleet. However, analysts express scepticism about the timeline, citing technological and regulatory challenges (Reuters, 2024).

In the UK, the development of APS is progressing through government-backed initiatives and private sector collaborations, focusing on integrating autonomous vehicles into complex urban environments. The UK government has committed up to £150 million in funding to support self-driving transport technologies through 2030, aiming to position the UK among world leaders in this sector (Centre for Connected & Autonomous Vehicles, 2023). Commentators have predicted that “robo-taxis’ could change the face of travel within the next 5 years (Scalise et al., 2018). The Department for Transport (DfT) has outlined a vision for self-driving vehicles which emphasises the need for a comprehensive regulatory, legislative, and safety framework to support the integration of automated vehicles into public transport systems (HM Government, 2022). Although they are not yet available for public use in the UK, there are trials underway to assess the feasibility of APS in urban settings with rigorous safety protocols in place, such as safety drivers.

One notable initiative is the ServCity project, a consortium including Nissan, the Connected Places Catapult, TRL, Hitachi, and the University of Nottingham. Launched in 2020 and concluded in 2023, ServCity aimed to develop a blueprint for deploying automated vehicle technologies in UK cities. The project involved over 1,600 autonomous test miles in London, addressing challenges such as vehicle-to-infrastructure communication and urban traffic navigation (TRL, 2024). Another significant development is the collaboration between Oxa, a UK-based automated vehicle software company, and eVersum to explore the use of automated vehicles for passenger transport and logistics. These efforts focus on controlled environments, contributing to the foundational work necessary for broader APS deployment in the UK (Oxa, 2023).

<u>Summary</u>

- Waymo operates in Phoenix and Los Angeles, claiming 85% fewer crashes, with plans for Austin in 2025 (Lindzon, 2024).
- Cruise halted operations of self-driving taxis in 2024 after safety concerns in San Francisco.
- Tesla announced the "Cybercab" for 2026, facing scepticism over readiness (Reuters, 2024).
- In the UK, the government pledged £150 million to self-driving tech but has no public APS deployments yet (HM Government, 2022).

1.4 Literature review

The Equality Act 2010 defines protected characteristics, including age, disability, gender reassignment, race, religion or belief, sex, and sexual orientation. Failure to accommodate the needs of individuals with these characteristics in transport systems can lead to inequitable access and compromised safety. This section reviews studies on the specific transport needs of individuals with protected characteristics, focusing on cognitive and sensory impairments, physical accessibility, and tailored safety measures. It first explores the challenges faced by these users and then examines practices proposed in research to address their needs.

Challenges faced in transport by users with protected characteristics

Mackett (2017) conducted a comprehensive investigation into the travel challenges faced by individuals with a range of cognitive and behavioural impairments. The study grouped these challenges into five broad categories: learning impairments (e.g., dyslexia), intellectual impairments (e.g., dementia), behavioural conditions (e.g., autism, ADHD), memory-related impairments (e.g., dementia), and mental health conditions (e.g., anxiety, agoraphobia, depression). Across all groups, recurring issues included anxiety, lack of confidence, overcrowding, and negative attitudes from other passengers. These challenges impacted individuals' ability to travel alone and use public transport, as well as how frequently they could travel overall. Those with cognitive and behavioural impairments in this study travel less frequently than the general population.

Schräder (2019) investigated the specific tasks that dependents, such as children and individuals with impairments, may struggle with when using automated vehicles. The study identified several key challenges, including difficulties in receiving information (e.g., due to decreased eyesight), limited cognitive competence (e.g., being very young or having age related cognitive impairments), and physical restrictions (e.g., impaired motor abilities or coordination). Dependents were often unable to perform essential tasks, such as recognising hazards, stowing luggage, or securing seatbelts, without external assistance.

Millonig and Fröhlich (2018) focused on accessibility challenges in automated systems, particularly for individuals with disabilities or mobility impairments. The study noted that in traditional transport systems, drivers often provided essential support for boarding and exiting vehicles. In APS, these tasks would need to be automated, raising concerns about the adequacy of current designs. The researchers highlighted the importance of inclusive design to address the needs of families with strollers, individuals with luggage, and passengers with mobility aids.

Low (2020) examined the barriers faced by visually-impaired passengers in accessing transportation systems. The study revealed that visually-impaired passengers often encountered difficulties in navigating vehicles safely and quickly, especially when obstacles were present or when vehicles stopped for short durations. Most participants relied on digital tools, such as mobile apps for journey planning, with very few using traditional resources like printed timetables. Visually-impaired passengers expressed a strong preference for maintaining independence in planning their journeys, reflecting a desire for tools that minimise reliance on external assistance.

Pigeon (2021) reviewed safety measures in self-driving vehicles, focusing on features like seatbelts, child safety seats, and emergency stop buttons. The study identified manual controls, such as stop buttons that open doors during emergencies, as critical for enhancing passenger feelings of safety. Participants also valued real-time communication with remote authorities, such as video assistance systems, which provided reassurance in high-stress scenarios. The study noted that the absence of a driver in self-driving vehicles often heightened passengers’ sense of vulnerability, particularly during emergencies or encounters with disruptive individuals. The research also highlighted gender differences in safety perceptions, with women expressing greater concerns about personal safety in self-driving vehicles compared to men.

The Department for Transport (DfT, 2020) has also highlighted the multifaceted nature of challenges faced by individuals with protected characteristics in transport systems. The report emphasises that protected characteristics are not mutually exclusive; many individuals possess multiple protected characteristics, resulting in overlapping challenges and opportunities. For example, a person with a physical disability may also experience age-related mobility issues or economic disadvantages, compounding the barriers they face in accessing transportation. These combined effects can amplify both positive and negative experiences, depending on the context and the specific interplay of characteristics.

Summary

- **Physical and cognitive barriers:** Individuals with cognitive and mobility impairments face difficulties with tasks such as recognising hazards, securing seatbelts, and stowing luggage, often requiring external assistance (Schräder, 2019; Millonig & Fröhlich, 2018).
- **Emotional and psychological challenges:** Anxiety, lack of confidence, and mental health conditions (e.g., depression, agoraphobia) hinder travel frequency and independence, particularly for individuals with cognitive and behavioural impairments (Mackett, 2017).
- **Accessibility issues:** Visually-impaired passengers struggle with navigating vehicles and rely heavily on digital tools for journey planning. In automated systems, traditional support tasks provided by drivers (e.g., boarding, exiting) need to be automated to ensure accessibility (Low, 2020; Millonig & Fröhlich, 2018).
- **Safety and vulnerability in automated vehicles:** The absence of a driver increases passengers' vulnerability, especially in emergencies, with concerns over manual controls, emergency stop features, and communication with remote authorities (Pigeon, 2021).
- **Overlapping challenges:** The combined effects of multiple protected characteristics, such as physical disability with age-related mobility issues, can amplify challenges, making transportation even more difficult for affected individuals (DfT, 2020).

Recommendations by research to support individuals with needs related to protected characteristics in transport

Mackett (2017) proposed several interventions to support individuals with cognitive and behavioural impairments. These included travel training programs to enhance skills and confidence, as well as special transport services like dial-a-ride for individuals requiring additional support. Simplifying the journey was identified as critical, with infrastructure recommendations such as making local environments more legible, improving parking provisions, and providing clear, inclusive pre-journey information. The study also emphasised the importance of support during the journey itself, through staff training, passenger assistance schemes, and technologies like mobile apps offering real-time navigation. Their findings underline the need for self-driving transport systems to proactively support individuals with cognitive and behavioural impairments by addressing both environmental and interpersonal barriers.

Schräder (2019) recommended in their research that dependents, such as children and individuals with impairments should have an accompanying individual to help in facilitating ingress tasks such as requesting the ride, managing luggage, ensuring the dependent's safety, and overseeing their interactions with the vehicle. At the destination, they ensured dependents exited safely and coordinated with others if the dependent required further care. These findings highlight the critical role of external support and the need for automated systems to incorporate features that address these limitations, such as automated doors, accessible seating, and hazard detection mechanisms.

Low (2020) identified consistency across the transport network was critical for visually-impaired passengers to navigate confidently. Features such as tactile paving and uniform interior layouts helped passengers develop mental maps, enabling safer and more efficient travel. Audio announcements were highlighted as a key feature, as they reduced anxiety and helped passengers locate their stops. The study recommended multiple, strategically placed audio outlets within vehicles to improve clarity and accessibility to overcome challenges which arose from environmental noise, such as traffic or crowded vehicles, which often made it difficult to hear these announcements.

Hallewell and Large (2022) explored the role of human-machine interfaces (HMIs) in enhancing user interactions with automated taxis. Using two distinct virtual reality (VR) environments, the study examined tasks associated with boarding, travelling, and exiting automated vehicles. In the first environment, participants interacted with a roadside scene featuring multiple self-driving taxis, while the second environment simulated an in-transit experience using a 360-degree video. Participants were encouraged to discuss potential HMI solutions and manipulate pre-selected 3D objects, such as touchscreens, keypads, and digital assistants, to envision design features. They concluded that spoken natural language interfaces (NLIs) were considered to be the most obvious, intuitive and accessible communication options to people without auditory impairments. Participants preferred combining speech with gestures to communicate non-critical instructions, such as "stop over there." The study also highlighted the importance of adaptability in HMI design, allowing passengers to personalise interfaces based on their preferences or needs. These findings point to the potential of HMIs to bridge accessibility gaps and enhance user acceptance of automated technologies.

The Department for Transport (DfT, 2020) report stresses that addressing these overlapping needs requires an intersectional approach to transport design and policy. The emerging findings suggest that future transport technologies must consider the interconnected effects of protected characteristics to avoid perpetuating inequalities. Millonig and Fröhlich (2018) recommend that transport systems should balance efficiency with inclusivity, ensuring equitable access for disadvantaged passengers. Pigeon (2021) recommends designing self-driving systems with clear safety protocols and reliable emergency measures to address the diverse needs of passengers. Designing systems that recognise and adapt to this complexity is critical for ensuring equitable access and fostering inclusive mobility solutions.

Catering equally to all individuals is essential for ensuring equitable and inclusive transport systems. The Equality Act 2010 mandates addressing diverse user requirements, but the introduction of self-driving taxis brings new challenges and uncertainties. Unlike traditional transport systems, where drivers play a key role in meeting passenger needs, self-driving taxis rely on automated systems, which may alter the nature of user requirements. Some existing needs may no longer be relevant, while new needs may emerge, particularly in emergency situations where the absence of a driver changes the dynamics of user support.

Summary

- Simplify journeys with clear, accessible information and support throughout, including staff training and real-time navigation apps (Mackett, 2017).
- Ensure dependents, such as children and those with impairments, have external assistance for tasks like boarding, luggage handling, and exit coordination (Schräder, 2019).
- Enhance consistency in transport networks for visually-impaired passengers, using tactile paving, audio announcements, and uniform layouts (Low, 2020).
- Design adaptable human-machine interfaces (HMIs) for automated taxis, allowing passengers to personalize communication methods (Hallewell & Large, 2022).
- Apply an intersectional approach in transport design to accommodate the diverse and overlapping needs of all users, ensuring equitable access to transport (DfT, 2020b; Millonig & Fröhlich, 2018).

Emergency protocols in traditional vs self-driving taxi services

In traditional taxi services, drivers are pivotal in managing emergencies, with established protocols in place to ensure passenger safety. Emergency management in traditional taxis relies heavily on the presence of a driver, who plays a critical role in ensuring passenger safety. For example, in the UK, taxi drivers are advised to follow specific guidelines depending on the nature of the emergency for example, taxi drivers are expected to call 999 in urgent situations both inside and outside the vehicle, such as medical emergencies or accidents. They are also encouraged to remain calm and communicate clearly with passengers (UK Government, 2023). In cases of personal safety threats, such as passenger altercations, drivers are advised to move to well-lit, populated areas, often monitored by CCTV. These measures provide an additional layer of security for both drivers and passengers (Greater Manchester Combined Authority, 2024). Disabled Persons Transport Advisory Committee have called for all taxi drivers to receive training to assist passengers with disabilities during emergencies. For instance, a taxi driver may need to get out and help evacuate a wheelchair user during a fire by using a ramp or other accessibility features (DPTAC, 2022). These measures would ensure compliance with the Equality Act 2010, which mandates reasonable adjustments to accommodate individuals with protected characteristics.

The management of emergencies in APS, particularly in fully automated taxis, is a critical area of focus. Without a driver, the responsibility for safety shifts entirely to the vehicle's systems and remote support teams. In the US, Waymo has implemented an emergency response protocol validated by TÜV SÜD, a German technical services provider. This protocol ensures that vehicles can identify emergency vehicles, yield appropriately, and respond to traffic signals issued by law enforcement. First responders are provided with tools to manually disable the automated system if necessary. This capability has been integrated into Waymo's design to account for unpredictable scenarios, such as road closures or accidents requiring human intervention (Hawkins, 2024). However, while TÜV SÜD validated Waymo's protocols, there is limited publicly available evidence on how these systems perform in highly dynamic and unstructured environments. In San Francisco, where Waymo operates extensively, reports have surfaced of robotaxis obstructing emergency response efforts. For instance, a Waymo vehicle allegedly blocked the path of a fire truck responding to an emergency, delaying its arrival (Simonite, 2024). Such incidents raise questions about the adaptability of emergency protocols to real-world scenarios.

To support these protocols, Waymo has trained over 15,000 emergency responders across 75 agencies in the US, equipping them with the knowledge to interact safely with highly automated vehicles (Waymo, 2024). Such programmes are essential for ensuring that emergency personnel can navigate the complexities of engaging with vehicles that lack human drivers. However, concerns remain regarding the variability in knowledge and experience across different agencies. Not all personnel will have undergone training, especially in locations where Waymo has recently expanded, which may hinder effective coordination during emergencies (Mobility Masterclass, 2024).

In the UK, emergency protocols for APS remain under development, with trials focused on understanding how systems respond to unexpected events. Projects like ServCity, a UK government-funded initiative, have included simulations of emergency situations, such as vehicle breakdowns and interactions with emergency services (TRL, 2023). These trials highlight the need for comprehensive frameworks to manage passenger safety, vehicle reliability, and communication with first responders. Public understanding of how to interact with automated vehicles during emergencies remains limited. Without widespread awareness campaigns, passengers and bystanders may not know how to safely engage with an APS in situations like a fire, collision, or medical emergency.

Key challenges in the UK include developing real-time communication channels between vehicles, passengers, and emergency services and addressing the needs of passengers with disabilities or other protected characteristics under the Equality Act 2010 in the event of an emergency without a driver present.

<u>Summary</u>

- Traditional taxis rely on drivers to manage emergencies, including calling emergency services and assisting passengers (Greater Manchester Combined Authority, 2024; DPTAC, 2022).
- In APS, vehicle systems and remote support handle emergencies, with no driver present to intervene (Hawkins, 2024).
- APS protocols, like Waymo's, enable automated responses to emergencies but have faced real-world issues, such as blocking emergency vehicles (Simonite, 2024; Waymo, 2024).
- Emergency responder training in the US has been implemented, but knowledge gaps remain across different agencies (Waymo, 2024; Mobility Masterclass, 2024).
- In the UK, APS emergency protocols are under development, with a focus on communication and accessibility for passengers with protected characteristics (TRL, 2023).

1.5 Task analysis research

Task analysis, as defined by Kieras and Butler (1997), is a systematic process that examines the tasks that users must perform to achieve their goals, breaking these down into cognitive and physical components. This method identifies the knowledge, skills, and tools required for task completion, providing a foundation for designing systems that are intuitive and user-centred. In the context of self-driving taxis, task analysis is critical for developing emergency response systems that cater to the needs of all passengers, particularly those with protected characteristics such as age, disability, or cognitive differences. By understanding how users interact with the system during emergencies, designers can ensure functionality supports effective task completion while enhancing safety and inclusivity. Given the diverse and overlapping needs associated with protected characteristics, it is vital to approach self-driving technology without preconceived assumptions. Allowing users to define their own needs ensures that future designs are grounded in real-world insights, fostering inclusivity and responsiveness in self-driving systems. This work aims to contribute to the development of transport systems that meet the broad spectrum of user requirements while adhering to the principles of equity and accessibility.

In any emergency scenario, passengers must first interpret the situation and decide how to respond. Task analysis systematically breaks down these actions into cognitive tasks—such as interpreting alerts and making decisions—and physical tasks—such as unlocking doors or using egress mechanisms. This breakdown helps identify potential barriers that passengers may encounter and informs the design of features that address these challenges.

The importance of designing systems that proactively manage emergencies has been explored in various fields. Ahmed and Demirel (2020) emphasised that task analysis combined with performance metrics can evaluate how individuals with diverse characteristics respond to emergencies including scenarios such as a fire in an aircraft cockpit. This approach enables systems to be tailored to meet users' unique needs. Their study showed emergencies involving smoke and fire lead to increased cognitive load and mental demand, with individuals adapting their posture and movement to complete tasks like reaching oxygen masks or kill switches. This finding highlights the need to minimise cognitive overload through intuitive design and improved system feedback, ensuring tasks can be performed effectively in challenging conditions. Their framework highlights the need to reduce cognitive overload through intuitive design and improved system feedback, principles that are directly applicable to self-driving taxis.

Loft, Tatasciore, and Visser (2023) discussed the interplay between workload, performance, and situational awareness in aviation systems, emphasising the importance of managing cognitive demands in high-pressure situations. Applying this to self-driving taxis, adopting a task analysis approach can help ensure that future passengers are provided with adequate support to maintain situational awareness and take appropriate actions during emergencies. For instance, automated alerts, clear egress options, and immediate connection to emergency services can empower passengers to respond effectively without undue stress.

Task analysis also informs iterative design processes. By identifying usability challenges during testing, designers can refine system functionality to better align with passenger needs. For example, Niu et al. (2023) applied task complexity analysis to automated metro systems, revealing how environmental factors and cognitive demands influence user behaviour in emergencies. These insights are equally relevant to self-driving taxis, where passengers may encounter similar challenges, such as interpreting system alerts or navigating emergency egress routes.

Moreover, task analysis can guide the selection of benchmark scenarios for user testing, ensuring systems are evaluated under realistic conditions. As Kieras and Butler (1997) noted, understanding user tasks at the design stage establishes the upper boundary of system usability. For self-driving taxis, this means designing emergency protocols that are not only technically robust but also user-centred, prioritising clear communication and accessible features.

<u>Summary</u>

- Task analysis helps identify the cognitive and physical actions users need to perform during emergencies, ensuring systems support user needs effectively. It is crucial for designing emergency systems in self-driving taxis, especially for passengers with protected characteristics like disability or age.
- By understanding user interactions during emergencies, designers can create more intuitive and inclusive systems.
- Task analysis informs the iterative design process, ensuring that emergency protocols are accessible and effective for a diverse range of passengers.

1.6 Brief and Project Aims

The emergence of self-driving technologies in public transport introduces challenges in emergency scenarios as the absence of a driver places greater responsibility on passengers. This project aimed to explore how protected characteristics, as defined by the Equality Act 2010, influence passenger experiences during emergencies, and identify diverse user needs to support passenger safety in emergency situations. The research was designed to understand the unique challenges posed by APS and their implications for passenger tasks, with a focus on inclusivity. By clarifying these tasks and responsibilities, this project aimed to provide insights that inform inclusive policies and frameworks for APS emergency management. Through task analysis, this research aims to systematically understand what passengers need to do during emergencies in self-driving taxis, breaking these actions into cognitive and physical components. Using task analysis will facilitate understanding of what people need to do during emergencies, how the different protected characteristics influence their perceived ability to achieve these tasks, and therefore what provisions need to be in place to support a diverse population to use APS in the future.

The objectives of this project were designed to guide the understanding and resolution of the key challenges faced by end-users, particularly those with protected characteristics, in emergency scenarios. These objectives were:

- to identify tasks that may have to be performed by users during emergencies and consider their needs for performing these tasks,

- to conduct a task analysis of what tasks might be involved in this process, to identify where responsibilities lie and, where relevant, the interfaces which will facilitate these processes, and
- to develop qualitative understanding of diverse user experiences (cognitive, behavioural, emotional responses) during these tasks.

To achieve these objectives, Lacuna Agency worked in partnership with Loughborough University, combining expertise in Human Factors research and VR simulations. The project used a VR approach to closely replicate real-life emergency scenarios in a self-driving taxi to prompt diverse participants to consider what tasks they would need to do and their needs for achieving them. This collaboration, together with DfT and CCAV aimed to provide evidence-based insights to inform emergency accessibility protocols whilst also contributing to a framework of differentiated support mechanisms for users with different abilities and journey purposes. The research particularly focused on individuals who fall under protected characteristics outlined in the Equality Act 2010, ensuring transport services are inclusive and accessible for everyone. This project represents a novel methodology in the field of transport research, leveraging advanced VR simulations to generate user insights in an innovative and highly immersive way.

2. Method

This study employed a qualitative research approach using focus groups supported by Virtual Reality (VR) simulations to explore user needs and behaviours in self-driving taxis during emergency scenarios. A quota sampling strategy was adopted to ensure representation across diverse participant demographics, with particular attention to individuals falling under the protected characteristics defined by the Equality Act 2010.

The research focused on six carefully designed emergency scenarios, each representing distinct types of emergencies, including internal (e.g., medical emergencies), external (e.g., vehicle collisions), environmental (e.g., flooding), and interpersonal situations (e.g., passenger altercations). These scenarios were developed in collaboration with stakeholders, ensuring they were realistic and reflective of potential challenges in automated passenger services.

By immersing participants in these VR simulations, the study elicited detailed feedback on the tasks passengers would need to perform during emergencies and their specific needs to achieve them. This innovative approach facilitated the generation of rich qualitative data, offering valuable insights into designing inclusive and effective emergency protocols for self-driving taxis.

2.1 Design

Apparatus

The virtual emergency scenarios were hosted on the open-source social VR platform, Mozilla Hubs Community Edition, which operates directly within a web browser. Two distinct models were developed to support the emergency scenarios. The first model represented a low-traffic neighbourhood, designed to emulate a tranquil residential setting with minimal vehicular movement, while the second depicted a bustling urbanised city environment, complete with dense architectural layouts and diverse traffic patterns. Both models were created in Autodesk Revit and once completed, the models were imported into Unreal Engine using the Datasmith plugin.

Pico 4 VR headsets were used throughout testing (not connected to a computer) with hand controllers used for gesturing but with control functions switched off. A high-performance laptop (64GB RAM and NVIDIA RTX 3080 GPU) was used to render complex scenes and run VR applications. The modelling and rendering of 360-degree videos in Unreal Engine were carried out on an Alienware m17 R4 gaming laptop. To further enhance the functionality and interactivity of the scenarios advanced features were implemented through blueprint visual scripting within Unreal Engine such as real-time changes in weather conditions (e.g. rain) and detailed character animations (e.g. pedestrians interacting with the emergency).

All scenarios were rendered in Unreal Engine as 360-degree videos and imported into Mozilla Hubs via Spoke as 360-degree video environments, which served as dynamic backgrounds. The car model and animated characters were the only objects imported into Hubs as GLB files. Within Hubs, once the avatars (participants) occupy the car models, the 360-degree video environment begins playback, creating the illusion of movement. This integration ensured that the car appeared to be in motion while the scenario unfolded, to achieve the desired level of immersion and functionality.

Audio elements for each scenario were designed to enhance the immersive experience. Environmental sounds, such as rainfall, street noise, and general city ambience, were created within Unreal Engine using blueprint scripting. Character-specific audio, such as the voice of the ‘unwell’ avatar, was produced using Eleven Labs, an AI-based voice generator. This tool was employed to create a gender-neutral avatar voice, providing inclusivity and adaptability for diverse user groups.

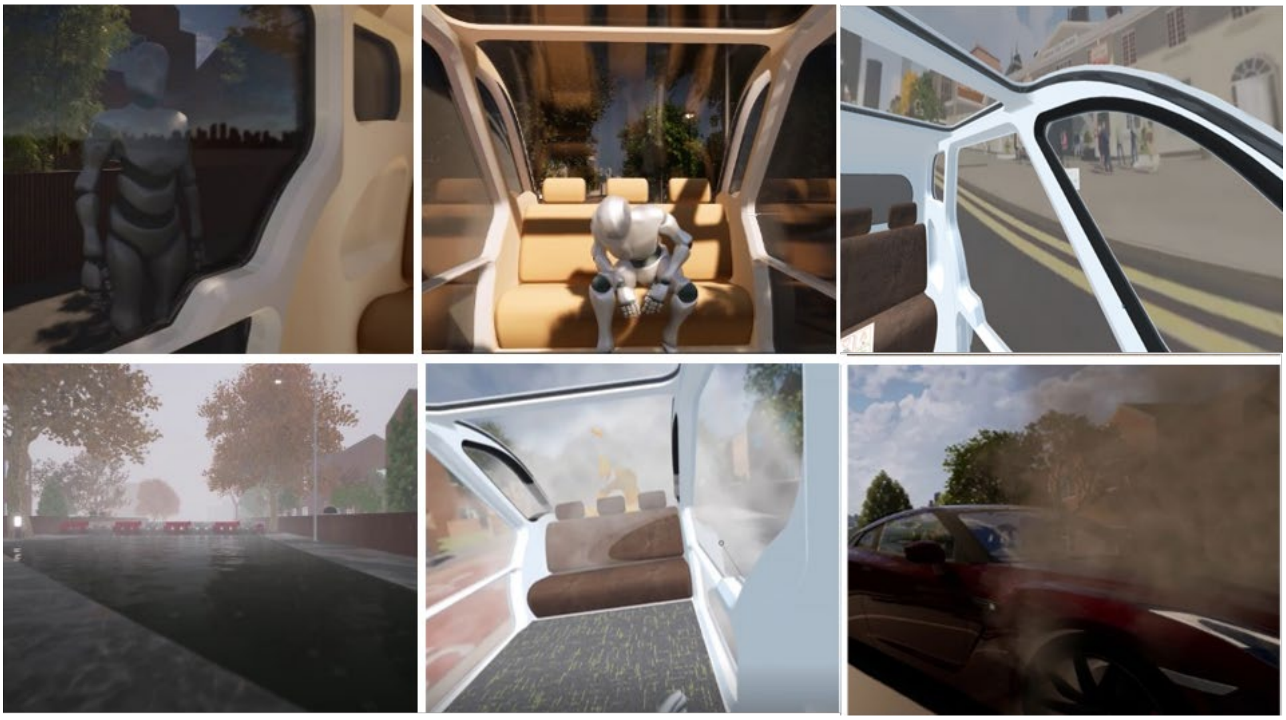
Scenario storyboarding

The study included six distinct emergency scenarios, each crafted to simulate a specific type of potential emergency within a self-driving taxi. These scenarios were designed to reflect a range of challenges passengers might face, spanning internal incidents (e.g., medical emergencies), external threats (e.g., collisions), environmental hazards (e.g., flooding), and interpersonal conflicts (e.g., passenger altercations). The scenarios aimed to capture both the practical and emotional responses of participants in situations where no human driver is present to manage the emergency.

The scenarios were developed in collaboration with CCAV through a workshop involving key stakeholders. This workshop sought to achieve consensus on the types of emergencies to prioritise, focusing on those deemed either common, probable, or of significant concern to potential users. By incorporating input from stakeholders, the scenarios were tailored to address both technical feasibility and user-centric considerations. The six scenarios are detailed in Table 1 with pictures of each scenario shown below.

Table 1 Description of the six emergency scenarios presented to participants via a VR headset

Scenario	Description of scenario	Type of Scenario
Pedestrian interaction	During the journey, a pedestrian attempts to open the taxi door at a red light.	External event involving a stranger/ potential threat/ interpersonal interaction
Medical emergency	Participants share the self-driving taxi with an unfamiliar passenger (a VR avatar) who becomes unwell during the journey.	Internal event with a stranger/ interpersonal interaction
Incorrect stopping point	Participants are travelling to the library. The self-driving taxi drives past the library and attempts to drop them off further away from the intended destination.	Location based error/ system issue
Road closure due to flooding	Participants are using a self-driving taxi in bad weather. During the journey, heavy flooding and a barricade force the taxi to stop.	External environmental threat
Fire or smoke emergency with door malfunction	Participants are heading home in a self-driving taxi. During the journey, the vehicle catches fire, producing smoke and flames, while the doors fail to open despite the vehicle stopping.	Internal environmental threat
Vehicle collision	Participants are travelling in heavy traffic. During the journey, the self-driving taxi is hit from behind by another vehicle while stopped at a red light.	Other road user error/ potential injury



Emergency scenarios shown in the VR headset. Top row: Left to right: ***Pedestrian interaction scenario, Medical emergency scenario, Incorrect stopping point scenario*****. Bottom row: left to right:** ***Road closure due to flooding scenario, Fire and smoke emergency with door malfunction scenario, Vehicle collision scenario*****.**

To help participants understand why the scenario they were about to experience in the virtual reality environment (VRE) was an emergency, a brief context for each scenario was given by the moderator prior to putting on the headset. Table 2 outlines the moderator script for each scenario.

Table 2 Description of each scenario given to participants during the study by the moderator

Scenario	Moderator Script
Pedestrian Interaction	*In this scenario, you have chosen to take a self-driving taxi to a destination of your choice. This is a trip just for you and no one else should be entering the vehicle at any point.*
Incorrect Stopping Point	*In this scenario, there is another passenger that you do not know in your self-driving taxi.*
Road Closure Due to Flooding	*In this scenario, you have chosen to go to the library. Your self-driving taxi will take you there and drop you outside the library.*
Medical Emergency	*In this scenario, you have chosen to take a self-driving taxi due to bad weather.*
Fire or Smoke Emergency with Door Malfunction	*While a self-driving taxi is moving, it is standard practice for the doors to be closed, with the 'door closed' sign illuminated. When it is stopped and the doors are ready to open, the 'door open' sign will illuminate.*
Vehicle Collision	*In this scenario, you are taking a self-driving taxi back to your home.*

Presentation of scenarios

Prolonged VR exposure can cause discomfort, fatigue, or overwhelm some individuals particularly those with protected characteristics such as neurodivergence or sensory impairments. Given this, and to ensure a meaningful but manageable experience for all participants, exposing participants to all six scenarios was deemed impractical. During piloting, it was decided that participants would experience three out of the six scenarios, selected randomly, to provide diverse exposure while avoiding cognitive or physical strain.

To ensure all scenarios were viewed equally, we grouped them based on their similarities. *Pedestrian interaction scenario* and *Medical emergency scenario* were paired as both are people-centred scenarios focused on human interaction and well-being. *Incorrect stopping point scenario* and *Road closure due to flooding scenario* were grouped together because they involve unplanned stops and the inconvenience or danger of exiting at the wrong place, highlighting their emergent nature. Lastly, *Fire or smoke emergency with door malfunction scenario* and *Vehicle collision scenario* were categorised together as they both represent extreme emergency situations that require immediate, critical action. After grouping, a rotation matrix was organised into 8 combinations rotated across participants. Appendix 7.1 shows the order of rotations relating to the specific scenarios.

Study Design

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.

- **Solo VR Testing:** This format simulated the experience of a single passenger travelling alone in a self-driving taxi. It explored how participants manage emergencies when they are solely responsible for decision-making and actions, such as contacting emergency services or attempting to resolve the issue themselves. This setup was designed to highlight the unique challenges of being alone in an emergency, including heightened feelings of vulnerability, independence, or self-reliance.

- **Social VR Testing:** In this format, four participants shared the self-driving taxi journey, represented as friends or family in the virtual environment. This setup replicated the dynamics of group travel, where multiple passengers may contribute to problem-solving during emergencies. It examined how group interactions, shared decision-making, and social support influence responses to crises. Social VR also provided insights into how individuals may react when their safety depends on or affects others in the vehicle.

By including both solo and social contexts, the study captured a comprehensive range of experiences, ensuring that the scenarios represented realistic situations passengers might encounter. This approach allowed for a deeper understanding of how different social dynamics influence emergency responses, providing valuable insights for designing inclusive and effective self-driving taxi services.

Stakeholder consultation on emergency scenarios and user groups

The workshop, held with stakeholders from key transport charities and organisations PAVE UK, Motability, Transport for All, and Veigel, aimed to inform the design of the study and gather feedback on the proposed VR scenarios. The stakeholders represented a diverse range of expertise, including passenger automated technology, transport for disabled users, minority users of transport, and adaptations for disabled drivers. All participants in the workshop had extensive experience working with diverse user groups in public transport. This variety of perspectives was invaluable in ensuring that the research design was inclusive and catered to the needs of individuals with different protected characteristics.

The workshop began by presenting the proposed flow of the study, followed by a review of the six emergency scenarios developed for the VR simulation. After each scenario, the group discussed the implications of the self-driving technology and its potential impact on individuals with protected characteristics, focusing particularly on accessibility and how the scenarios might affect different groups. The stakeholders' feedback played a crucial role in refining the study design to better reflect the needs of people with disabilities and other minority groups.

Overall, stakeholders found the study design to be positive but offered several suggestions for improvement. Their feedback focused primarily on accessibility and ensuring that participants with a wide range of disabilities and other protected characteristics were fully supported throughout the study.

Changes to study protocols and scenario design

Participant breaks and sensory needs: Stakeholders recommended providing more frequent breaks during the testing process to ensure participants were comfortable and to prevent fatigue. This was particularly important for neurodivergent participants, such as those with ADD/ADHD, who are more susceptible to overstimulation. In response, we incorporated scheduled breaks throughout the study to accommodate varying energy levels and prevent cognitive overload. A dedicated "chill-out" area was also created for participants to take time out if needed, and drinks and snacks were provided to help participants feel more settled during breaks.

For participants with sensory issues, we explained the study setup in advance and tailored the environment to their specific needs. Adjustments included dimming the lighting or reducing the number of research assistants in the room. We also allowed participants to have others leave the room during testing if that was more comfortable for them. These changes aimed to make the study environment as accommodating as possible, allowing participants to engage fully without feeling overstimulated or overwhelmed.

Acclimatisation to VR environment: Stakeholders also highlighted the importance of ensuring that participants felt comfortable before the scenario began, particularly those older participants who might feel anxious about using new technology. To address this, we introduced a practice session where participants could explore the virtual environment and practice using the controllers, by waving at the moderator inside the virtual world. We also limited the amount of effort participants needed to engage with the VR technology to get ‘into’ the virtual world. Research assistants were present in each session to assist with setting up the technology and ensure participants were in the correct position within the self-driving taxi simulation. Once the technology was ready, the headset was handed to the participants to place on their head, situating them perfectly inside the self-driving taxi, allowing them to focus on the scenario itself without worrying about the setup.

Additionally, we incorporated a feature that allowed participants to pause the scenario simply by lifting their headset. This change gave participants control over the experience, making them feel more comfortable if they needed to take a break or process the scenario. If they found the headset uncomfortable, they could also view the scenario on a large screen in the room, ensuring they could still participate without being forced to wear the headset.

Carer and support needs: Stakeholders suggested that participants with disabilities or special needs should be encouraged to bring carers for additional support during the sessions. We implemented this feedback by making it clear to recruiters that carers were welcome to assist participants throughout the process. This was particularly crucial for individuals with mobility impairments or cognitive disabilities who might require extra assistance to fully engage in the study. Some carers engaged in the study themselves in the social focus groups, whereas others just remained in the room in the chill-out area as a support person.

Wheelchair and mobility access: To accommodate physically-impaired users, we ensured the venue had lift access and rearranged the physical setup of the space so that participants in wheelchairs could remain in their seated positions during the study. This change helped create a more comfortable and accessible environment for wheelchair users, enabling them to participate without needing to transfer to a different seat.

Transportation and access to venue: Some stakeholders raised concerns about transportation barriers, particularly for participants with mobility impairments. To mitigate these issues, we assigned a dedicated Host role to assist participants with parking, guide them to the correct venue, and ensure they felt comfortable and prepared before the study began. This approach helped eliminate potential barriers related to travel, allowing participants to focus on the study itself.

We also provided detailed instructions on how to reach the venue, including pictures, maps, and parking instructions, to help participants navigate easily. This was particularly important for ensuring that participants with physical or cognitive impairments did not face unnecessary challenges when attending the study. For pregnant participants and those with children, we adapted the timing of the scenarios to provide more frequent breaks or flexibility in case they needed to attend to their children or got tired more quickly. Sessions were scheduled at various times throughout the day, including evenings and weekends, to accommodate participants with caregiving responsibilities.

Scenario-Specific Adjustments

Pedestrian interaction scenario: Stakeholders suggested making the avatar more accessible for individuals with visual impairments. Initially designed to be gender and race-neutral, the avatar's design was simplified to improve visibility. We adopted a high-contrast, robot-like silver body, making it easier for participants with low vision to see and identify the avatar.

Road closure due to flooding scenario: Feedback indicated that the background rain noise made it difficult for hearing-impaired participants to hear the moderator. In response, we gave participants the ability to adjust the background sound levels on their headsets or allowed a VR technician to do so manually, ensuring that participants could hear the moderator clearly and fully engage with the scenario.

Fire or smoke emergency with door malfunction scenario: This scenario raised concerns about psychological distress, particularly for people with neurodiverse disabilities such as ADHD. Stakeholders suggested simplifying the fire depiction to a cartoonish style to reduce potential distress for those with cognitive impairments. In response, we made the fire imagery less intense and more cartoon-like, and we also reduced the intensity of the sound effects to prevent overwhelming participants with sensory sensitivities. This adjustment aimed to make the scenario more manageable and less likely to induce anxiety or fear, particularly for those with emotional or psychological challenges.

Suggestions from stakeholders not adopted in the study

While the workshop provided valuable feedback, not all suggestions were incorporated into the study design. Some changes were not feasible due to logistical constraints, the study's focus, or technical limitations. One suggestion that we did not fully implement was to recruit participants from specific ethnic groups or focus more on cultural backgrounds and intersectionality. Although we understood the value of including diverse cultural backgrounds, logistical challenges in recruitment and the need to prioritise disability representation meant that we could not fully incorporate this approach.

In the *Fire or smoke emergency with door malfunction scenario*, stakeholders suggested delaying the fire's onset to reduce distress. While we acknowledged this concern, we felt that delaying the fire would reduce the immediacy and realism of the emergency, which was central to the study's goal of simulating real-life scenarios. However, we did adjust the visual and auditory elements to reduce potential distress. Stakeholders also suggested combining multiple emergency factors, such as road closures and vehicle malfunctions, we opted to keep the scenarios more focused. This allowed for more controlled testing and better understanding of specific responses to individual emergency events.

2.2 Participants

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.

People were selected representing the different protected characteristics related to the Equality Act 2010 (Age, Gender, Race, Religion, Sexual Orientation, Gender Reassignment, Marriage and Civil Partnership and Disability) balanced across the sample. 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). A full sample breakdown is shown in Table 3.

Table 3 A table presenting the breakdown of participant's protected characteristics in this study NB. Some participants did not answer all demographic questions or had multiple protected characteristics

Category	Subcategories	Frequency
Age	8-18 (children: 10) (11), 19-25 (10), 26-35 (18), 36-45 (16), 46-65 (26), 66+ (10)	91
Gender	Male (41), Female (48), Trans female (1), Non-binary (1)	91
Disability	Physical (10), Hearing (11), Vision (5), Speech (1), Neurodivergent (3), Learning Difficulties (3), Autism Spectrum Disorder (7), ADHD (10), Dyslexia (10), None (40)	100**
Race	White (65), Asian/Asian British (15), Black/Caribbean (7), Mixed (3), Other (1)	91
Religion	Christianity (31), Islam (5), Judaism (3), Hinduism (1), Buddhism (2), Sikhism (3), No religion (42), Other (4)	91
Sexual orientation	Heterosexual (68), Gay (6), Bisexual (4), Asexual (2), Other (1)	81*
Marital status	Single (20), In a relationship (23), Married/Civil Partnership (33), Separated (2), Divorced (3), Widowed (0)	81*
Pregnancy/maternity	Pregnant (4), Had child in the last year (5), Neither (80)	89***

*Child participants were not asked to complete these questions
**Some participants had more than one disability
***Two participants skipped this question

For some Social VR sessions, participants with similar protected characteristics were grouped together to encourage openness and comfort during discussions. This approach was based on the idea that individuals may feel more at ease sharing their experiences with others who have similar characteristics. For example, participants with physical impairments were invited to participate in testing sessions alongside others with similar experiences to promote a supportive and relatable environment. In some cases, for social VR sessions, participants were strangers, while others attended with friends or family members. Children were only invited to attend Social VR sessions and were required to take part in the same group as their parent/s.

To recruit a sample that reflected diverse protected characteristics, a combination of recruitment methods was used. These included accessing both internal and external recruitment panel databases, as well as engaging with local networks and communities. This approach ensured the inclusion of participants from various backgrounds, representing the full range of protected characteristics relevant to the study. Adult participants were compensated £70 cash and child participants given a £50 voucher for their travel and time, with the study taking approximately an hour to complete.

Sample restrictions

The participants were required to be capable of using public transport independently (or for children accompanied by a parent or carer) and feel comfortable using taxi-like services. While most participants were open to automated transport, we included 20% rejectors in the sample to avoid bias in the data. Additionally, a small sample of digitally excluded participants were included (i.e., those who do not regularly use smartphones or the internet), ensuring representation of those with limited access to technology, as well as those who do not use technology at all, to promote inclusivity and diversity in the data.

Participants were excluded from taking part in the study if they suffered from dementia or Alzheimer’s as there was potential that the virtual world could confuse them between what was simulated and what was reality which could cause them psychological distress. Individuals with previous trauma or experiences in emergency situations involving taxis were also excluded to prevent triggering past trauma or PTSD.

Additionally, participants were excluded if they had photosensitivity, such as epilepsy, or negative reactions to bright lights, as well as those with neurological disorders. Anyone currently taking medication that may impair cognitive function or reaction time was also excluded. Those affected by cyber sickness or motion sickness were informed they could complete the study using a laptop, although this option is considered less immersive and would be a last resort. Participants were also advised to refrain from attending the study if they were feeling unwell, as symptoms like a head cold or blocked nose can increase susceptibility to cyber sickness.

2.3 Ethics

The study was conducted in adherence to the ethical standards set by Loughborough University Ethics Committee to ensure participant safety, inclusivity, and data privacy. Comprehensive consent procedures were followed throughout the study. Informed consent forms were provided to all participants, along with parental consent for child participants, who also provided assent. Participants were fully informed about the study's purpose, processes, and any potential risks, and their right to withdraw from the study at any time was emphasised. To accommodate diverse needs, alternative formats for consent and study materials were made available, including verbal explanations and large-print documents.

In response to feedback, particular care was taken to ensure that participants felt comfortable before engaging with the virtual scenarios. To address potential concerns, a practice session was included to allow participants to acclimatise to the VR environment before the study scenarios began. Flexible scheduling and a dedicated "chill-out" area was provided to further enhance participant comfort. Participants were also given the option to adjust the study's environment (such as lighting and noise) to suit their sensory needs, and they were encouraged to bring carers for additional support.

The study design included several measures to protect participant privacy and ensure the secure handling of personal data. All data was anonymised, and personal identifiers were stored separately from the research data. No filming of participants in the real world occurred; avatars represented individuals in the virtual environment, with only voice recordings used for analysis purposes. Participants were informed that they could choose whether to allow their recordings to be used for dissemination purposes. Only anonymised and aggregated data was used in any reports or publications, in compliance with GDPR regulations.

To protect vulnerable participants, such as children or individuals with cognitive impairments, special consent procedures were followed. All children were accompanied by their parents or guardians during the study, ensuring continuous support. Screening measures ensured that participants were appropriately assessed for their ability to engage meaningfully with the study and provide informed consent. Comprehensive Level 1 safeguarding training was provided to all research staff, Level 3 training for safeguarding to the lead investigator who acted as the Designated Safeguarding Lead. Staff were also trained to recognise signs of distress and were equipped to provide support or refer participants to appropriate services if needed.

The study was designed to explore the needs and responses of participants in emergency scenarios. While the scenarios aimed to simulate real-world emergencies, all participants were regularly reminded of their right to pause or withdraw from the scenarios at any point. Adjustments were made to reduce potential distress, including simplifying the intensity of visual and auditory elements in some scenarios. Additionally, follow-up support was available to participants if they experienced any discomfort or anxiety, although all participants reported afterwards that they were happy to have taken part and did not require any further support.

All data collected in this study was securely stored and anonymised. Identifiable personal information was only held until the study was completed, at which point it was destroyed. Data was stored in accordance with university guidelines and archived for future research. The study was designed with the utmost respect for participants' dignity, privacy, and well-being, ensuring that their rights were protected throughout the process.

2.4 Procedure

Physical set-up and virtual reality environment (VRE)

The qualitative testing for this study took place in the User-Centred Design (UCD) Lab at Loughborough University. This lab was equipped to facilitate both in-person and virtual reality (VR) sessions, where participants could share a virtual self-driving taxi experience and then discuss their reactions in a focus group. The aim was to combine immersive VR experiences with traditional group discussions to gather insights into participants' responses to emergency scenarios in self-driving vehicles.

Each participant was assigned a seat in the physical environment, and the seating was clearly marked with mats corresponding to their avatar colours in the virtual environment (red, green, blue, purple). The moderator’s chair was positioned outside the virtual car setup to mirror their virtual avatar’s location. The moderator was both physically and virtually present to guide participants through the experience and facilitate the discussions afterward.

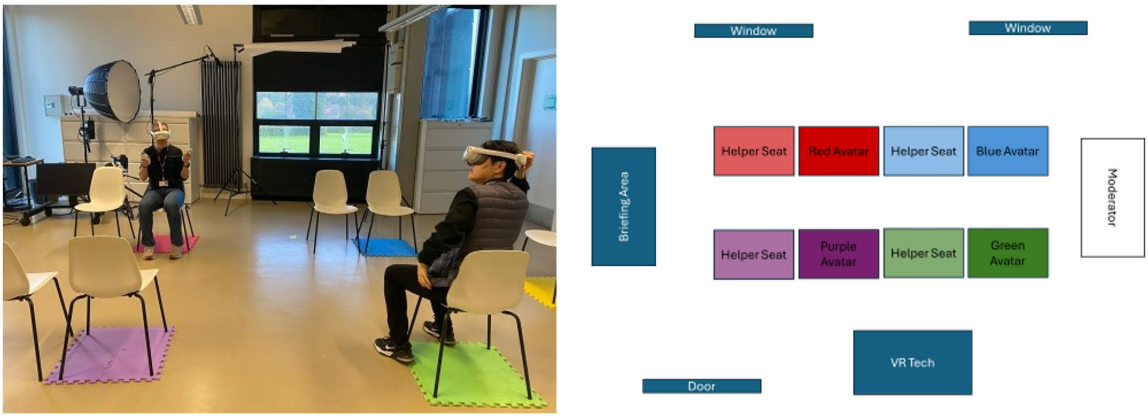
- **Social VR Sessions:** For social VR sessions, four participants were present in the room at once. Each participant had a dedicated "guardian square" to keep them within the designated safe area during the VR experience. Research assistants assisted participants with headset preparation, but once participants were set up, research assistants left the room to allow participants to engage in the experience without distraction.
- **Solo VR Sessions:** In solo sessions, only the participant and the moderator were present.

In the physical setup, each participant's chair was placed on a mat matching their avatar's colour, while the moderator’s chair was positioned on a rainbow-coloured mat. The fifth chair for the moderator was located outside the car setup to mirror the virtual environment. Additional chairs were available for the study team to assist participants. Participants were instructed to sit in a physical chair corresponding to the same seating orientation and colour as in the VRE. They were physically placed in the same positions in real life, as they would occupy when in the virtual vehicle, but space was left between the chairs for them to move their controllers/hands around without hitting anyone. The team ensured participants were seated correctly, selected the appropriate avatar in the start menu, and passed the headsets and controllers to the participant to put on.

A custom-designed home menu within Mozilla Hubs enabled research assistants to select their assigned avatar upon entering the virtual environment. This allowed participants to "jump" to the correct position corresponding to their seating in the taxi. The virtual self-driving taxi had four coloured avatars, each corresponding to a different participant's physical position, with the moderator appearing as a fifth avatar outside the vehicle. The images below show the set-up of the room and the home menu in Mozilla Hubs.

Focus group protocol

Welcome and safety briefing: The session started with the Host welcoming participants and introducing them to the research. They were informed that the study aimed to explore user experiences and needs during emergency scenarios in self-driving taxis, focusing on individuals with protected characteristics under the Equality Act 2010. The session lasted approximately one hour, including the VR simulation and post-simulation discussion. Participants were reminded that their responses would be confidential, and their involvement would be recorded for analysis. They signed an electronic consent form and completed a short questionnaire about their attitudes towards new transport technologies.



An image to show the physical setup; each participant's chair was placed on a mat matching their avatar's colour, while the moderator's chair was positioned on a yellow-coloured mat (right). The fifth chair for the moderator was located outside the car setup to mirror the virtual environment. Additional chairs were available for the study team to assist participants.

An image to show the different coloured avatars as well as the camera and moderator seated positions. From left to right top: Red avatar, moderator seat, blue avatar seat. From left to right bottom: Purple avatar sear, camera seat, green avatar seat.

Pre-VR Session Setup: Before entering the virtual environment, participants were briefed on the safety precautions, including the use of the guardian squares and staying seated during the VR experience to prevent accidents. The Host checked for any conditions that could cause VR-induced sickness, such as severe motion sickness, and participants were advised to remove the headset immediately if they felt unwell.

VR practice session: Before entering the virtual environment, participants were briefed on the safety precautions, including the use of the guardian squares and staying seated during the VR experience to prevent accidents. The Host checked for any conditions that could cause VR-induced sickness, such as severe motion sickness, and participants were advised to remove the headset immediately if they felt unwell.

VR simulation: Each participant experienced three different emergency scenarios in the virtual self-driving taxi. The moderator provided a brief explanation of the scenario before it began. The participants were encouraged to respond as they would in real life, vocalising their thoughts and actions as they engaged with the VR environment. The scenarios lasted approximately 10-15 seconds and were repeated to ensure participants had sufficient time to fully engage with the situation.

In-VR Reflection: While in the VRE, participants were prompted by the moderator to reflect on their actions and decisions in the scenario. The prompts were designed to allow participants to express their immediate reactions to the emergency scenario while being guided to think about their personal needs and how their protected characteristics influenced their responses (see Table 4 for moderator prompts). If any participant experienced VR-induced discomfort throughout the study, the study was paused, and they were given the option to continue using a television screen instead of wearing a headset or to finish the study early (and still receive full payment).

Post-VR in-person discussion: After the VR experience, participants removed their headsets and continued the discussion in-person either in focus groups (social VR) or with the moderator on their own (solo VR). The focus group allowed participants to share their experiences, compare their reactions, and provide deeper insights into the implications of the self-driving taxi technology. In the social VR setup, participants were encouraged to respond to each other's comments and reflect on the differences in their perspectives. This approach fostered discussion and helped the research team gain a better understanding of the diverse needs and responses from participants with varying backgrounds and characteristics. In addition to the in-VR prompts, the moderator encouraged participants to consider the absence of a driver and how this might affect their ability to manage emergency scenarios, as well as the features and communication methods they would expect from a self-driving taxi service (see Table 4 for moderator prompts).

Table 4 A table representing the prompts moderators used during the VR session

In-VR moderator prompts	In-person (post-VR) moderator prompts
What is happening in this scenario?	There is no driver/self-driving taxi, what's the implication of this scenario? What would you need to do to continue your journey?

Would you see this as an emergency?	Were there any things you thought the self-driving car should do for you?
What would you have to do in this situation?	How should it communicate that information with you? How should you communicate with the system?
Would you be able to do this independently?	
Thinking of your own protected characteristics, are any of these influencing your response to this emergency?	

Post-Simulation reflections: After all scenarios were completed, the Host took the participants back to the sofas in the briefing area and asked them to fill out a post-simulation questionnaire to provide additional feedback on their experiences and to assess their overall satisfaction with the VR and focus group session.

Conclusion and Debrief: The session concluded with the Host thanking participants for their involvement and organising the incentive payments.

Figure 1 shows the flow of the study protocol.

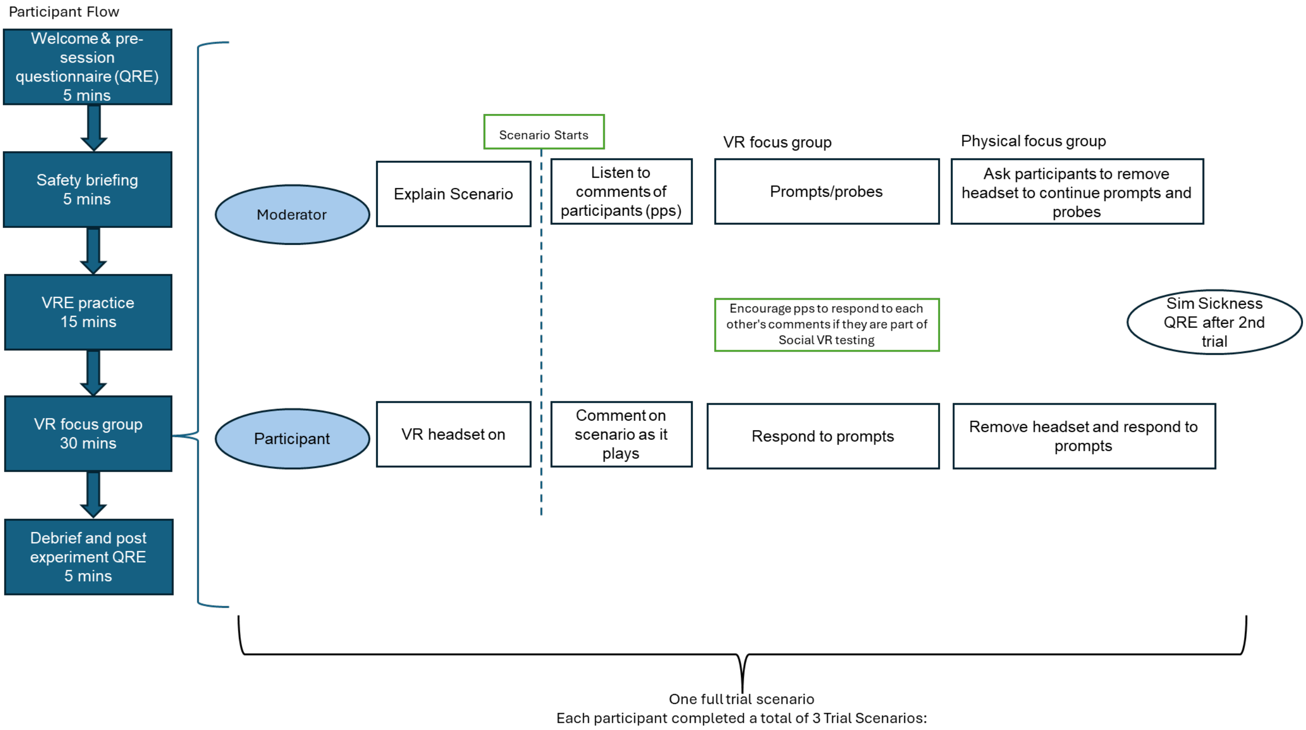


Figure 1 Overview of the research procedure. The image visually represents the sequence and timing of each phase in the study on the left, with boxes indicating the tasks and arrows showing the flow from one step to the next.

2.5 Data collection

The study gathered multiple types of data to address the research questions comprehensively:

1. **Demographic data**: Information about participants' protected characteristics, as defined by the Equality Act 2010, was gathered to explore the impact of these characteristics on their experiences. This data was matched against each participant's individual responses to the study.
2. **Pre-experiment feedback**: Participants completed a pre-experiment questionnaire, providing initial feedback on their openness to technology and entering details about their protected characteristics. This data was mainly quantitative, with qualitative insights from open-text responses. It was used to confirm that participants arrived for the correct session and were assigned to the appropriate group, as the study involved testing people with similar characteristics together.
3. **Focus group and solo interview data**: Qualitative data was collected during discussions and interviews, providing rich, in-depth insights into participants' thoughts, emotions, and behaviours in response to the scenarios.
4. **Scenario-specific observations**: Participant responses were collected for each of the six emergency scenarios, focusing on their task-related actions, cognitive thoughts, emotional reactions, and system expectations.

2.6 Analysis flow and validation

The data analysis process began with reviewing the recordings from the focus groups and solo interviews. These recordings were transcribed using CoLoop AI transcription software. To ensure clarity and accuracy, the transcripts were reviewed by two researchers, who cross-checked them for consistency and accuracy. A thematic content analysis was then conducted using a predefined codebook, which categorised participant responses according to their protected characteristics. The codebook also included categories for emotional, cognitive, and behavioural responses, with illustrative quotes linked to each scenario. Additionally, responses where participants indicated that their protected characteristic was not relevant were also documented as "non-relevant" responses.

A key component of the analysis involved scenario-specific task analysis, which aimed to develop a detailed understanding of the actions participants would take during emergency situations and the system requirements to support them. Each participant's responses were coded into sequential steps, outlining the flow of tasks (such as "first action," "second action," etc.), alongside their emotional and cognitive reactions to these tasks. In cases where multiple responses were possible, the overall frequency across the participants responses was recorded. The analysis also captured alternative actions at the same hierarchical level to reflect the variability in participants' behaviours during the emergency scenarios.

To ensure inter-rater reliability, the coding of data was conducted by four researchers, who independently coded the transcripts using the predefined codebook. A fifth researcher, who had not been involved in the study and was unaware of its aims, independently reviewed the data to further validate the coding process. This approach ensured the consistency and reliability of the coding process. After the initial coding was completed, the lead researcher reviewed all coded data to ensure it aligned with the study's objectives and aims.

The coded data, along with demographic information, was then collated to identify common tasks and user needs across all emergency scenarios. These common tasks were grouped based on similarity, and a table was created to summarise the user requirements needed to facilitate these actions. Themes and patterns that emerged across the scenarios were identified through iterative discussions among the research team. This process led to a comprehensive understanding of how participants' protected characteristics influenced their responses and what common user requirements emerged across the scenarios.

Finally, diagrams were created to visualise the task analysis for each scenario. These diagrams illustrated the series of actions, thoughts, and system interactions participants proposed for managing emergencies in a self-driving taxi. This visual representation helped to capture the flow of tasks and the various considerations that were important for participants' protected characteristics need in each emergency scenario. The analysis process can be seen in Figure 2.

Figure 2 This flow diagram shows the process of analysis. From left to right: Recordings of focus groups and solo interviews, Thematic content analysis, Scenario-specific task analysis, Overarching themes and patterns, Creation of visualisations of task analysis.

3. Analysis

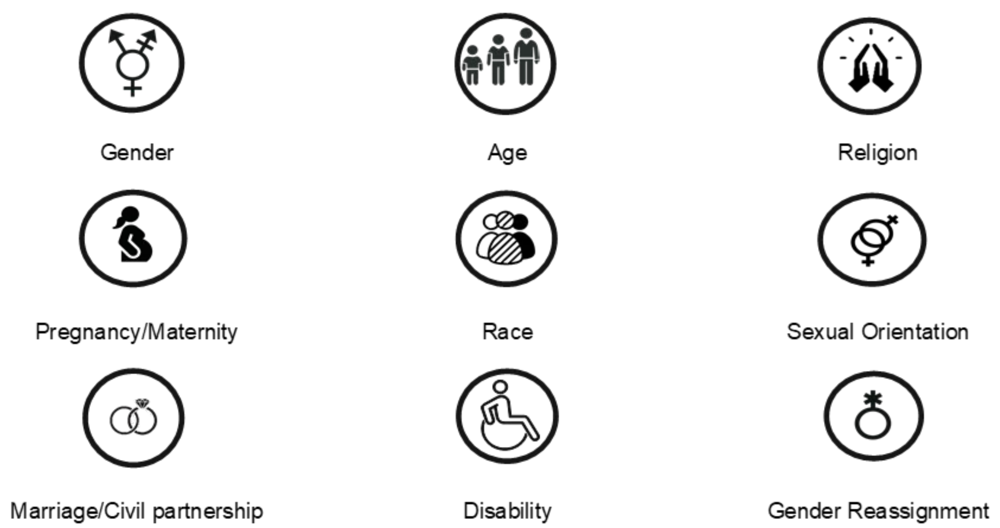
In this section, each of the six emergency scenarios is addressed individually through a task analysis. The task analysis captures the series of actions, thoughts, and system interactions participants proposed in the interviews and focus groups to manage the emergency scenarios showed via a virtual self-driving taxi simulation. This is accompanied by a detailed explanation of the coded data, highlighting participants' emotional, cognitive, and behavioural responses to the scenario. These analyses address whether participants were able to perform the required tasks independently or whether additional features or mechanisms would be necessary to support them.

This section also explores the key challenges individuals face when managing emergency tasks in self-driving taxis, where the absence of a driver plays a significant role in shaping user experiences. These challenges are influenced by passengers' protected characteristics, which can intersect to create unique barriers or amplify vulnerabilities. While some difficulties are common across all users and scenarios, others are specifically tied to particular emergency situations studied in this research. The analysis is supported by qualitative insights drawn from interviews and focus group discussions, offering a deeper understanding of user experiences.

Finally, having examined user needs within specific emergency scenarios, it is important to consider how overlapping characteristics influence broader patterns of experience. Section 3.3 highlights the role of intersectionality—how multiple protected characteristics, such as age, disability, gender, and religion, interact to shape challenges faced by users during emergencies. Identifying the tasks users must perform in emergencies and the barriers these characteristics introduce, pinpoints shared needs and opportunities for inclusive design.

3.1 Task analyses for emergency scenarios in self-driving taxi services

For each scenario, a diagram is provided to visualise the tasks participants needed to perform and the steps they followed. The diagram uses a coding system to interpret the flow of actions, thoughts, and system requirements: **yellow rectangles** represent user actions, **yellow hexagons** depict cognitive processes, **green lozenges** indicate system features needed to support users, **purple lozenges** highlight protected characteristic considerations accompanied by the relevant icon (shown in the image below), and **blue diamonds** signify onward journey options. If a step has been *inferred* but not directly mentioned by participants (for example, continuing the onward journey after exiting the vehicle) the connecting line is dashed. Each visualisation contains the coding key for simple interpretation. If a step was mentioned directly as impacting a particular protected characteristic, an icon denoting that protected characteristic was added next to it, to illustrate its relevance.



An image showing the icons used in the task analysis diagrams to indicate which protected characteristics are relevant to that step

Pedestrian interaction scenario

Scenario: A pedestrian is attempting to enter the self-driving taxi while it is stationary, and participants must decide how to handle the interaction.

Recognising the Presence of a Pedestrian: Users begin the process by recognising that someone is outside the vehicle, attempting to access it. This moment of awareness is critical as it initiates the decision-making process. For users with visual impairments, the system would need to provide an alert tone to indicate interference with the door, as they may not notice visual cues. Without this feature, these users could remain unaware of the situation. Recognising the pedestrian's presence triggers cognitive considerations about the person's intentions and whether they might pose a threat.

Understanding the Pedestrian's Intentions: Once the presence of the pedestrian is recognised, users focus on interpreting their behaviour. They may ask themselves questions such as: *"What is that person doing outside?"* or *"Do they look threatening?"*. This stage involves assessing whether the pedestrian's actions are harmless or potentially threatening. Without a driver to mediate or interpret the situation, users are required to make these assessments themselves. For visually-impaired users, voice-activated notifications describing the pedestrian's actions would be required, as visual observation is not possible. This cognitive process adds complexity and stress, as users would need to make safety-critical judgements independently.

Decision: Stay Inside or Exit the Vehicle

- ***Option 1: Stay Inside with Locked Doors* -** If users perceive the pedestrian as threatening or uncertain, they are likely to choose to remain inside and lock the doors. This action would require the system to provide a manual door-locking feature to allow users to secure themselves quickly. While remaining inside, users might question whether the pedestrian realises the vehicle is occupied, thinking: *"Do they assume this is their booking?"* or *"Should I let them know someone is inside?"*. Participants highlighted features that would assist in these scenarios, such as an illuminated "occupied" sign, a manual window control for direct communication, or an intercom to speak with the pedestrian without opening the door. These tools are particularly helpful for users who feel a moral obligation to clarify the situation or defuse potential misunderstandings. However, without these features, users—especially those who feel vulnerable—may experience heightened anxiety or a greater sense of risk.
- ***Option 2: Exit the Vehicle Safely* -** If remaining inside feels unsafe, users may choose to exit. For this option, the system would need to support safe egress by providing features such as an emergency door release. Physically-impaired users would require an assisted ramp to facilitate their exit. Participants, particularly female users, expressed the need for the opposite door to open to create distance from the pedestrian. This functionality allows users to control their exit path based on the context, offering them a greater sense of safety. These features are essential in situations where the absence of a driver removes the human element of guidance or assistance.

Post-Decision: Inform, report, and/or drive away

- **Inform the Pedestrian:** If the pedestrian's behaviour suggests confusion rather than hostility, users might choose to inform them that the vehicle is occupied. To achieve this, the system would need to include features such as an illuminated "occupied" sign, a manual window control for communication, or an intercom for safe verbal interaction. This step is especially important for users who feel a responsibility to avoid escalation or assist others. For users with specific impairments, these features would need to be tailored to their needs. For example, hearing-impaired users may require screen subtitles, while visually-impaired users would need voice guidance to operate the intercom. The absence of a driver makes these tools critical for ensuring effective communication and diffusing misunderstandings.
- **Report the Incident to an Operator:** If users feel unsafe or if the situation escalates, they might choose to report the incident to an operator. This action would require the vehicle to include a live intercom system for connecting with external assistance. Inclusive features are necessary here to address diverse needs, such as subtitled interfaces for hearing-impaired users or voice-activated systems for visually-impaired users. Participants with specific requirements, such as pregnant users, also emphasised the importance of operators being trained in inclusive communication to provide reassurance and guidance during stressful incidents. Without a driver, the system becomes the sole point of contact for help, making these features essential for passenger safety and confidence.
- **Instruct the Vehicle to Drive Away:** users might decide to avoid the interaction altogether by instructing the vehicle to drive away. This action would depend on the system offering an intuitive and accessible manual override. Participants with visual or hearing impairments noted the need for adaptive controls, such as voice commands or interfaces that are easy to navigate. This feature would provide users with a means of immediate escape, ensuring that they can quickly leave the situation when they feel threatened. The lack of a driver amplifies the importance of this functionality, as users rely entirely on the system to respond to their instructions.

Continuing the Journey or Seeking Alternative Mobility: After resolving the immediate situation, users face the decision of whether to continue their journey in the vehicle or seek alternative mobility options. If they choose to remain in the taxi, the system would need to enable a smooth transition back to normal operations to ensure users feel safe proceeding with their trip. Alternatively, users may choose to disembark and find another form of transport. Physically-impaired users, in particular, would require further assistance, such as ramps or connections to accessible mobility services. The system would need to accommodate these needs to support onward travel, regardless of whether users remain in the vehicle or opt for other solutions.

Figure 3 provides a visualisation of the task analysis steps for *Pedestrian interaction scenario*.

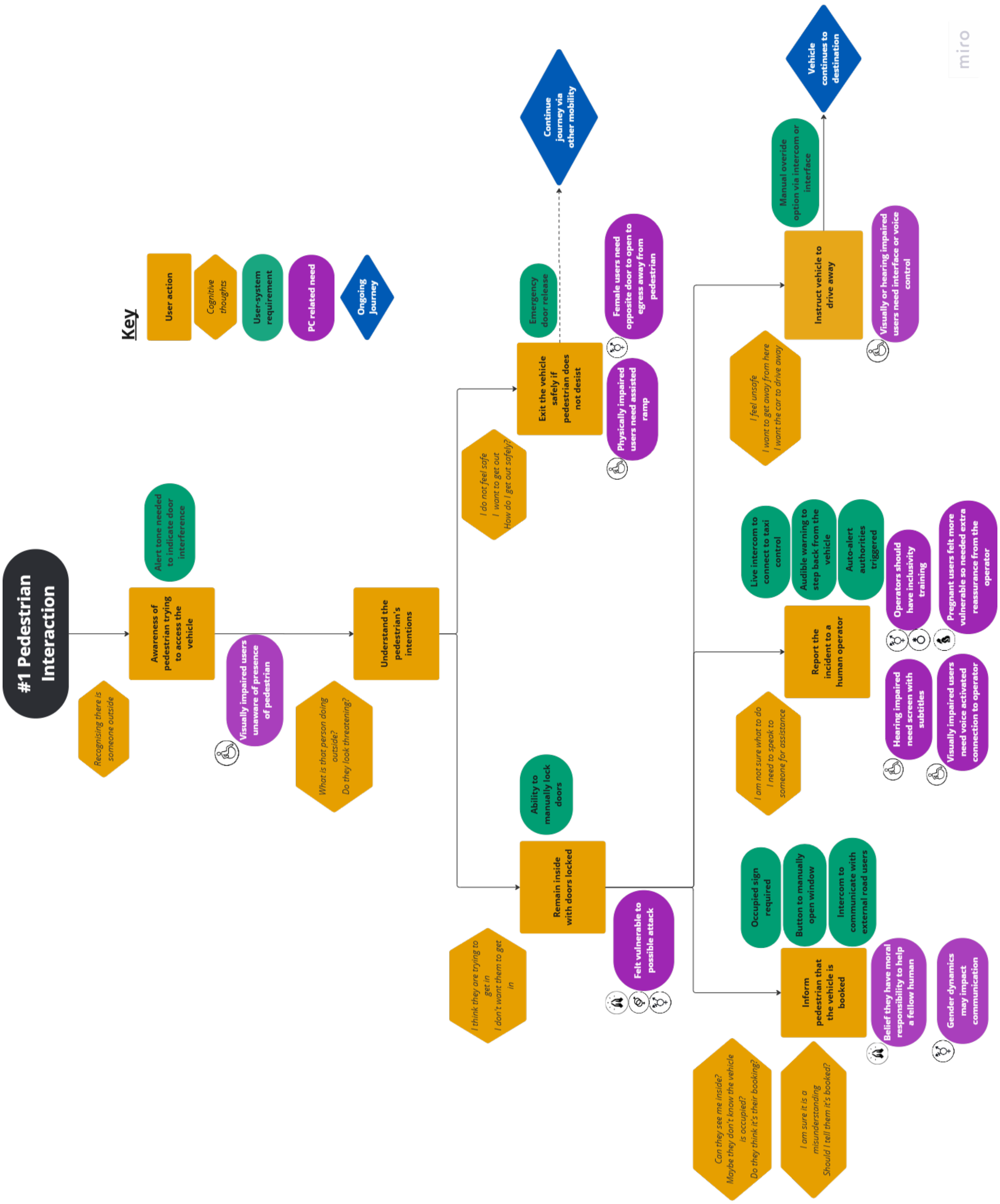

#1 Pedestrian Interaction
Key
User action
Cognitive thoughts
User-system requirement
PC related need
Ongoing journey
Recognising there is someone outside
Awareness of pedestrian trying to access the vehicle
Alert tone needed to indicate door interference
Visually impaired users unaware of presence of pedestrian
Understand the pedestrian's intentions
What is that person doing outside? Do they look threatening?
I do not feel safe I want to get out How do I get out safely?
Exit the vehicle safely if pedestrian does not desist
Emergency door release
Female users need opposite door to open to egress away from pedestrian
Physically impaired users need assisted ramp
Continue journey via other mobility
I think they are trying to get in I don't want them to get in
Remain inside with doors locked
Ability to manually lock doors
Felt vulnerable to possible attack
I feel unsafe I want to get away from here I want the car to drive away
Instruct vehicle to drive away
Manual override option via intercom or interface
Visually or hearing impaired users need interface or voice control
Vehicle continues to destination
I am not sure what to do I need to speak to someone for assistance
Report the incident to a human operator
Live intercom to connect to taxi control
Audible warning to step back from the vehicle
Auto-alert authorities triggered
Operators should have inclusivity training
Pregnant users felt more vulnerable so needed extra reassurance from the operator
Hearing impaired need screen with subtitles
Visually impaired users need voice activated connection to operator
Can they see me inside? Maybe they don't know the vehicle is occupied? Do they think it's their booking?
I am sure it is a misunderstanding Should I tell them it's booked?
Inform pedestrian that the vehicle is booked
Occupied sign required
Button to manually open window
Intercom to communicate with external road users
Belief they have moral responsibility to help a fellow human
Gender dynamics may impact communication
miro

Figure 3 *Pedestrian interaction scenario* task analysis. Yellow rectangles represent user actions, yellow hexagons depict cognitive processes, green lozenges indicate system features needed to support users, purple lozenges highlight protected characteristic considerations accompanied by the relevant icon (shown in the image below), and blue diamonds signify onward journey options. If a step was mentioned directly as impacting a particular protected characteristic, an icon denoting that protected characteristic is added next to it, to illustrate its relevance.

Medical emergency scenario

Scenario: A fellow passenger (virtual avatar) is on the floor of the self-driving taxi saying, 'I don't feel well'.

Awareness of Person on the Floor: The process begins when users notice someone in the vehicle has collapsed or is lying on the floor. This initial awareness triggers immediate thoughts such as: *"What is happening?" "Should I stay?"* or *"I want to leave."*. The absence of a driver intensifies these thoughts, as users lack a figure of authority to observe, manage, or offer reassurance about the situation. For visually-impaired users, the system would need to provide a voice command feature to stop the vehicle, as they might not easily locate physical controls. Similarly, physically-impaired users may require an automatic ramp to exit the vehicle safely if they decide not to engage further. Without a driver, the burden falls entirely on the system to enable users to make informed and safe decisions.

Decision: Exit the vehicle or gather more information

- **Exit the vehicle -** Before assessing the medical severity of the situation or interacting with the sick passenger, some users may choose to exit the vehicle immediately. This decision stems from thoughts such as: *"I don't want to get involved," "I don't want them to be sick on me,"* or *"How do I stop the vehicle to leave?"*. These thoughts reflect a prioritisation of personal comfort or an aversion to involvement due to uncertainty or fear. Exiting the vehicle requires the system to support this decision with features like an emergency stop button or emergency door release. Visually-impaired users would require a voice command option to stop the vehicle and initiate the exit process, while physically-impaired users would need an automatic ramp for safe egress. The absence of a driver means there is no one to facilitate or oversee this exit, which may increase feelings of vulnerability for users opting to leave. Once outside, users may then order a replacement vehicle via an app. This app would need to offer accessible options for visually-impaired users to ensure they can continue their journey without additional barriers.
- **Assess the medical emergency severity -** For users who choose to remain in the vehicle, the next step is to assess the severity of the medical emergency. This involves cognitive processes such as: *"What are they doing?" "Are they okay?" "Are they drunk?"*. The absence of a driver places the responsibility of evaluating the situation entirely on the user, which may lead to hesitancy or a delay in action, particularly for users uncertain of their ability to assess the situation accurately. At this stage, users might communicate directly with the sick passenger to better understand their condition. For visually-impaired or hearing-impaired users, the system would need to facilitate accessible interactions, such as voice-controlled

systems or subtitled intercom communication. Without these features, users may struggle to gather the necessary information to make an informed decision, particularly under the stress of the situation.

Decisions While Assisting: Move the Passenger, Offer First Aid, or Call for Help

Users who remain in the vehicle and choose to assist must decide how to engage with the sick passenger. Each action introduces unique considerations and system requirements.

- **Move the Passenger Off the Floor**: Users may attempt to make the passenger more comfortable, but concerns about personal safety or social repercussions may deter them. For example, younger users may feel inexperienced, while male users may worry about accusations of inappropriate behaviour. In these cases, 24-hour CCTV could provide reassurance and accountability, enabling users to act with greater confidence.
- **Offer Minor First Aid**: Some users might try to provide basic assistance, such as opening a window for fresh air or administering first aid. These actions depend on the availability of a first aid kit and the user’s physical ability to manually open the window. Without a driver to guide or assist, users may be uncertain about the best way to proceed.
- **Contact Emergency Services**: If the situation is critical, users might escalate by contacting emergency services. This would require the vehicle to include an emergency button for e-calls and voice-activated systems for visually-impaired users. In a driverless environment, the system would need to ensure this process is intuitive, as users may already be under stress and lack clarity on the steps to take.

Redirecting the Vehicle to a Hospital: If users determine that the passenger requires urgent medical attention, they might decide to redirect the vehicle to a hospital. This decision requires the system to support features such as a live intercom to connect users with taxi control and voice control options for visually-impaired passengers. Users may also need reassurance about how to resume their own journey after the emergency is resolved, highlighting the importance of clear guidance from the system.Without a driver to facilitate this decision, users are entirely responsible for evaluating the situation and utilising the system’s tools to act appropriately. This could introduce additional cognitive load, especially for users unfamiliar with the system’s capabilities.

Continuing the Journey or Seeking Alternative Mobility

After addressing the medical emergency, users face the decision of whether to continue their journey in the vehicle or seek alternative transport.

- **Continuing the Journey**: For users who wish to remain in the vehicle, the system would need to ensure a seamless transition back to normal operations. Some users, however, may feel uneasy about resuming their journey without a driver to provide reassurance after the incident.
- **Seeking Alternative Mobility**: Users who prefer to leave the vehicle might use an app to book a replacement taxi. This app would need to provide accessible options for visually-impaired users and ensure that alternative transport is readily available to minimise delays or inconvenience.

Figure 4 provides a visualisation of the task analysis steps for *Medical emergency scenario*.

User requirements to enable passengers of automated passenger services (APS) to perform journey tasks during emergencies

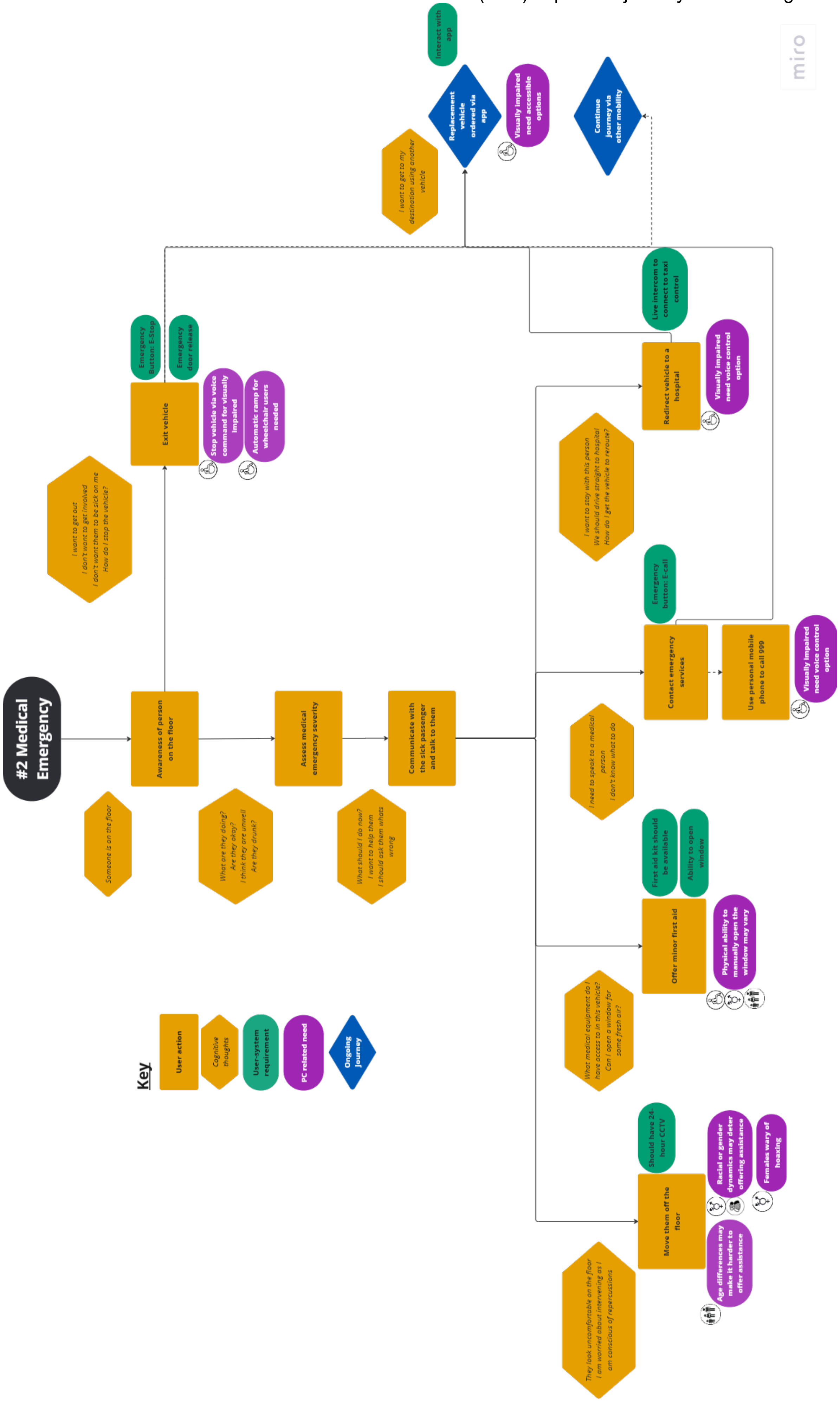


Figure 4 *Medical emergency scenario* task analysis. Yellow rectangles represent user actions, yellow hexagons depict cognitive processes, green lozenges indicate system features needed to support users, purple lozenges highlight protected characteristic considerations accompanied by the relevant icon (shown in the image below), and blue diamonds signify onward journey options. If a step was mentioned directly as impacting a particular protected characteristic, an icon denoting that protected characteristic is added next to it, to illustrate its relevance.

Incorrect stopping point scenario

Scenario: The self-driving taxi misses the intended stop, and the participant must navigate the situation to continue their journey.

Awareness of approaching the destination: The process begins when users become aware that the vehicle is nearing their destination. In this scenario, the destination is the library, and users may prepare to disembark. Thoughts at this stage might include: *"We're almost there,"* or *"I should get ready to leave soon."* The system would need to provide clear **audio and visual cues** to indicate that the vehicle is nearing the drop-off point, which is particularly important for visually-impaired users who rely on non-visual feedback. Without a driver to confirm or announce the location, passengers must depend entirely on automated notifications.

Realisation the vehicle has not stopped at the correct location: As the vehicle fails to stop at the designated drop-off point, users realise something is wrong. This triggers immediate thoughts such as: *"Why hasn't it stopped?" "How far are we from the library?"* or *"What should I do now?"*. The absence of a driver to clarify the situation increases uncertainty and may cause frustration or anxiety, particularly for users who are unfamiliar with the system or unsure how to intervene. The system would need to provide **real-time updates** on the current route and stopping decisions to help users understand the situation. For example, a message explaining why the vehicle didn't stop—such as obstacles at the designated point—could alleviate confusion. For users with mobility impairments, the system must confirm whether the alternative stopping point is safe and accessible.

Immediate decision: Allow the vehicle to continue or exit using a manual override

Users must decide whether to allow the vehicle to continue to the next available stopping point or to take control and exit manually.

- **Option 1: Allow the vehicle to continue -** Some users may choose to let the vehicle continue its journey and find the next safest stopping point. Thoughts guiding this decision could include: *"It's probably not far," "I don't know how to stop it,"* or *"I trust the car will sort this out."* For this option, the system would need to provide reassurance through audio feedback or a notification on the interface explaining the adjusted route. Users might expect to see or hear: *"Approaching an alternative stopping point in 200 metres."* For users with impairments, such as those visually impaired, the system would need to provide clear voice guidance to explain what is happening and how far the new stop will be.

- **Option 2: Manual override and exit the vehicle -** Other users may feel uncomfortable allowing the vehicle to proceed, particularly if the alternative stopping point is perceived as inconvenient or unsafe. They may think: *"I don't want to go further away from my destination,"* or *"I need to get out now."* To accommodate this, the vehicle would need to offer a manual override function that allows users to stop and exit the vehicle safely. Actions at this stage would involve users pressing an emergency stop button or using voice commands to halt the vehicle. Once stopped, the system would need to confirm that it is safe to open the doors, particularly for physically-impaired users who require automatic ramps. The absence of a driver means passengers must independently assess the situation and determine whether exiting is viable, which can heighten stress for users unfamiliar with the process.

Decisions After Stopping: Exit or Address the Issue

After the vehicle has stopped—whether automatically or through manual intervention—users face another decision: whether to exit the vehicle or remain inside and attempt to address the incorrect stopping point.

- **Option 1: Exit the vehicle -** Users who feel confident navigating from the current location may choose to exit. This decision could be influenced by thoughts such as: *"I can manage from here,"* or *"It's not worth waiting to fix this."* However, users with mobility impairments or those unfamiliar with the area may need the system to confirm whether the location is safe and accessible.
- **Option 2: Address the issue -** Users who remain in the vehicle may attempt to correct the situation using the vehicle's interface or app. Actions at this stage might include:
    - **Reporting the issue via the interface**: Users could interact with the system to highlight that the vehicle has not stopped at the correct location. For visually-impaired users, voice controls and audio confirmations would be required to ensure accessibility.
    - **Requesting a route adjustment**: Users may input their original destination again or request a new stopping point. This would require a user-friendly interface with real-time navigation feedback, as well as visual or audio prompts to confirm the updated route.
    - **Connecting to remote assistance**: For users unsure how to proceed, the system would need to offer a live intercom to connect with customer support. Hearing-impaired users would require subtitled communication to understand instructions.

Onward journey actions

Once the issue has been addressed or users have exited the vehicle, they must consider how to complete their journey.

- **Continuing to the original destination**: Users who remain in the vehicle would rely on the system to navigate back to their intended destination. The vehicle would need to provide ongoing updates, such as: *"Now approaching the library. Estimated time: 2 minutes."* For users with impairments, additional guidance on disembarking safely at the corrected location would be essential.

- **Seeking alternative mobility**: Users who exit the vehicle prematurely may need to book another mode of transport. For visually-impaired users, the app for ordering a replacement vehicle would require voice commands and accessible navigation options. Additionally, the system could offer features to assist users in locating nearby public transport or pedestrian-friendly routes.

Figure 5 provides a visualisation of the task analysis steps for *Incorrect stopping point scenario*.

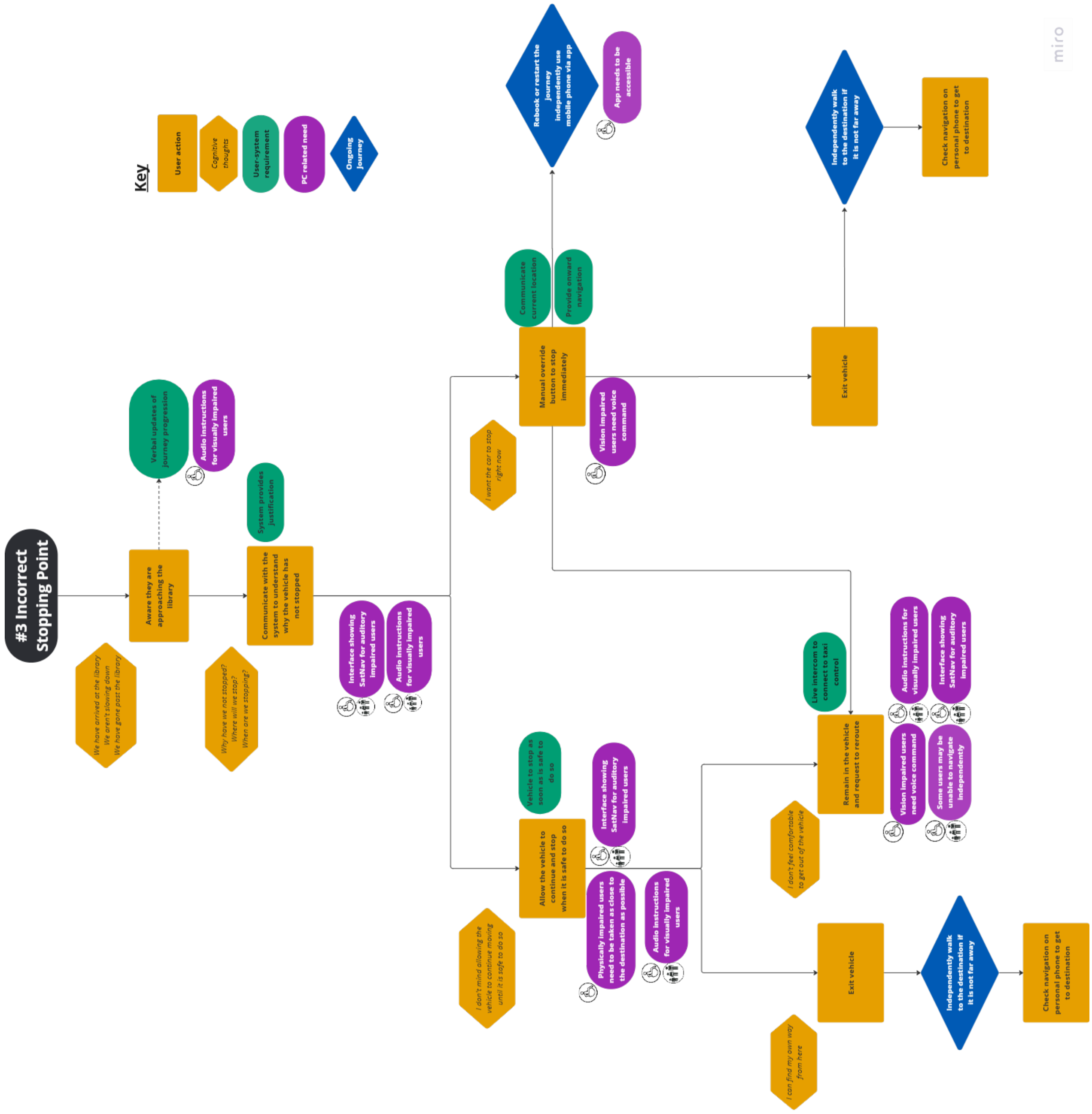


Figure 5 *Incorrect stopping point scenario task analysis*. Yellow rectangles represent user actions, yellow hexagons depict cognitive processes, green lozenges indicate system features needed to support users, purple lozenges highlight protected characteristic considerations accompanied by the relevant icon (shown in the image below), and blue diamonds signify onward journey options. If a step was mentioned directly as impacting

a particular protected characteristic, an icon denoting that protected characteristic is added next to it, to illustrate its relevance.

Road closure due to flooding scenario

Scenario: The self-driving taxi is stopped by a road closure caused by flooding.

Awareness of Weather Conditions: The process begins when users notice the extreme weather conditions, such as heavy rain and flooding. Initial thoughts might include: *"The rain is getting worse,"* or *"There's a lot of water on the road."* For visually-impaired users, the system should provide audio descriptions of the weather conditions, ensuring they are informed about potential disruptions. In a self-driving taxi, the absence of a driver to offer updates or reassurance increases the responsibility of the system to pre-emptively inform users about hazards. Notifications such as: *"Severe flooding detected ahead; the vehicle is preparing to adjust,"* would help mitigate confusion. For physically-impaired users, the vehicle would be required to assess whether the current conditions might affect accessibility (e.g., if ramps will be safe to deploy in flooded areas). Without a driver, these checks should be automated and clearly communicated.

Recognising the Vehicle Has Stopped: Users realise that the vehicle has stopped due to the flooding. Initial reactions might include: *"Why have we stopped?" "Is this the destination?"* or *"Is there a problem?"*. Without a driver to explain the reason for the stop, users are left to interpret the situation based solely on the system's feedback. The system should provide clear real-time notifications to inform users of the reason for stopping, such as: *"The road ahead is blocked due to flooding. The vehicle is assessing options."* For hearing-impaired users, this information would need to be available as visual text updates on the interface.

The lack of a human driver to make dynamic decisions, such as finding an immediate detour or confirming the severity of the hazard, may heighten user anxiety. For visually-impaired users, audio cues such as the location of barriers or environmental details (e.g., *"standing water detected"*) would be required to provide context.

Understanding the Reason for Stopping: Once users recognise the vehicle has stopped, they move to understanding why and what this means for their journey. They may think: *"What should I do now?"* or *"Is there an emergency plan in place?"*.

The system should provide guidelines for emergency protocols, including explanations of the situation and suggested next steps. For visually-impaired users, audio instructions would help clarify the process, while hearing-impaired users would require text-based guidance on the interface. Users who feel unsafe might request assistance, highlighting the need for a live intercom connection to remote support.

For users with physical impairments, the system would need to assess whether environmental conditions, such as standing water, pose risks to deploying ramps or disembarking safely. In the absence of a driver to assist, these evaluations should be automated and communicated clearly to users.

Decision: Seek Further Information or Exit the Vehicle

At this point, users face a choice between gathering more information about their options or exiting the vehicle.

- **Option 1: Seek Further Information** - Some users may choose to remain in the vehicle and seek clarity on what to do next. They might think: *"Can the vehicle bypass the flooding?"* or *"Is there a detour available?"*. The system would be required to:
    - Provide clear rerouting options, such as: *"Attempting to find an alternative route around the flooded area. Estimated delay: 15 minutes."*
    - Ensure accessibility through audio prompts for visually-impaired users and interface-based visuals for hearing-impaired users.
    - For neurodivergent users who may feel overwhelmed by unexpected disruptions, the system should provide reassurance and structured guidance. For example: *"The vehicle is exploring a safe alternative route. You don't need to take any action right now."*
- **Option 2: Exit the Vehicle -** Other users may feel uncomfortable remaining in the vehicle and opt to leave. Thoughts at this stage might include: *"I don't feel safe staying here,"* or *"I'd rather find my own way."* Exiting safely requires the system to:
    - Offer emergency exits or ramps for physically-impaired users, ensuring they can disembark without risk of slipping or encountering deep water.
    - Activate vehicle hazard lights for visually-impaired users to ensure the area around the taxi is well-lit and visible.
    - Notify users of potential dangers outside, such as deep water or uneven ground, which is especially important for users with mobility aids or reduced situational awareness.

Without a driver to assess external hazards, the system should communicate these risks clearly and provide step-by-step assistance for users preparing to exit.

Decision: Request Reroute or Act Independently

If users remain in the vehicle, they must decide whether to request a reroute or seek alternative mobility options.

- **Option 1: Request Reroute** - For users who prefer to continue their journey without leaving the vehicle, the system should offer rerouting options. Users might think: *"I just want to get to my destination another way,"* or *"I don't want to deal with the rain."* The system is required to:
    - Provide **real-time updates** on rerouting progress, such as: *"A safe detour has been found. Estimated time to destination: 20 minutes."*
    - Ensure accessibility through **voice commands** for visually-impaired users and **text-based instructions** for hearing-impaired users.
- **Option 2: Act independently -** Users who feel they can no longer rely on the vehicle may choose to contact external services or exit to find alternative transport. For instance, they may use the live intercom to connect with taxi control or request emergency assistance. Hearing-impaired users would require

text communication options, while visually-impaired users would need audio-based support to access help.
For those exiting, the system should guide them to nearby public transport options or suggest a safe waiting area for a replacement vehicle. For example: *“There is a bus stop 50 metres away. Directions are being sent to your mobile device.”*

Onward Journey: Alternative Transport or Independent Travel

Once users leave the vehicle, they must determine how to proceed.

- **Option 1: Alternative Transport:** The system can suggest nearby transport options, such as buses or taxis. For visually-impaired users, audio navigation would assist in locating these options, while hearing-impaired users would need step-by-step visual directions on their mobile devices.
- **Option 2: Independent Travel:** Some users may choose to navigate to their destination independently. For example, physically-impaired users might require assistance identifying wheelchair-accessible routes or pedestrian paths unaffected by flooding. The system should proactively offer safety tips, such as avoiding standing water or unlit areas.

Figure 6 provides a visualisation of the task analysis steps for *Road closure due to flooding scenario*.

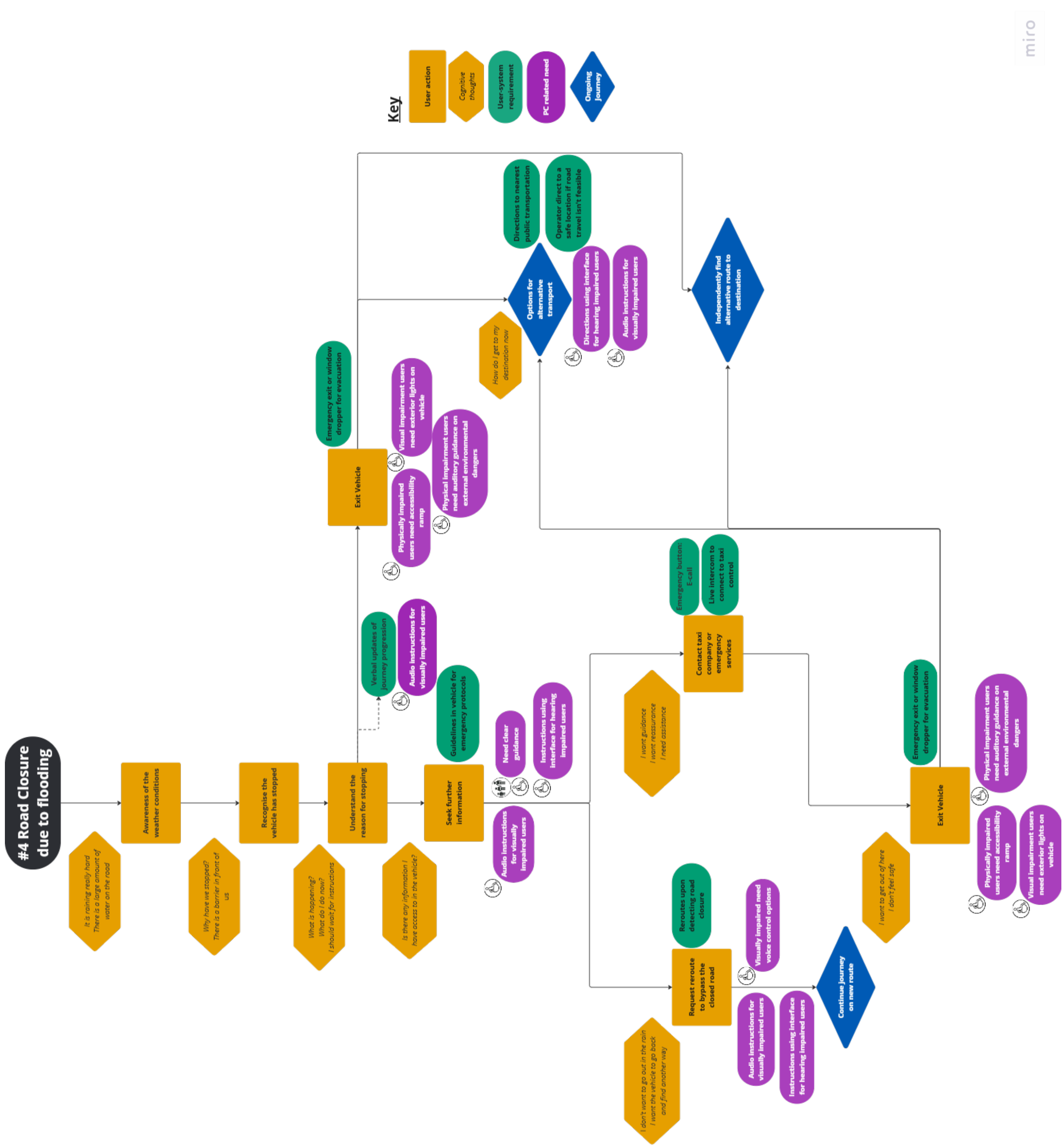


Figure 6 ***Road closure due to flooding scenario task analysis.*** **Yellow rectangles represent user actions, yellow hexagons depict cognitive processes, green lozenges indicate system features needed to support users, purple lozenges highlight protected characteristic considerations accompanied by the relevant icon (shown in the image below), and blue diamonds signify onward journey options. If a step was mentioned directly as impacting a particular protected characteristic, an icon denoting that protected characteristic is added next to it, to illustrate its relevance**.

Fire and smoke emergency with door malfunction scenario

Scenario: The self-driving taxi catches fire while in motion, and the doors malfunction, remaining closed.

Awareness of the Fire: The process begins when users become aware of a fire in the vehicle. This awareness may come from visual, auditory, or sensory cues, triggering thoughts such as: *"The vehicle is on fire!" "I can smell smoke,"* or *"How do I get out quickly?"*. Without a driver to confirm the danger or provide instructions, users rely entirely on automated alerts. The system should incorporate automatic fire detection with both auditory alerts for visually-impaired users and visual indicators such as flashing lights for hearing-impaired users.

For older passengers or those with cognitive impairments, the system would need to ensure that the alerts are not overly complex or overwhelming, using clear, simple instructions such as: *"There is a fire in the vehicle. Please prepare to exit safely."* Additionally, passengers with mobility impairments may immediately question their ability to escape quickly, thinking: *"Will the ramp work in this situation?"* or *"What if the fire blocks my exit?"*. In a self-driving taxi, the absence of a driver to assess these risks means the system should anticipate these concerns and provide tailored guidance.

Assessing the Situation: After becoming aware of the fire, users must assess the severity of the situation. This may include thoughts such as: *"Is the fire spreading?" "Can I stop the vehicle?"* or *"Do I need to wait for assistance?"*. The lack of a driver leaves passengers entirely responsible for evaluating their options. The system should:

- Automatically activate smoke ventilation systems to reduce the immediate danger of inhalation, especially for passengers with respiratory conditions or pregnant individuals who may be more vulnerable to smoke exposure.
- Highlight illuminated emergency exits to guide passengers, which would be especially important for visually-impaired users or passengers unfamiliar with the layout of the vehicle. For example, tactile indicators or contrasting colours on exit handles could make them easier to locate.
- Provide an intercom to connect with remote operators, allowing users who feel uncertain to ask for guidance. Neurodivergent users, for instance, may find the stress of the situation overwhelming and benefit from a calm, structured conversation with a trained operator.

Stopping the Vehicle: If the vehicle is still moving, users must stop it before attempting to evacuate. Common thoughts might include: *"I need to stop the car!"* or *"Where is the emergency button?"*. The absence of a driver to take control means the system must ensure stopping mechanisms are intuitive and accessible. The system should:

- Provide an emergency stop button (E-stop) that is easy to locate, with tactile and visual cues for users with sensory impairments. For example, a visually-impaired user might feel for a textured or raised button near their seat, while a hearing-impaired user could rely on flashing lights around the button.
- Automatically stop the vehicle in a safe location where passengers can exit without stepping into additional danger, such as traffic or waterlogged areas.
- Immediately unlock the doors upon stopping, ensuring physically-impaired users can evacuate without needing additional input.

Older users may struggle with unfamiliar systems, so instructions such as: *"Press the red button to stop the vehicle,"* displayed in simple text or spoken aloud, would be required to minimise confusion.

Decision: Exit the Vehicle
After stopping the vehicle, users must decide how to exit safely. This stage is particularly challenging in a self-driving taxi, as there is no driver to assist with opening doors, providing reassurance, or assessing external hazards.

- **Option 1: Exit Through Doors** - Users who can exit through the doors might think: *"Are the doors unlocked?"* or *"Will I need help getting out?"*. The system should:
    - Automatically open the doors or provide a manual override for users to unlock them if automated systems fail.
    - Provide tools to break windows as an alternative exit, with instructions on how to use them. For physically-impaired users, such as those with limited upper-body strength, simpler tools (e.g., pre-scored glass) would be required.
    - Deploy accessibility ramps to accommodate wheelchair users, ensuring they can exit safely without additional assistance.
- **Option 2: Exit Through Windows** - Users unable to use the doors may consider exiting through the windows, which raises concerns such as: *"Can I fit through the window?"* or *"How will I get down safely?"*. Pregnant users or those with mobility challenges might struggle to climb through a window, highlighting the need for alternative evacuation options. For example, the vehicle could provide a removable roof panel or additional safety features to make window exits more manageable.

Post-Evacuation: Receiving Medical Attention
Once users have exited the vehicle, their focus shifts to ensuring their safety and seeking medical attention if necessary. Thoughts at this stage might include: *"Am I okay?" "Is anyone else hurt?"* or *"What do I do next?"* The system should:

- Trigger an automatic E-call to alert emergency services and provide the vehicle's location. This is particularly important in remote or poorly marked areas, where passengers might struggle to communicate their exact location.
- Provide clear, ongoing guidance to passengers, such as: *"Move at least 50 metres away from the vehicle and wait for help."* For visually-impaired users, audio instructions would be essential to guide them to safety, while hearing-impaired users would require visual prompts. First responders arriving on the scene would need training to understand diverse passenger needs, such as providing ramps or carrying aids for physically-impaired individuals.

Alerting Nearby Road Users
After ensuring their safety, users or the system must consider the broader risks posed by the fire to other road users. Without a driver to manually warn others, the system should be required to:

- Activate warning lights and sounds to alert approaching vehicles, particularly in low-visibility conditions.
- Use audio and visual signals to direct nearby pedestrians or cyclists to maintain a safe distance.

Passengers may feel a sense of responsibility, thinking: *“I need to make sure others know there’s a fire,”* but should not be expected to take on this task themselves.

Onward Journey Decisions
Once the immediate danger has passed, users must decide how to continue their journey. In a self-driving taxi, the absence of a driver means the system must offer options and support for onward travel.

- **Option 1: Request a Replacement Vehicle:** Some users may think: *“I need to get to my destination as soon as possible,”* and request another self-driving taxi. The system should make this process seamless, ensuring users can book through an accessible app interface with audio prompts and visual guidance.
- **Option 2: Use Public Transport:** Users who no longer feel comfortable in a self-driving taxi might opt for public transport, thinking: *“I don’t trust getting back in another one.”* Directions to the nearest bus or train station should be provided, with audio navigation for visually-impaired users and text-based maps for hearing-impaired users.
- **Option 3: Use a Taxi with a Driver:** For those seeking reassurance, thoughts might include: *“I’d feel safer with a human driver.”* The system could suggest traditional taxi options nearby and assist with the booking process.
- **Option 4: Contact a Friend:** Some users might feel too shaken to continue independently, thinking: *“I just need someone I know to pick me up.”* The system should suggest safe waiting areas and provide guidance on how to remain visible to friends or family.

Figure 7 provides a visualisation of the task analysis steps for *Fire and smoke emergency with door malfunction scenario*.

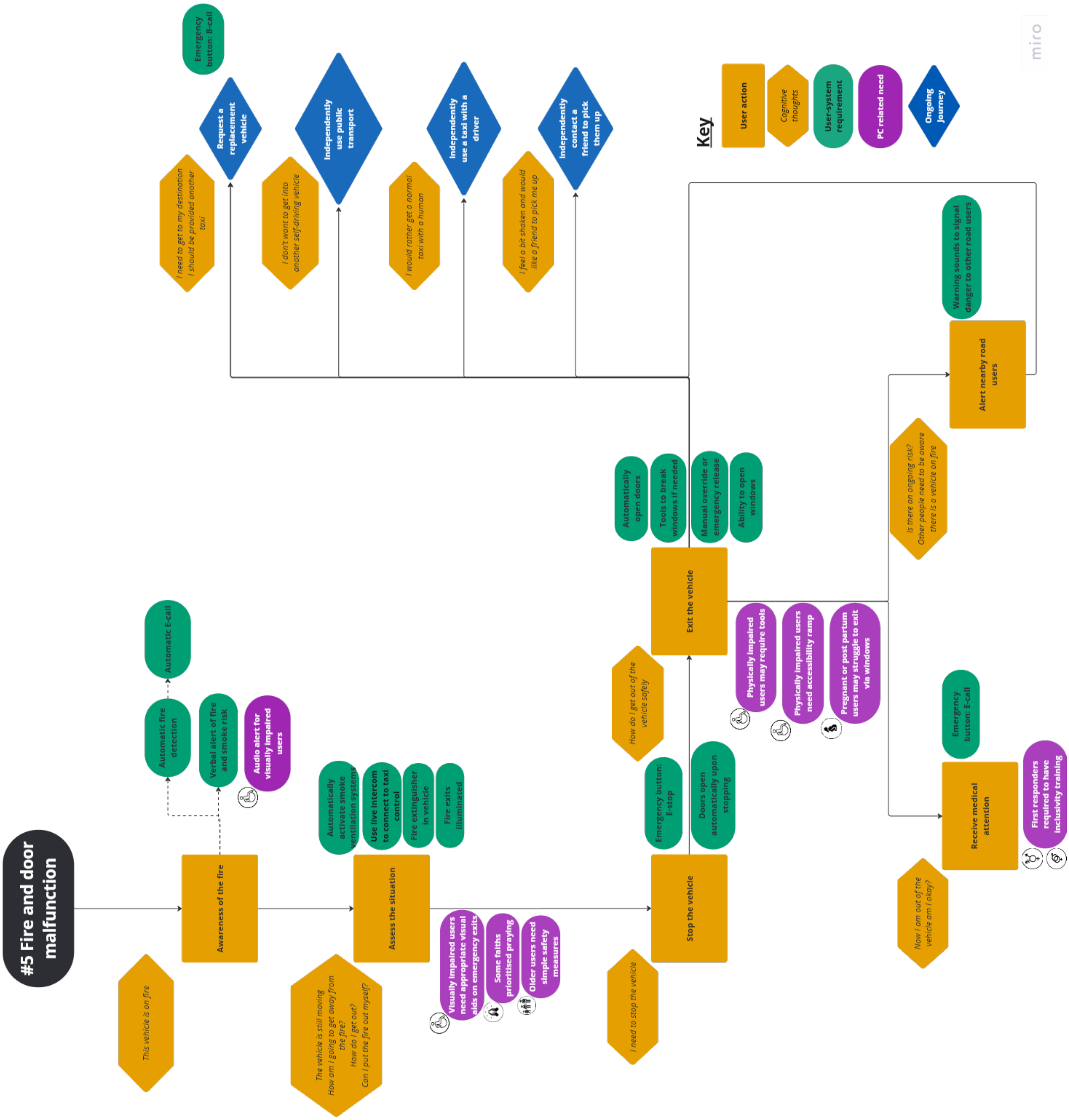

#5 Fire and door malfunction
Awareness of the fire
This vehicle is on fire
Automatic fire detection
Verbal alert of fire and smoke risk
Audio alert for visually impaired users
Automatic E-call
Assess the situation
The vehicle is still moving
How am I going to get away from the fire?
How do I get out?
Can I put the fire out myself?
Automatically activate smoke ventilation systems
Use live intercom to connect to taxi control
Fire extinguisher in vehicle
Fire exits illuminated
Visually impaired users need appropriate visual aids on emergency exits
Some faiths prioritised praying
Older users need simple safety measures
Stop the vehicle
I need to stop the vehicle
Emergency button: E-stop
Doors open automatically upon stopping
Exit the vehicle
How do I get out of the vehicle safely
Automatically open doors
Tools to break windows if needed
Manual override or emergency release
Ability to open windows
Physically impaired users may require tools
Physically impaired users need accessibility ramp
Pregnant or post partum users may struggle to exit via windows
Request a replacement vehicle
I need to get to my destination
I should be provided another taxi
Emergency button: B-call
Independently use public transport
I don't want to get into another self-driving vehicle
Independently use a taxi with a driver
I would rather get a normal taxi with a human
Independently contact a friend to pick them up
I feel a bit shaken and would like a friend to pick me up
Receive medical attention
Now I am out of the vehicle am I okay?
Emergency button: E-call
First responders required to have inclusivity training
Alert nearby road users
Is there an ongoing risk?
Other people need to be aware there is a vehicle on fire
Warning sounds to signal danger to other road users
Key
User action
Cognitive thoughts
User-system requirement
PC related need
Ongoing Journey
miro

Figure 7 ***Fire and smoke emergency with door malfunction scenario task analysis.*** **Yellow rectangles represent user actions, yellow hexagons depict cognitive processes, green lozenges indicate system features needed to support users, purple lozenges highlight protected characteristic considerations accompanied by the relevant icon (shown in the image below), and blue diamonds signify onward journey options. If a step was mentioned directly as impacting a particular protected characteristic, an icon denoting that protected characteristic is added next to it, to illustrate its relevance.**

Vehicle collision scenario

Scenario: The self-driving taxi is involved in a collision whilst at a red light.

Awareness of Being in a Collision: The process begins when passengers realise the self-driving taxi has been involved in a collision. Passengers might think: *"Why has the car stopped?" "What is that sound?"* or *"Have we been hit?"*. For passengers with auditory impairments, the system would need to provide visual cues—such as flashing interface alerts or lights—to signal the collision. Meanwhile, visually-impaired users would rely on audio descriptions, such as: *"The vehicle has been involved in a collision. Please remain calm and follow instructions."*

In the absence of a driver to immediately explain the situation, the system should automatically activate emergency response features, including:

- **Automatic E-call** to alert emergency services with the vehicle's location and situation details.
- **Auditory or visual updates** to reassure passengers, such as: *"The vehicle is stationary, and assistance has been contacted."*

Passengers with specific vulnerabilities—such as older users or neurodivergent passengers—might feel overwhelmed by the unexpected disruption. For these individuals, the system should provide calm and structured notifications, avoiding excessive details that could cause confusion.

Assessing the Severity of the Situation: Once passengers are aware of the collision, they need to assess its severity. Thoughts might include: *"Is anyone hurt?" "How bad is the damage?"* or *"Can we keep going?"*. Without a driver to evaluate the situation or offer guidance, passengers must rely entirely on the system to provide this information.
The system should:

- Automatically assess the vehicle's functionality and communicate whether it is safe to continue. For example: *"The vehicle is not operational. Please prepare to exit safely."*
- Prompt passengers to check their own well-being and that of others in the vehicle. Audio announcements might say: *"Please check for injuries and notify us via the intercom if you require medical assistance."*
- Offer guidance tailored to passengers' needs. For example:
    - Auditory-impaired users would require text-based instructions on the interface about the vehicle's condition.
    - Visually-impaired users would need detailed audio cues, such as the location of nearby hazards.

- Physically-impaired passengers may need confirmation that ramps, or other accessibility features will work correctly during evacuation.
- Neurodivergent users may benefit from simple, repetitive reassurance, such as: *"Help is on the way. You are safe."*

Decision: Remain in the Vehicle or Exit

After assessing the situation, passengers face a decision to either remain in the vehicle or evacuate. This choice depends on perceived risks, external hazards, and system feedback.

- **Option 1: Remain in the Vehicle -** Passengers who feel safer staying inside may think: *"I don't want to confront the other driver,"* or *"I feel safer waiting here."* The system should:
    - Activate hazard lights and audible alerts to notify nearby vehicles of the collision, reducing the risk of further accidents.
    - Provide locking options for the doors, reassuring vulnerable passengers, such as women or users with visible disabilities, who may feel unsafe engaging with others outside the vehicle.
    - Offer live intercom access to a trained operator who can provide reassurance and confirm whether it is safe to remain inside. For example, an operator might say: *"Emergency services are on their way. Please stay seated and keep the doors locked."*

  For users with sensory impairments, the system should present updates in multiple formats. Visually-impaired users might rely on audio announcements about the situation outside, while hearing-impaired users would benefit from interface-based updates on emergency services' progress.
- **Option 2: Exit the Vehicle:** Passengers who feel unsafe or at risk of further harm may decide to evacuate. Thoughts might include: *"What if another car hits us?"* or *"I need to get out and assess the damage."* The system should:
    - Automatically unlock doors or provide emergency releases to facilitate evacuation.
    - Deploy accessibility ramps for wheelchair users or those with mobility impairments, ensuring they can exit independently.
    - Warn passengers about external hazards, such as: *"Please exit cautiously. There is debris nearby."*

  Pregnant users, older passengers, or those with limited mobility may struggle to exit quickly, so the system should ensure sufficient time and clear instructions, such as: *"Take your time exiting through the rear doors. Ramps are being deployed."*

Communicating with the Other Driver: Once outside the vehicle, some passengers may feel the need to communicate with the driver of the other vehicle. Thoughts at this stage might include: *"Is everyone in the other car, okay?"* or *"I want to make sure this wasn't my fault."*

The system could assist by:

- Using vehicle cameras to capture video evidence of the collision, reducing the need for direct confrontation between passengers and the other driver.

- Providing pre-recorded messages or text cards (e.g., displayed on a digital screen) to communicate information such as: *“Emergency services are on their way. Assistance is being provided to all parties.”*
- Reassuring passengers, particularly neurodivergent users or those who feel vulnerable, that they are not obligated to interact directly with the other party.

Gathering Evidence: Passengers who feel comfortable assisting in the post-collision process might decide to gather evidence. This could include taking photos, recording witness statements, or reporting the incident to the taxi company. Thoughts might include: *“They’ll need my details for the report,”* or *“I should take pictures of the damage.”* The system should:

- Provide clear instructions on what evidence to gather, such as: *“Please take a photo of the other vehicle’s license plate if it is safe to do so.”*
- Offer automated tools, such as vehicle cameras, to document the incident independently.
- Reassure passengers who are unsure of their responsibility, such as: *“Your assistance is appreciated but not required. The vehicle has logged all necessary information.”*

For passengers with sensory impairments, such as auditory-impaired users, the system could guide them through evidence collection with interface visuals, while visually-impaired users might rely on verbal prompts to describe their surroundings.

Onward Journey: Continuing or Arranging Transport: After addressing the immediate situation, passengers must decide how to continue their journey.

- **Option 1: Request a Replacement Vehicle**
  Some passengers might think: *“I still need to get to my destination,”* and choose to request another self-driving taxi. The system should facilitate this by:
  - Automatically offering replacement options via voice-controlled interfaces or text-based prompts for hearing-impaired users.
  - Ensuring accessibility for passengers with physical impairments, such as vehicles equipped with ramps.
- **Option 2: Use Public Transport or Traditional Taxis**
  Passengers who feel shaken might prefer not to re-enter a self-driving taxi, thinking: *“I’d feel safer with a driver,”* or *“I’ll just take the bus.”* The system should provide:
  - Directions to nearby public transport, including audio navigation for visually-impaired users and visual maps for hearing-impaired passengers.
  - Assistance in booking a traditional taxi, ensuring the process is seamless and accessible.
- **Option 3: Contact a Friend or Family Member**
  Some passengers may decide to contact someone they trust for support, thinking: *“I just want someone I know to pick me up.”* The system could assist by:
  - Identifying safe waiting areas and providing alerts about nearby hazards while passengers wait.
  - Offering emergency contact options, such as one-tap calling via the interface.

Follow-Up Support: After the incident, the system should provide follow-up care to ensure passenger well-being. This could include:

- A 24-hour check-in via phone, text, or email to ask: *"Are you feeling okay? Do you need additional support?"*
- Assistance with insurance or legal matters, particularly for users unfamiliar with these processes. For example, older passengers might appreciate simplified guidance, while neurodivergent users could benefit from structured, step-by-step explanations.

Figure 8 illustrates the task analysis steps for *Vehicle collision scenario*.

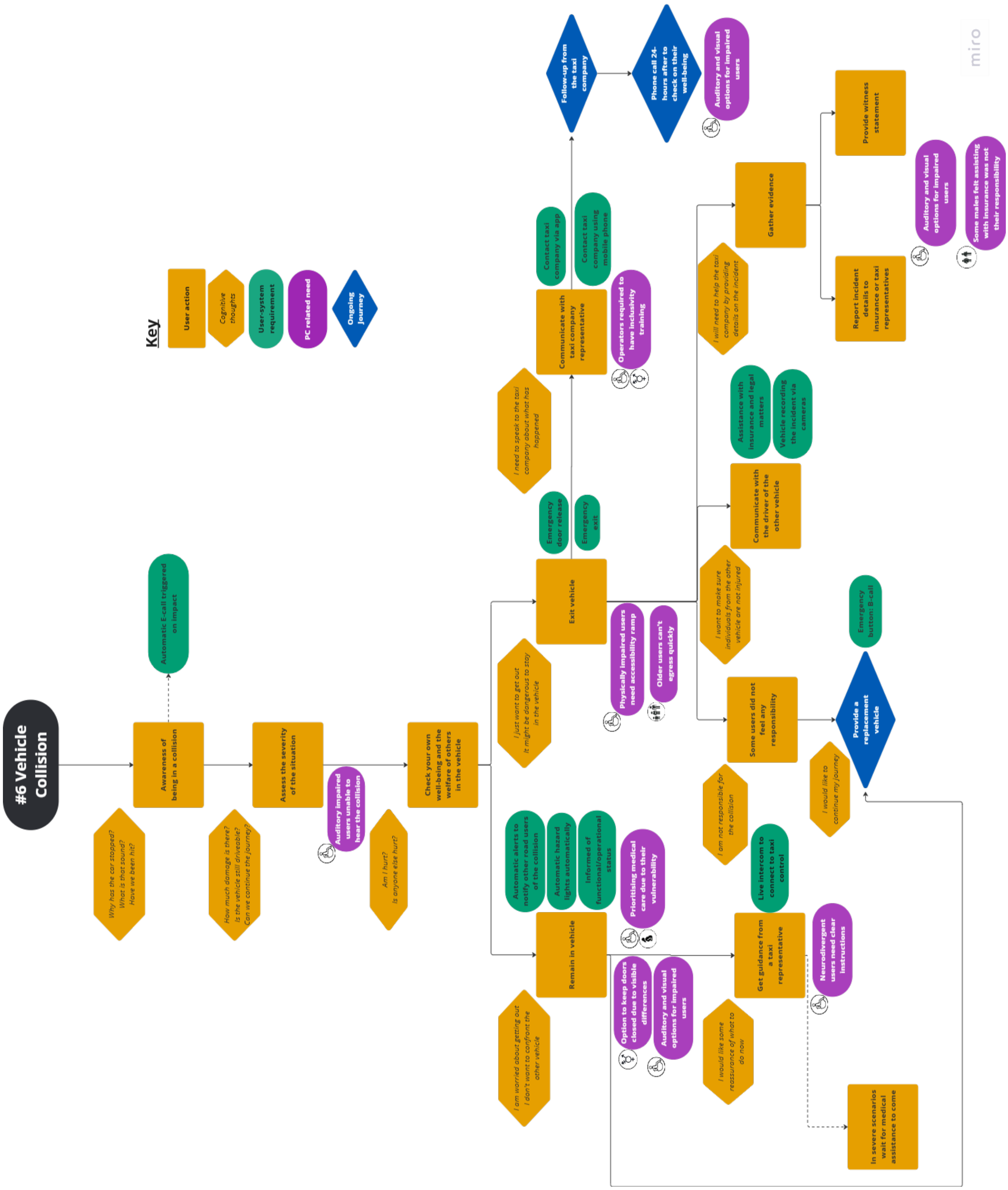

#6 Vehicle Collision
Key
User action
Cognitive thoughts
User-system requirement
PC related need
Ongoing journey
Awareness of being in a collision
Automatic E-call triggered on impact
Why has the car stopped? What is that sound? Have we been hit?
Assess the severity of the situation
How much damage is there? Is the vehicle still driveable? Can we continue the journey?
Auditory impaired users unable to hear the collision
Check your own well-being and the welfare of others in the vehicle
Am I hurt? Is anyone else hurt?
Exit vehicle
I just want to get out It might be dangerous to stay in the vehicle
Emergency door release
Emergency exit
Physically impaired users need accessibility ramp
Older users can't egress quickly
I need to speak to the taxi company about what has happened
Communicate with taxi company representative
Contact taxi company via app
Contact taxi company using mobile phone
Operators required to have inclusivity training
Follow-up from the taxi company
Phone call 24-hours after to check on their well-being
Auditory and visual options for impaired users
I want to make sure individuals from the other vehicle are not injured
Communicate with the driver of the other vehicle
Assistance with insurance and legal matters
Vehicle recording the incident via cameras
I will need to help the taxi company by providing details on the incident
Gather evidence
Report incident details to insurance or taxi representatives
Provide witness statement
Auditory and visual options for impaired users
Some males felt assisting with insurance was not their responsibility
I am not responsible for the collision
Some users did not feel any responsibility
Provide a replacement vehicle
I would like to continue my journey
Emergency button: B-call
Remain in vehicle
I am worried about getting out I don't want to confront the other vehicle
Automatic alerts to notify other road users of the collision
Automatic hazard lights automatically
Informed of functional/operational status
Prioritising medical care due to their vulnerability
Option to keep doors closed due to visible differences
Auditory and visual options for impaired users
Get guidance from a taxi representative
I would like some reassurance of what to do now
Live intercom to connect to taxi control
Neurodivergent users need clear instructions
In severe scenarios wait for medical assistance to come
miro

Figure 8 *Vehicle collision scenario task analysis*. Yellow rectangles represent user actions, yellow hexagons depict cognitive processes, green lozenges indicate system features needed to support users, purple lozenges highlight protected characteristic considerations accompanied by the relevant icon (shown in the image below), and blue diamonds signify onward journey options. If a step was mentioned directly as impacting a particular protected characteristic, an icon denoting that protected characteristic is added next to it, to illustrate its relevance.

3.2 Users' needs in managing emergency tasks in self-driving taxi services across protected characteristics

This section highlights the key challenges experienced by individuals in managing tasks that are required in the event of an emergency in a self-driving taxi where the absence of a driver is impacted by their protected characteristics. Some challenges identified are generic and others are related specifically to the individual emergency scenarios that they experienced in the study. The analysis is illustrated and supported by qualitative responses from the recordings of the solo interviews and focus group discussions.

Disability

The absence of a driver significantly amplifies the challenges faced by uses with disabilities during emergencies in a self-driving taxi, as it removes the human support that might otherwise assist them in navigating difficult scenarios. In the *Pedestrian interaction scenario*, participants with physical disabilities expressed fears about their inability to evacuate quickly if faced with a potential threat. The reliance on mobility aids such as wheelchairs or crutches further limited their response options without the assistance of a driver to facilitate evacuation. For vision-impaired passengers, the lack of a driver heightened concerns about reduced situational awareness. Without someone to help interpret visual cues or assess the intentions of individuals outside the vehicle, these participants felt particularly vulnerable.

Hearing-impaired individuals also experienced increased anxiety in the absence of a driver, particularly in scenarios like the *Road closure due to flooding scenario*, where auditory cues might be essential for understanding the environment. The absence of verbal guidance meant they had to rely entirely on system features to replace auditory input, which could fail or be insufficient in stressful situations. Neurodivergent participants frequently noted that chaotic environments triggered sensory overload, confusion, or panic. Without a driver to provide structured and calming guidance, these participants struggled to process the situation and make effective decisions and felt overwhelmed by processing decisions.

"I would worry that I wouldn't be able to get out if they managed to get in... I also wouldn't be able to get out as fast as an able-bodied person."– Catherine, [Physical impairment], (Pedestrian interaction scenario)

"Could there be a screen or something that could enlarge the person's face so I could see it better?... [otherwise] I wouldn't know it wasn't someone I knew until they'd opened the door and got closer."– Jessica, [Vision impairment], (Pedestrian interaction scenario)

"...there's so much going on, the car's got no driver. You've got people talking. Because everybody would be talking. You're all friends. There's stuff going on. You're going towards a blocked barrier. You're in the middle of that water, you're not at the side. There's a lot of information going on in there for me. So, there would be a quite heightened level of anxiety."– Steve, [Neurodivergent], (Road closure due to flooding scenario)

In the *Pedestrian interaction scenario*, participants with disabilities emphasised the importance of accessible features to mitigate fears. For physically disabled individuals, automated unlocking systems and clear, unobstructed pathways for evacuation were identified as crucial. Vision-impaired passengers suggested human-machine interfaces that display clear visual information about pedestrians outside the vehicle, enabling them to make informed decisions. Neurodivergent participants highlighted the need for structured, concise instructions, particularly from a remote operator or call centre, to prevent overstimulation and ensure their safety during emergencies.

In scenarios involving medical or fire-related emergencies, such as the *Medical emergency scenario* and the *Fire or smoke emergency with door malfunction scenario*, participants with physical disabilities expressed a need for systems that could assist with limited mobility. These include adjustable seating, ramps, and manual overrides for malfunctioning doors. Hearing-impaired participants requested visual aids, such as instructional videos and real-time updates, to ensure they could follow safety procedures effectively. All out neurodivergent participants emphasised the importance of calming prompts and step-by-step guidance to reduce anxiety and confusion in such high-stress situations.

"It may be a situation where it's completely okay for other people to stay in the car, because, for them, it's safer. But for myself, or for other people [with ADHD], it may be a ***requirement*** *to get out of the car [as I need to get out of the situation]." – Ryan, [Neurodivergent], (Pedestrian interaction scenario)*

"If I had to deal with external agencies, I would need to let them know that I can't hear very well." – Simon, [Hearing impairment], (Medical emergency scenario)

"So, if it comes to a stop and the doors open but the electrics have gone, can the ramp still fold out?" – Nicola, [Physical impairment], (Fire or smoke emergency with door malfunction scenario)

To address the fears and needs of passengers with disabilities across various scenarios, self-driving taxis should incorporate robust accessibility features. Automated and manual emergency systems are essential, including door unlock overrides and reliable ramps for egress in the *Fire or smoke emergency with door malfunction scenario*. Vision-impaired passengers in scenarios like the *Incorrect stopping point scenario* require voice-guided navigation, while hearing-impaired users benefit from real-time visual updates and non-verbal alerts. Neurodivergent passengers, particularly in overstimulating situations like the *Road closure due to flooding scenario*, need structured, simple instructions delivered in calming tones or visuals.

Interactive communication systems are vital, allowing passengers to connect with a remote operator who can provide tailored support in the absence of an in-person driver. For example, in the *Pedestrian interaction scenario*, a live operator could guide a vision-impaired passenger through assessing the safety of a pedestrian attempting to interact with the vehicle.

"It could have a video or even a safety screen before you board, or an app with a video [to show what to do in a fire]." – Jess, [Vision impairment], (Fire or smoke emergency with door malfunction scenario)

"I would want to have a phone number printed on the car itself for emergency contact... I would want to interact with someone over the phone. I would need something other than an emergency button where it sends a signal. I want to do it myself."– Salma, [Neurodivergent], (Road closure due to flooding scenario)

Sex

Participants' fears related to the protected characteristic of sex were primarily shaped by perceptions of safety and vulnerability, especially in situations without a driver present. Female participants consistently reported heightened anxiety when dealing with unknown male pedestrians (*Pedestrian interaction scenario*). The absence of a driver to mediate interactions or provide a sense of safety further exacerbated their concerns, leading to fears of potential aggression or threatening behaviour. Non-binary participants expressed similar concerns, noting feelings of insecurity when alone in the vehicle.

In emergencies such as the *Medical emergency scenario*, female participants feared being alone with an unwell male passenger in isolated or dark locations. Some worried about their physical safety, as they may be being 'hoaxed' and the passenger was not really unwell but was just trying to get them to interact with them. Male participants, in contrast, expressed concerns about their actions being misinterpreted when assisting female passengers, reflecting broader societal anxieties about gender dynamics.

The *Vehicle collision scenario* introduced further concerns, with female participants highlighting a heightened sense of vulnerability in confrontations with potentially aggressive male drivers. Male participants worried about gendered dynamics in high-stress situations, such as male-to-male confrontations escalating into conflict. In the *Incorrect stopping point scenario* and the *Road closure due to flooding scenario*, sex was not identified as a relevant factor influencing participants' responses or shaping their experiences.

"If that was a man outside, I'd feel more anxious and uncomfortable. A lot would depend on how they're reacting or responding [to not be able to get in the taxi]."
– Charlotte J, [Female], (Pedestrian interaction scenario)

"If I had to, I'd get out of the taxi [to get away from the pedestrian] when it had stopped. But then... being a woman, if it was dark and late, I would then start to think about my own safety and the situation I had put myself in."
– Latayah, [Female], (*Medical emergency scenario)*

"I think being a male, if it was a female [unwell passenger on the floor] ... I would want CCTV recording that I never did anything bad to them... so gender will be an issue."
– Abel, [Male], (Medical emergency scenario)

"I'm female, I'm going to be vulnerable in this taxi. I don't know if that's a guy or a female driving [the car that hit us], but if they caused an accident, now they might come up and blame ***me*** *for being a slow driver."*
– Naledi, [Female], (Vehicle collision scenario)

The absence of a driver in self-driving taxis creates a unique gap in perceived safety, particularly for female and non-binary passengers. To address these fears, participants overwhelmingly emphasised the need for direct communication systems, such as an emergency button or live operator connection, to provide immediate reassurance and assistance. In scenarios such as the *Pedestrian interaction scenario*, female participants suggested practical features like the ability to exit the vehicle from the opposite side of the interaction or activating an emergency system to deter threats.

In the *Medical emergency scenario*, participants highlighted the need for measures that ensure transparency and accountability during interactions. For male passengers assisting female passengers, features such as CCTV monitoring and audio recording were seen as critical to avoid potential misunderstandings. Female participants suggested that self-driving taxis offer enhanced security measures, such as panic buttons or automated alerts, to help mitigate fears of being left vulnerable. In the *Vehicle collision scenario*, both male and female participants noted the need for systems that de-escalate confrontations, such as immediate connections to emergency responders or taxi operators. Female participants prioritised tools that enhance their sense of security, such as visible cameras or alerts to notify authorities about potential aggression.

"If I was in an Uber, for example, I would feel a bit more comfortable knowing that I've got a male driver there [in an accident], as it takes the responsibility off me to speak to the person outside."
– Catherine, [Female], Pedestrian interaction scenario

"I would want to be able to call someone for help... like an emergency button to get the police's attention or, if it's not that serious, then to speak to someone who runs the company...so I can tell them what the situation is."
– Kiara, [Female], Medical emergency scenario

To address these concerns, self-driving taxis could include robust communication and safety systems. Transparent monitoring tools, such as interior CCTV and audio recording, are essential for ensuring accountability during sensitive interactions, especially in scenarios such as the *Medical emergency scenario*. Features like panic buttons, automated locking mechanisms, and live operator connections are crucial for offering reassurance in the *Pedestrian interaction scenario*.

In high-stress situations like the *Vehicle collision scenario*, the system should include tools that promote de-escalation and facilitate immediate access to emergency services. For female and non-binary passengers, practical safety measures such as alternative exit routes and visible distress signals can help mitigate feelings of vulnerability. Male participants assisting others can benefit from clear protocols that minimise the risk of misinterpretation.

Sexual orientation

Participants expressed various fears related to their sexual orientation, with concerns varying across scenarios. Gay male participants, for example, highlighted specific risks of being targeted or harassed, particularly when departing from venues associated with their sexual identity, such as gay pubs (*Pedestrian interaction scenario*). The lack of a driver heightened their feelings of vulnerability, as the self-driving taxi offered no human presence to mediate or deter potential threats. Similarly, non-binary participants reported feeling insecure and vulnerable when alone in the vehicle, particularly if faced with threatening or aggressive behaviour from others.

The single pansexual participant in the study raised concerns about potential bias from first responders in emergency situations as they had experienced in the past (*Medical emergency scenario*). They worried that personal prejudices might affect the quality or urgency of the assistance they received, increasing their anxiety during already stressful scenarios. These fears underscore the need for the self-driving taxi system to include safeguards that ensure fair and equitable treatment of all passengers, regardless of their sexual orientation.

"Depending on where I've come from...if I've come from a gay pub or something like that... I'd be thinking are they feeling intimidated and want to threaten me." – Alan G, [Gay], (Pedestrian interaction scenario)

"when the [emergency] people get there, like the first responders or something... if they are against people like me, they might not help me." – Paige, [Pansexual], (Medical emergency scenario)

Participants identified several system requirements to ensure their needs are met and their fears alleviated. High-quality CCTV systems should be installed inside and outside the cab to provide monitoring and accountability, particularly during external interactions or in high-risk areas (*Pedestrian interaction scenario*). Additionally, emergency buttons and live operator connections should be integrated to enable passengers to report homophobic threats and receive real-time support.

To address concerns about bias, AI-powered systems capable of recognising discriminatory behaviour or language should be implemented. These systems could automatically trigger alerts or actions to mitigate risks and ensure passengers' safety. Furthermore, automated emergency protocols must be designed to deliver fair and consistent responses, reducing the risk of unequal treatment during incidents (*Medical emergency scenario*).

> *"[Technology that] picks up on derogatory terms or anything like that that would be good. They need to have a camera, CCTV as well [to prevent homophobia]."* – Nicole, [Bisexual], (*Pedestrian interaction scenario*)

Religion

Participants' religious beliefs and cultural values rarely influenced their responses to scenarios, with concerns primarily tied to interpersonal interactions and emergencies governed in the first instance by other protected characteristics they had. When directly prompted if religion would be a factor, in the *Pedestrian interaction scenario*, one Muslim [female] participant expressed significant discomfort when imagining an interaction with a male pedestrian attempting to enter the self-driving taxi. She identified her discomfort stemmed from her faith's discouragement of certain interactions between opposite sexes, amplifying her feelings of vulnerability in the absence of a driver. A few Sikh participants also noted fears related to their visible religious markers, such as wearing a turban, which they felt could make them targets for prejudice or aggression. In the *Vehicle collision scenario* and the *Fire or smoke emergency with door malfunction scenario*, some participants from different religious backgrounds mentioned the psychological role of prayer as a coping mechanism in high-stress situations, using it to ground themselves and seek reassurance.

> *"I'd worry they were being aggressive because of my appearance... because I wear a turban." – Sulakhan, [Sikh], (Pedestrian interaction scenario)*
>
> *"Because I'm Christian, in emergency, I like say a small prayer before I do anything." – Sylvia, [Christian], (Vehicle collision scenario)*
>
> *"There is a [Jewish] prayer that most people would recite [in an emergency situation]. But then again, presumably that would be the same in Catholicism, Islam..." – Mel, [Jewish], (Fire or smoke emergency with door malfunction scenario)*
>
> *"As a female, and as a Muslim as well, if he's a man, I would be really scared in this situation." – Salma, [Muslim], (Pedestrian interaction scenario)*

Sikh participants in particular highlighted the need for visible safety features, such as CCTV, to ensure accountability and deter discriminatory behaviour based on their religious identity. These systems would provide an additional layer of reassurance by documenting any potential incidents of aggression. However, most participants generally focused on logistical or physical challenges rather than any concerns tied to their faith.

Age

Age-related fears often intersected with other protected characteristics, such as disability, sex, and pregnancy, influencing participants' experiences and needs. Age rarely stood alone as a primary influencing factor. For middle-aged participants, it was not initially perceived as relevant and had to be prompted for consideration. Younger participants (8–17 years) highlighted a sense of vulnerability tied to the lack of an authority figure, such as a driver or parent, within the self-driving taxi. Their fears centred around making decisions independently, particularly in ambiguous or threatening situations. For older participants (65+), age-related concerns frequently overlapped with mobility challenges, which they associated with physical disability. They worried about being perceived as frail or unable to respond effectively in emergencies. These fears were compounded by the absence of a human figure to offer age-sensitive assistance, particularly in emergencies where physical exertion or quick decision-making was required.

Participants in middle-age categories (45–65 years) rarely cited their age as a factor influencing their responses unless prompted to consider it. Their concerns tended to focus on broader issues of safety, communication, and effective system responses rather than age-specific challenges.

Participants indicated that age had no direct relevance to the *Road closure due to flooding scenario* or the *Fire or smoke emergency scenario*. Concerns in these scenarios were more closely tied to physical and sensory impairments rather than age-specific challenges.

"...I don't think you should be under a certain age limit... travelling alone without your parents... [if I was alone] I don't think letting them in would be a good idea." – Hugo, [12], (Pedestrian interaction scenario)

"I suppose the only relevant protected characteristic in this scenario for me would be my age, perhaps. I'm going to be a little more frail [and would feel vulnerable]." – Tony, [80] (Pedestrian interaction scenario)

Participants' age-related needs varied significantly across age groups. Younger passengers expressed a strong desire for reassurance and structured guidance. They wanted systems that could simulate the role of a parent or authority figure, providing clear instructions and real-time support to help them navigate unfamiliar or potentially threatening situations.

Older participants prioritised accessibility features, such as wide doors, low steps, and manual overrides, to accommodate physical limitations often associated with ageing. They also highlighted the need for tailored emergency assistance, such as real-time operator connections or medical alerts, that could address age-related health concerns in high-stress scenarios.

Middle-aged participants' needs focused more on the system's ability to provide transparent and effective communication. They valued step-by-step guidance and live updates to ensure that emergencies were handled efficiently, regardless of their age.

"I suppose being young can make you feel a bit vulnerable. I would want to know that there was, like, a 24-hour helpline to get in touch [with older people to help me]." – Emily B, [35], (Pedestrian interaction scenario)

"If the rear window was the only escape point, then, because of my age, I might not be able to easily get out.'' – Noel, [61], (Vehicle collision scenario)

To meet the diverse needs of passengers across age groups, self-driving systems must incorporate features that address age-specific challenges and their intersections with other characteristics. For younger passengers, the system should provide robust communication tools, such as live operator support, voice-guided instructions, and visual aids, to offer the reassurance typically provided by a parent or authority figure.

For older passengers, accessibility features, such as wide doors, low steps, and manual overrides, are essential for ensuring physical safety. Integrated medical alerts, emergency buttons, and connections to emergency services are critical for addressing age-related health risks.

Middle-aged participants suggested that the system's transparency and clarity in emergency responses were key. Features like automated updates, real-time guidance, and context-specific instructions would help alleviate concerns and ensure effective responses across scenarios.

Pregnancy and maternity

Pregnant participants expressed heightened feelings of vulnerability due to their dual responsibility for their own safety and that of their unborn child in multiple scenarios. In the *Pedestrian interaction scenario*, the ambiguity of a pedestrian's intentions—whether they were attempting to provide some assistance or posed a threat—was particularly unsettling. This uncertainty made pregnant participants acutely aware of the need for immediate communication with a human operator to assess and manage potential risks. Those participants in the postpartum phase also commented that having their child with them made them particularly fearful of anything unusual, and they noted that they might interpret situations as threatening that they wouldn't have previously when travelling alone.

In the *Fire or smoke emergency with door malfunction scenario*, participants who were pregnant highlighted the physical limitations imposed by pregnancy, such as reduced mobility and an inability to perform physically demanding tasks like climbing through a window to evacuate. These constraints heightened the need for accessible and effortless evacuation options. Similarly, in the *Vehicle collision scenario*, pregnant participants emphasised the need for immediate medical checks following a collision to ensure the well-being of both themselves and their child.

“Something might have happened to me inside the taxi and [the pedestrian could be] trying to get in to help me.” – Sophie, [3-months pregnant], (Pedestrian interaction scenario)

“Even if I could break a window [to escape the fire], I wouldn't want to jump out with being pregnant.” – Natalie, [6-months pregnant], (Fire or smoke emergency with door malfunction scenario)

“Depending on how badly we were hit, I would then start to panic about getting to a hospital and getting the baby checked over.” – Laura H, [8-months pregnant], (Vehicle collision scenario)

Many of the needs that pregnant participants outlined were shared by those with other protected characteristics but were specifically related to their unique physical and emotional well-being during emergencies. For instance, communication tools that provide immediate access to support or reassurance, particularly in ambiguous or threatening situations (*Pedestrian interaction scenario*), were mentioned in relation to other protected characteristics. However, features such as automated door unlocking and emergency buttons were particularly important for pregnant participants, as they enabled rapid responses without physical strain and evacuation was their primary concern.

In other scenarios also requiring evacuation, such as *Fire or smoke emergency with door malfunction scenario*, participants emphasised the need for features like low-threshold ramps and automatic doors that function reliably even during system malfunctions. Pregnant participants also expressed a preference for self-driving taxis that provide clear instructions on how to evacuate safely, paired with non-invasive monitoring tools to assess their well-being post-incident.

“I have a young baby...when I'm travelling with her, I do generally feel quite a bit more vulnerable, than when I’m by myself.” – Latayah, [9 months postpartum], (Pedestrian interaction scenario)

“I probably wouldn't try to put the fire out if I was with my daughter. I think I'd just concentrate on getting the hell out.” – Francesca, [Maternity leave], (Fire or smoke emergency with door malfunction scenario)

Participants noted that pregnancy had no direct relevance to the *Incorrect stopping point scenario* or the *Road closure due to flooding scenario*. Responses in these scenarios focused primarily on mobility and accessibility issues, which were not explicitly tied to pregnancy even when directly prompted.

To meet the needs of pregnant and postpartum passengers, the self-driving taxi system must integrate several key features. Reliable communication tools, such as emergency buttons or live operator connections, are essential for providing reassurance in ambiguous or high-stress situations. Automated systems must also account for physical limitations, with accessible evacuation tools such as wide, low-threshold doors, ramps, and automated guidance systems that remain functional during emergencies.

Medical support systems should be integrated into the vehicle, including the ability to connect passengers with medical professionals or dispatch emergency responders. Post-incident support, such as notifications to nearby healthcare facilities or built-in medical monitoring, could further enhance passenger safety and confidence.

Race

Race was not frequently mentioned as a primary factor influencing participants' responses, but in certain situations, it intersected with other characteristics such as Sex to shape perceptions of safety and vulnerability. Some participants who identified as Black or from visible minority backgrounds expressed concerns about how their race might influence others' perceptions of their actions, particularly in situations where assistance or intervention was required. Participants generally indicated that race was not relevant to the *Incorrect stopping point scenario*, the *Road closure due to flooding scenario*, or the *Fire or smoke emergency with door malfunction scenario*. These scenarios were primarily influenced by other characteristics, such as disability or sensory impairments.

In the *Medical emergency scenario*, one participant noted their own hesitation in offering help to an unwell passenger would be due to fears of being misjudged because of their race. Similarly, in the *Pedestrian interaction scenario*, concerns were raised about how race might impact interactions with strangers outside the vehicle, particularly in ambiguous or high-stress situations. This could be the race of the pedestrian trying to get in or the race of the passengers inside. Participants also highlighted the potential for racial prejudice or stereotyping, which could influence their comfort levels during certain interactions. These fears reflect broader societal issues, underscoring the need for self-driving taxis to incorporate features that promote accountability and equity. These fears were intensified by the absence of a driver, who could mediate interactions.

> *"Yes, it's an emergency. But I'm Black so, you know, I don't know how [another non-black passenger] might take me approaching them." – Abel, [Black], (Medical emergency scenario)*

Participants emphasised the need for self-driving systems to include mechanisms that could address fears of racial misjudgement and ensure equitable treatment for all users. Transparent accountability measures, such as real-time video or audio recording, were identified as essential for providing a sense of security. These features would help document interactions and reassure passengers that their actions would not be misinterpreted in the absence of a driver. The need therefore is for the system/emergency process to be sensitive to the role of race in social interactions.

Participants also highlighted the importance of communication features that could mediate interactions, particularly in emergencies. In the *Medical emergency scenario*, a system capable of facilitating clear and immediate communication between passengers and external responders was viewed as critical to minimising misunderstandings.

To address the specific concerns raised by participants about race, self-driving taxi systems must incorporate features that promote transparency, accountability, and trust. Real-time video and audio monitoring are essential for documenting incidents and ensuring that interactions are perceived as fair and unbiased. Additionally, the system should include advanced communication tools, such as live operator support, that can facilitate clear, mediated conversations between passengers and external responders. These tools would help address fears of racial stereotyping or misjudgement by providing an impartial layer of support. Automated responses, such as system-generated alerts or instructions, could also help reduce the reliance on passenger-led interactions, further mitigating concerns about prejudice.

Gender reassignment

The participant who identified as transgender highlighted unique fears tied to their gender identity, particularly in scenarios involving interpersonal interactions. In the *Pedestrian interaction scenario*, the participant (a transgender female) expressed heightened concerns about it being a potential hate crime. The absence of a driver in the self-driving taxi exacerbated her feelings of vulnerability, as it removed a potential deterrent to harmful behaviours. The participant worried about the intentions of individuals attempting to enter the vehicle and whether such interactions could escalate into targeted attacks based on her gender identity.

In the contract of an emergency, the lack of tailored support systems for transgender passengers further contributed to their fears. For example, the participant highlighted the risk of having her gender identity misrepresented or mishandled in high-stress situations, such as when emergency responders were involved. She expressed concern that standard emergency protocols might not adequately address the unique challenges faced by transgender individuals.

> *"...if I was in a driverless taxi on my own with no driver and somebody was trying to get in, I would think, what do they want? Is it a hate crime ... an attack? What is their intention?" – Drew, [Transgender Female], (Pedestrian interaction scenario)*

The participant identified several needs to address their fears and improve the self-driving system's inclusivity. First, she suggested a pre-filled "Diversity and Inclusion" forms within the system, which could inform emergency responders about the passenger's protected characteristics in a controlled and sensitive manner. This feature would allow responders to provide tailored support while respecting the individual's privacy and dignity.

Additionally, the participant confirmed the necessity of a reliable, immediate communication tools that could connect passengers with human operators during potentially threatening situations. Features such as audio and video monitoring systems were also seen as critical for ensuring accountability and deterring harmful behaviour from external individuals.

> *"It's not something I would want to announce on an alert, 'transgender woman'. So, for me, it would be good if you could fill all that information out in advance on the app and give permission for the information to be viable. So then, if you did raise an alert, whoever's running the app will know [it's a hate crime occurring]." – Drew, [Transgender Female], (Pedestrian interaction scenario)*

To meet the needs of transgender passengers and address their fears, self-driving systems should include features that ensure safety, inclusivity, and tailored support. Pre-filled diversity profiles should be an integral part of the system, allowing passengers to disclose relevant information confidentially. These profiles could be securely accessed by emergency responders to provide appropriate and sensitive care.

Communication tools must also prioritise accessibility and immediacy. Emergency buttons, live operator connections, and integrated monitoring systems, such as CCTV and audio recording, would provide reassurance to passengers and deter discriminatory behaviour. Training for operators and emergency responders on addressing the needs of transgender passengers could further enhance the system's inclusivity.

The transgender participant indicated that they felt that gender reassignment had no direct relevance to the *Medical emergency scenario*, *Incorrect stopping point scenario*, *Road closure due to flooding scenario*, or *Fire or smoke emergency with door malfunction scenario*. Any concerns in these scenarios focused on broader accessibility and safety issues rather than challenges tied specifically to gender identity.

Marriage and civil partnership

Marriage and civil partnership as a protected characteristic were consistently identified as not relevant factors influencing participants' responses across the various self-driving taxi emergency scenarios. Unlike other protected characteristics, marriage did not appear to directly affect participants' ability to perform tasks, interpret situations, or engage with the self-driving system in a meaningful way. This suggests that the absence of a driver or the automated nature of these vehicles did not intersect with marital or partnership status to influence participants' perceptions or experiences.

Digitally excluded participants

Four participants in the sample responded 'never' to screener questions regarding how often they used the internet or smartphones. Their responses to emergency scenarios in self-driving taxis provided insights into how unfamiliarity with technology could impact individuals' reactions and decision-making processes if there was an emergency in a self-driving taxi. These digitally excluded participants explained that they struggle with adapting to new technologies, acknowledging the importance of keeping up with advancements but also showing frustration when dealing with digital interfaces. They demonstrated a preference for traditional methods of communication during emergencies, such as putting down the window to ask someone for help or waiting for instructions from taxi operators rather than relying on automated systems. Additionally, an emphasis on personal safety first suggests a cautious approach influenced by limited experience with modern emergency response technologies.

There was also a clear preference for simpler navigation tools and traditional means of accessing emergency services among participants. Difficulty with digital interfaces was noted, which could hinder effective use of tech-based emergency features. The desire for access to established emergency protocols over newer digital alternatives highlights reliance on familiar systems.

These findings suggest that designing inclusive emergency response systems should firstly mirror existing procedures that exist in normal taxi services but should also consider providing alternative options not contingent on interacting with interfaces to cater to those less comfortable or experienced with digital technologies. This will ensure accessibility for all users regardless of their technological proficiency.

"I'll knock on the window, as there might be somebody outside who can help me" Ian, [Digitally excluded], (Pedestrian interaction scenario)

"One thing I've realised now, is that every person should keep up with the new technology." Onkhar, [Digitally excluded], (Medical emergency scenario)

"It's a new technology that the elderly will take time to learn." Sulakhan, [Digitally excluded], (Fire or smoke emergency with door malfunction scenario)

3.3 Intersectionality and its impact on experience and perception

Having explored user needs across specific emergency scenarios, it is important to step back and consider broader patterns. This section examines how protected characteristics intersect to shape user challenges and the common features required to address them. By focusing on the tasks users may need to perform during emergencies and the barriers they face, we aim to identify shared needs and opportunities for inclusive design. The findings of this study demonstrate the importance of considering intersectionality—how overlapping identities and protected characteristics influence individuals' experiences and perceptions.

Participants' responses highlighted that the interplay of multiple characteristics, such as age, disability, gender, and religion, often created unique challenges or compounded vulnerabilities in emergency scenarios.

Age and Disability
The intersection of age and disability was particularly pronounced in scenarios requiring physical mobility, such as evacuating a flooded area or escaping a vehicle fire. Older participants with mobility impairments expressed concerns about the compounded difficulties of navigating adverse environments, emphasising the critical need for accessible vehicle designs. For example, wheelchair users aged 65+ highlighted that their age-related health conditions, such as arthritis or heart problems, could further limit their ability to respond quickly in emergencies. In contrast, younger participants with disabilities noted that societal perceptions of their age sometimes led to a lack of consideration for their impairments. This demonstrates how the intersection of age and disability can either amplify or obscure specific accessibility needs.

Gender and Religion
The interplay between gender and religion emerged prominently in scenarios involving interpersonal interactions, such as the *Pedestrian interaction scenario*. One Muslim female participant described heightened feelings of vulnerability when faced with male pedestrians due to cultural or faith-based norms regarding gendered interactions. Although this was the only Muslim participant who raised this concern, it may be that others would share this reticence as part of socialised upbringing and segregated social practices. However, the orthodoxy of a person's practice may shape this concern most. What is most interesting was that their safety concerns were shaped not only by their gender but also by their faith, which framed their perceptions of acceptable social boundaries. The intersection of gender and religion highlights the need for automated vehicle systems to account for cultural sensitivities when designing features, such as emergency communication protocols.

Disability and Neurodivergence
Participants with both physical disabilities and neurodivergent conditions, such as autism or ADHD, reported experiencing unique challenges in emergencies. While physical impairments often limited their ability to perform certain tasks, neurodivergence influenced their emotional responses and decision-making processes. For instance, a participant with ADHD noted that while their condition enabled them to act quickly in chaotic situations, their physical limitations, such as mobility impairments, hindered their ability to implement those decisions effectively. This dual impact highlights the need for emergency systems that simultaneously address physical accessibility and cognitive load, such as by providing step-by-step guidance and ensuring that vehicle systems remain simple and intuitive.

Sexual Orientation and Safety
For LGBTQIA+ participants in this study concerns about personal safety often intersected with the absence of a driver in self-driving taxis. These participants emphasised the potential for bias or prejudice from first responders in emergency scenarios, particularly if they were departing from locations associated with their sexual identity. The combination of marginalised sexual orientation and the perceived vulnerability of being alone in an automated vehicle amplified their anxiety. However, for one participant, their unwillingness to interact with others who may be prejudiced against them based on appearance, actually

increased their likelihood of using self-driving taxis in the future, despite potential emergencies, as they wouldn't need to interact with a driver. This intersection underscores the need for automated systems to provide unbiased and reliable safety features, such as live monitoring and communication with trained operators, to alleviate fears tied to social bias. Although this isn't necessarily something that AVs can address, as it is a much wider societal issue, there may be options that could help such as communication and monitoring.

Pregnancy and Caregiving Roles
Pregnancy intersected with caregiving responsibilities to heighten participants' sense of urgency and protectiveness in scenarios involving potential harm, such as fires or collisions. For instance, pregnant participants noted that their mobility limitations could prevent them from physically assisting others, while postpartum participants reported heightened anxiety when travelling with their children. These responses illustrate how caregiving roles, compounded by physical vulnerability, create specific needs that automated vehicles could address through robust safety protocols and accessible emergency exits.

Race and Sex
While race was not a dominant factor in most scenarios, it intersected with situational contexts to influence participants' perceptions of safety and vulnerability. Concerns about racial misjudgement or stereotyping were particularly salient in scenarios requiring interaction with others from the opposite sex, such as assisting in medical emergencies or engaging with pedestrians. The absence of a driver in self-driving taxis was noted as a factor that heightened these fears, underscoring the need for systems that promote accountability and fairness.

Summary

- Older adults with mobility challenges highlighted the dual impact of age and disability on evacuation and emergency responses.
- Safety concerns shaped by cultural or faith-based norms intersected with gender, particularly in interpersonal scenarios like pedestrian interactions.
- Fears of racial misjudgement intersected with situational factors, such as interactions with pedestrians or emergency responders, emphasising the need for fairness and accountability.
- Participants' experiences were shaped by overlapping protected characteristics, such as age, disability, gender, religion, and sexual orientation, highlighting the importance of inclusive design.

4. Results

This section presents the findings from the task analyses across all emergency scenarios, identifying common tasks passengers must perform during emergencies in self-driving taxis in a master task framework. It outlines user requirements and system features needed to support these tasks, particularly in the absence of a driver. Key results include prioritising interventions based on the barriers faced by passengers with diverse needs and reflections on the effectiveness of the virtual reality method used to simulate emergency scenarios.

4.1 Master task framework in an emergency in a self-driving taxi service

The master task framework outlines the key tasks that users must perform during emergencies in self-driving taxis, where the absence of a driver fundamentally shifts responsibilities to automated systems and the passengers themselves. By breaking down the sequence of tasks into distinct stages, the framework highlights the processes, user needs, and system interfaces required to ensure safe and effective responses in emergency situations in APS compared to traditional human driven taxi services. Figure 9 shows the flow of processes visually.

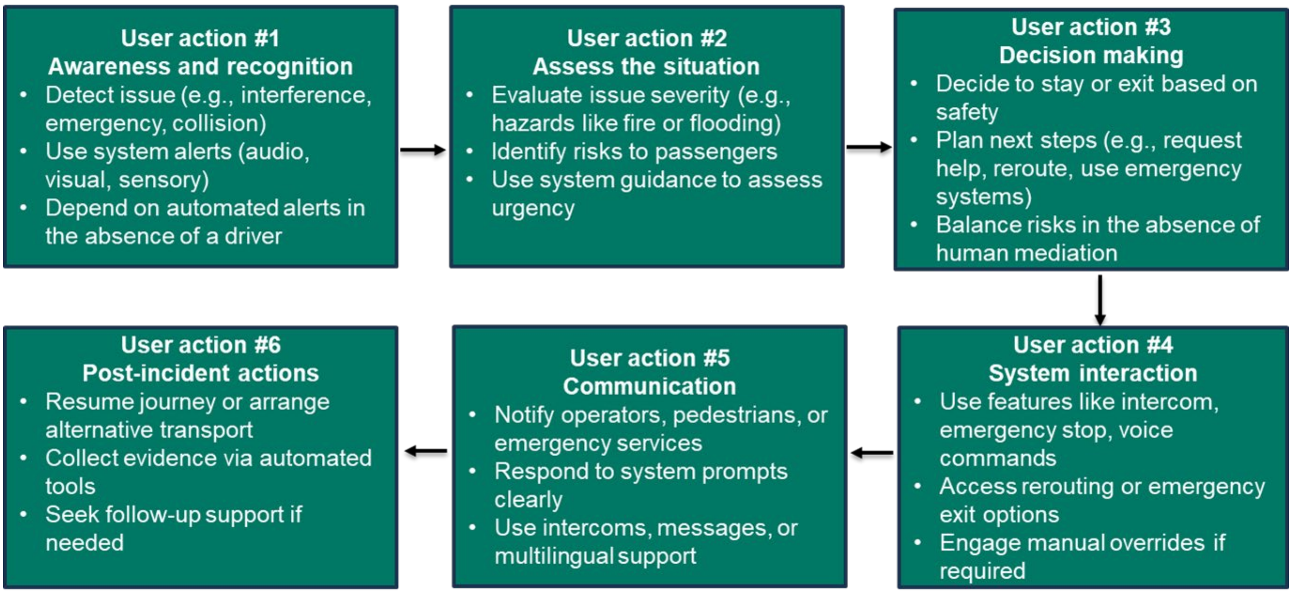


Figure 9 Flow diagram showing the user actions starting from top left to right: Awareness and recognition, Assess the situation, Decision-making. Bottom right to left: System Interaction, Communication, Post-incident actions.

User action #1 Awareness and recognition: The first stage focuses on users' ability to detect and understand potential issues. In traditional taxis, passengers rely on the driver's judgment to recognise and respond to emergencies. The driver is responsible for assessing the situation, deciding whether to contact emergency services, and taking any necessary actions, such as pulling over to a safe location or providing reassurance to passengers. Emergency alerts, such as flashing lights, sirens, or verbal cues, are typically provided by the driver, and the passenger's role is often passive.

In self-driving taxis, however, passengers will need to take on a more active role in recognising emergencies. This presents an opportunity to develop system features that provide clear and accessible alerts to notify passengers of potential issues, such as door malfunctions, accidents, or external threats. These notifications could be tailored to passengers' specific needs, particularly for individuals with sensory impairments. For example, passengers with visual impairments may benefit from audio cues, while those with hearing impairments may require visual signals or subtitles. As technology develops, there is potential to further explore and refine these features to ensure they meet the needs of all users, offering better ways to alert and inform passengers in real-time.

In the absence of a driver, passengers must rely entirely on system-provided alerts, such as audio cues, visual notifications, or other sensory signals, to identify risks. Automated systems play a crucial role in providing clear, timely, and accessible notifications to all users, ensuring that those with sensory impairments or cognitive challenges can understand the situation.

User action #2 Assess the situation: The second stage involves evaluating the severity of the issue and identifying immediate risks to safety. In traditional taxis, the driver is responsible for quickly assessing the situation during an emergency, whether it involves calling emergency services, taking immediate action to avoid further harm, or providing guidance and reassurance to passengers. For example, in a medical emergency, the taxi driver would assess the severity of the situation and respond accordingly, either by calling emergency services or ensuring that the passenger remains calm until help arrives.

In a self-driving taxi, this responsibility shifts to the user. This offers an opportunity to explore how self-driving vehicles can provide contextual guidance to help passengers assess the severity of the emergency. For example, if a fire or smoke emergency occurs, the system could alert the user and guide them through understanding the situation, perhaps with visual or auditory indicators of the severity of the emergency.

Without a driver to interpret the environment or guide passengers, users depend on the system's ability to provide contextual guidance. For example, passengers may need to assess hazards like fire, flooding, or external threats based on system notifications. This stage is critical for determining the urgency of the situation and deciding on appropriate next steps.

User action #3 Decision making: In the decision-making stage, users must choose how to respond to the emergency. In traditional taxis, passengers generally defer to the driver's expertise when deciding how to respond in an emergency. The driver makes critical decisions, such as whether to pull over, how to communicate with emergency services, and whether the passenger should stay in the vehicle or evacuate. Passengers are often passive participants in these decisions, following the driver's instructions.

In a self-driving taxi, passengers must make these decisions independently or with support from the vehicle's system. Decisions such as whether to stay in the vehicle or exit depend on the perceived level of danger and the clarity of system-provided information. The absence of a driver eliminates a key source of human mediation, requiring the system to provide intuitive and reliable support to facilitate informed decisions.

System features that help passengers make informed decisions could be introduced: for instance, emergency stop buttons (E-Stop), door overrides, and clear exit strategies could guide users during emergencies. This presents an opportunity to explore how adaptive controls, and accessible interfaces can be integrated to assist passengers with varying levels of ability and experience. As these technologies develop, there is an opportunity to fine-tune the interaction between the system and passengers, ensuring that decision-making is as intuitive and supportive as possible for a diverse range of users.

User action #4 System interaction: This stage highlights the need for passengers to engage with system features to execute their decisions. In traditional taxis, passengers rarely need to interact with the vehicle's systems during an emergency. The driver typically manages all aspects of the situation, including controlling the vehicle, accessing communication tools, and activating emergency features such as door locks or stop buttons.

In self-driving taxis, however, users will be responsible for interacting with the system directly to manage the emergency. This could include tasks such as activating emergency stop buttons, using voice commands, or accessing manual overrides for doors and other systems. System interfaces could be made user-friendly and adaptable to ensure that all passengers can interact with the system easily, regardless of their abilities. This could involve developing adaptive controls, such as voice-activated systems or tactile feedback for users with mobility or sensory impairments. As the technology matures, these system interfaces can be tested and refined to improve accessibility and usability for a broader range of passengers.

User action #5 Communication: Communication is another critical stage, where users must inform relevant parties—such as operators, pedestrians, or emergency services—about the situation. In traditional taxis, the driver acts as the intermediary between passengers and external parties. In an emergency, the driver typically makes the call to emergency services and communicates with others, either verbally or through gestures. The driver also reassures the passenger, offering support and guidance throughout the process.

In self-driving taxis, the communication responsibilities shift to the user, who may need to interact directly with emergency services, other passengers, or external parties. Robust communication tools, such as intercoms, pre-recorded messages, or operator support systems, will be required to ensure passengers can effectively communicate during emergencies. Multilingual options and accessibility features could be added to enhance the inclusivity of communication systems. These features compensate for the absence of a driver, who would typically facilitate such interactions but could also represent an enhancement in the taxi service for many users, making it a more appealing option than a traditional taxi service. This is an area where further development and testing are needed to ensure that communication systems can be made flexible and adaptive to the needs of all passengers, providing an effective means of interaction in a variety of emergency scenarios.

User action #6 Post-incident actions: Finally, the post-incident actions stage focuses on how passengers manage the aftermath of an emergency. After an emergency, traditional taxi passengers typically rely on the driver to manage follow-up actions, such as arranging alternative transport, contacting insurance, or receiving post-incident support. The driver may also provide emotional support, ensuring that passengers feel reassured and supported during the aftermath of the emergency.

In a self-driving taxi, however, users will need to manage these post-incident actions on their own or with support from the system. Tasks such as continuing the journey, arranging alternative transport, or accessing follow-up support require seamless system integration. Features like live operator assistance and automated tools would help users navigate these processes, ensuring that they feel supported even after the immediate emergency is resolved. As the technology develops, there is potential for more dynamic solutions to be integrated into self-driving systems, offering tailored assistance to passengers based on their individual needs. For example, real-time updates could be delivered in a format most accessible to the user, such as voice-guided systems for visually impaired users or simple text updates for users with cognitive impairments.

4.2 User requirements and system features required to support user requirement

This section summarises the general passenger needs identified across emergency scenarios in Automated Passenger Services (APS). Table 5 most common needs based on their frequency and importance across different user groups, highlighting the most critical requirements for ensuring safety and inclusivity in self-driving taxis. The ranking reflects user feedback from scenario task analyses (Section 3.1) and insights on protected characteristics (Section 3.2), providing a comprehensive view of user priorities.

The table emphasises the significance of clear and accessible communication during emergencies, which emerged as the top-ranked need across scenarios. Other priorities include safe egress methods, emotional support, and systems for reporting incidents, all tailored to address diverse user requirements. System features linked to these needs, such as audio-visual alerts, ramps, or operator support, aim to reduce barriers and enhance passenger confidence, particularly in the absence of a driver. Each need is linked to system features that would address it, such as emergency stop buttons, ramps, or intercom systems.

Table 5 Reported ranking of user requirements in a self-driving taxi service

Rank (frequency)	Most common user requirement	System features required to support user requirement
1	Clear and accessible communication of the emergency situation	E-call button, audio alerts, visual cues, subtitles, voice-activated notifications, structured interface messages
2	Safe and accessible methods for exiting the vehicle	Emergency stop button (E-stop), manual door overrides, ramps, tools for breaking windows
3	Guidance on interacting with external parties (e.g., other drivers, pedestrians)	Pre-recorded messages for external parties, intercom for live operator support, external hazard indicators

4	Reassurance and emotional support during stressful events	Structured and calm notifications, access to live operators, empathetic system prompts
5	Accessible systems for reporting incidents and seeking help	Subtitled or voice-based intercom systems, automated incident reporting, operator follow-up
6	Real-time updates on onward travel or alternative mobility options	Route adjustment options, accessible navigation apps, public transport suggestions
7	Assistance with post-incident follow-up (e.g., insurance, evidence collection)	Vehicle cameras for evidence gathering, intuitive evidence submission tools, operator assistance
8	Non-digital or simplified alternatives for digitally excluded users	Physical buttons, live intercom support, clear signage for emergency exits
9	Proactive hazard detection and mitigation systems	Sensors for fire, flooding, and collisions; automatic rerouting; system-initiated safety protocols
10	Physical and environmental safety monitoring (e.g., external dangers)	Live hazard assessments, external cameras, audible warnings, adaptive vehicle behaviour
11	Cultural or religious sensitivity in emergency protocols	Multilingual support, gender-sensitive communication, faith-based flexibility in notifications
12	Customisable or adaptive emergency response options for diverse needs	User preference settings for emergency responses, scalable solutions for different cognitive loads

4.3 Post simulation reflections on the VR method

After the study, participants were asked to reflect on their experience with the use of VR to evaluate whether their responses could be considered authentic. Recognising the innovative nature of the method, we collected anonymous data to understand how the VR experience influenced their engagement with the scenarios.

Participants rated their sense of "being there" within the VR environment. Most reported feeling highly immersed, describing the scenarios as both realistic and engaging (see Figure 10). This strong sense of presence was critical in ensuring that participants fully engaged with the tasks and challenges presented, which allowed for authentic and thoughtful responses to the emergency scenarios.

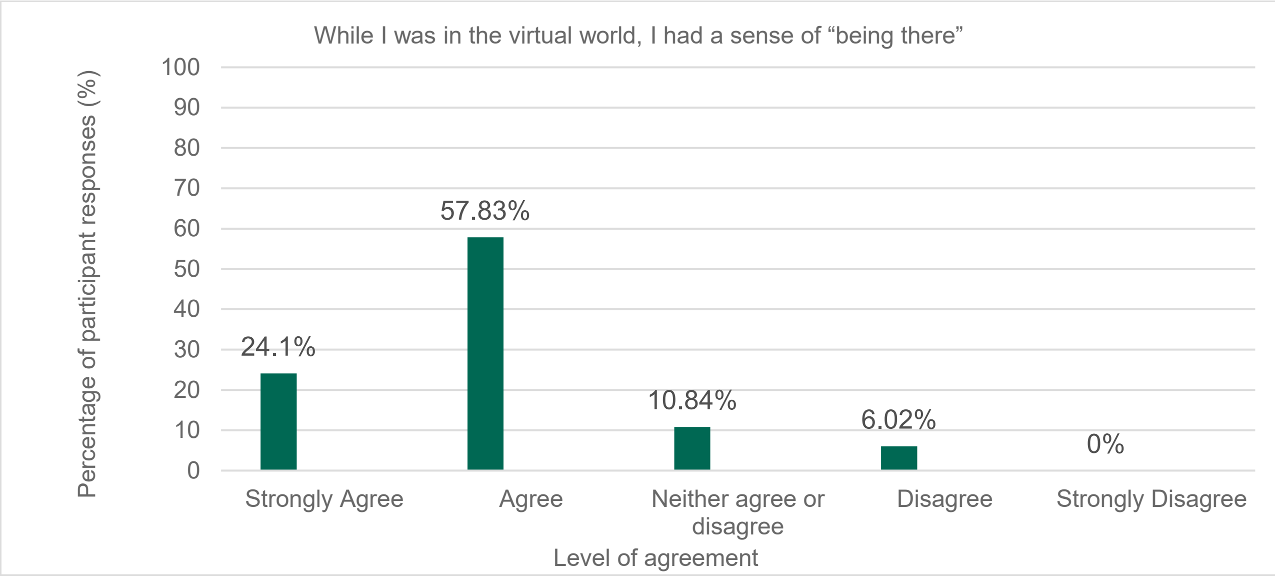


Figure 10 ***We asked, "While I was in the virtual world, I had a sense of "being there" N=83 (*8 participants did not complete the post experiment questionnaire)***

Additionally, participants assessed their level of immersion on a scale from 1 (least immersed) to 10 (most immersed). The majority of scores were above 5, highlighting that participants found the VR scenarios deeply engaging and realistic (see Figure 11). This immersive experience enabled participants to critically think about the challenges and opportunities associated with self-driving taxis, encouraging detailed and practical problem-solving. For example, the *Fire and smoke emergency with door malfunction scenario* was particularly impactful, with some participants describing how the sensation of heat in the virtual world prompted realistic reactions.

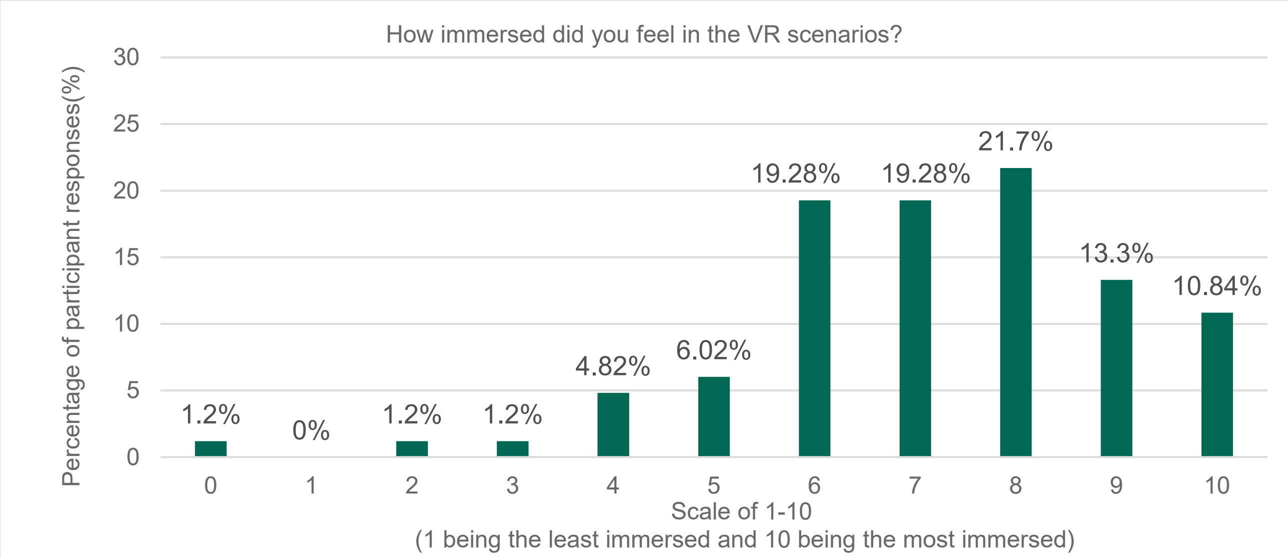


Figure 11 We asked, "How immersed did you feel?" using a scale of 1-10, 1 being the least immersed and 10 being the most immersed. N=83 (*8 participants did not complete the post experiment questionnaire)

Participants shared qualitative feedback that reinforced the value of the VR design in eliciting thoughtful responses. While the external environments were praised for their realism, some constructive feedback indicated that the taxi interiors could feel simplistic. Despite this, participants overwhelmingly agreed that VR enhanced their ability to engage with the scenarios and provided a clearer understanding of the challenges and opportunities associated with self-driving taxis, shown in the anonymous responses to the post-simulation questionnaire below:

“Personally, I liked how I had to look around at my surroundings to find the best solution to deal with the emergency.”

“[I found it] enjoyable because it was like I was in a little world. [In the fire scenario] I felt hot but when I took off the headset, I remembered I wasn't near heat.”

“The surroundings outside of the taxi looked quite realistic, but inside the taxi the graphics felt quite basic.”

However, participants also provided constructive feedback, such as noting that while the external environment appeared realistic, the interior of the taxi could feel simplistic. Despite this, the majority felt that the VR enhanced their ability to engage with the scenarios and provided a clearer perspective on the potential challenges and opportunities of self-driving taxis. The VR scenarios appeared detailed and realistic enough to evoke a strong sense of “being there.” This was a crucial element of the study, as it ensured participants could engage authentically with the emergency scenarios presented. When participants feel immersed in the environment, their reactions are more likely to reflect real-world behaviour, making the insights gathered more reliable and applicable.

For a study focused on self-driving taxis, the realistic and immersive nature of the scenarios enabled participants to critically evaluate challenges and consider practical solutions for emergency situations. The strong sense of presence provided a foundation for authentic responses, as participants were able to engage fully with the tasks and visualise themselves in real-life situations as shown in the final anonymous comments provided by some participants below:

“The VR made me think about different things, that I hadn't considered with driverless cars - like what I would need in an emergency situation”

“[The VR] put the scenario in perspective, [and gave it a] sense of realism”

“Compared to just discussing the self-driving taxis, the VR made it far more realistic and allowed me to think of more detailed answers”

“[After the VR experience] I understand better [now] how driverless taxi would work”

5. Discussion

The aim of this study was to explore the challenges users may face in managing emergency tasks within self-driving taxi services, focusing on the impact of their protected characteristics. The research investigated how individuals would navigate emergency situations in the absence of a driver, identifying the tasks they would need to perform, the barriers they might encounter, and the system features required to address their needs. This was achieved through a combination of solo interviews and focus group discussions with participants representing a diverse range of protected characteristics, including age, disability, gender, sexual orientation, religion, and race.

The findings provide valuable insights into the barriers faced by users during emergencies, particularly those from groups more likely to experience vulnerability or exclusion. A key observation is that individuals with disabilities, older adults, and younger passengers are most likely to face significant challenges in completing emergency tasks due to physical, cognitive, or sensory limitations. However, feelings of personal safety, shaped by factors such as race, religious beliefs, gender, or sexual orientation, also play a critical role in how individuals perceive and approach emergency situations. For example, fears of prejudice or misjudgement may interfere with some users’ willingness to seek help or take necessary actions.

This discussion section presents the key findings of the study, reflecting on these intersecting barriers and their implications for user experience in self-driving taxis. It also identifies limitations in the research and offers recommendations for designing accessible and inclusive systems that ensure all users can navigate emergencies effectively, even without the presence of a driver.

5.1 Key findings related to protected characteristics and user needs in self-driving taxi services

The absence of a driver in self-driving taxi services creates unique challenges for users related to their protected characteristics if there is an emergency during the journey. Without a driver to provide guidance, mediate interactions, or offer physical support, passengers must rely entirely on automated systems and interfaces. This section summarises the key findings in this study of how the lack of a driver influences the needs of users in relation to their protected characteristics and highlights the features participants in this study identified as required to address these challenges.

Disability
The absence of a driver removes the immediate assistance often required by users with disabilities. Physical impairments necessitate automated door unlocking, reliable ramps, and clear evacuation paths to compensate for the lack of human intervention during emergencies. Vision-impaired users, who might rely on a driver for situational context, require voice-guided navigation and audible alerts. Hearing-impaired users, without the option of verbal interaction, depend on visual aids and real-time updates. For neurodivergent passengers, the lack of a driver to provide calming guidance intensifies the need for structured, intuitive systems that minimise overstimulation.

Sex
The lack of a driver heightens feelings of vulnerability, particularly for female and non-binary passengers. Automated systems should replace the protective presence of a driver through features such as panic buttons, alternative exits, and live operator support. Male passengers, who might otherwise rely on a driver to mediate interactions, highlighted the need for transparent monitoring systems, like CCTV and audio recording, to ensure accountability and avoid misinterpretation during interactions.

Sexual Orientation
For LGBTQIA+ passengers, the absence of a driver to deter harassment or bias increases reliance on high-quality CCTV and live operator support to ensure safety in high-risk scenarios. Automated systems that detect and mitigate discriminatory behaviour should replace the reassurance a driver might provide, ensuring fair treatment and equitable emergency responses.

Religion
Without a driver to mediate or support passengers in emergencies, visible safety features like CCTV become critical for deterring prejudice and ensuring accountability, particularly for individuals with identifiable religious markers. In faith-based contexts, the lack of a driver to offer situational clarity emphasises the importance of alternative exits and culturally sensitive communication systems.

Age
The absence of a driver impacts younger and older passengers most significantly. Younger passengers (8–17 years), who might look to a driver for reassurance or authority, require live operator connections and structured guidance to fill this gap. Older passengers

(65+ years), who may depend on drivers for physical assistance, require accessible features like low-threshold doors, wide ramps, and tailored medical alerts to ensure safety without human support. Middle-aged passengers must rely on clear, step-by-step system guidance to navigate emergencies effectively in the absence of a driver.

Pregnancy and maternity
Pregnant passengers highlighted the absence of a driver as a significant factor in their sense of vulnerability during emergencies. Features such as automated door unlocking, low-threshold doors, and ramps are critical for safe evacuation without physical assistance. Live operator connections should provide the reassurance and support a driver might offer, while integrated medical response systems replace the driver’s role in assisting with health concerns post-incident.

Race
Without a driver to mediate interactions, passengers from racial minorities face increased anxiety about misjudgement or prejudice during emergencies. Real-time video and audio monitoring are essential for promoting fairness and accountability. Automated alerts and impartial instructions should take the place of driver intervention, ensuring inclusivity and reducing bias in high-pressure scenarios.

Gender Reassignment
For transgender passengers, the absence of a driver removes a layer of safety that could deter harmful behaviours. Real-time video monitoring and live operator support should replace this protective role, offering reassurance and accountability. Pre-filled diversity profiles provide responders with sensitive and tailored information to address emergencies appropriately, compensating for the lack of human understanding in self-driving taxis.

Marriage and Civil Partnership
This characteristic did not influence user needs directly, as the absence of a driver did not intersect meaningfully with this group’s responses.

Digital Exclusion
The absence of a driver amplifies the challenges faced by digitally excluded passengers, who rely on traditional methods of communication and support. Manual buttons, physical intercoms, and simple navigation tools should compensate for the lack of human guidance. Live operator connections and non-digital options ensure these passengers can access help effectively during emergencies.

These findings underscore how the absence of a driver fundamentally shifts the responsibilities onto the self-driving taxi system. To address these challenges, systems should be designed to provide robust, accessible, and inclusive features that fill the gap left by the lack of human intervention, ensuring all users can navigate emergencies safely and confidently.

5.2 Limitations of the study

The current study provides valuable insights into how protected characteristics shape individuals’ perceptions and responses to emergency scenarios in self-driving taxis together with the tasks that people need to do during emergencies and their ability to perform these tasks. This section acknowledges the methodological choices and trade-offs that were made and how these might have influenced the study.

Reliance on individual perspectives: One notable limitation was the reliance on single participants to represent broader demographic groups. For instance, there was only one transgender participant in this study, so generalisations from their experience to all transgender community members must be cautioned. Individual practices can vary based on personal, cultural, or contextual factors, and relying on single perspectives risks overgeneralising findings. Incorporating diverse participants from within demographic groups to capture the full spectrum of experiences should be a priority of all future research, potentially by offering individual sessions at people's homes.

Limited scenario exposure: The study's design limited participants to experiencing only three of the six VR scenarios to reduce the potential for fatigue or discomfort. While this approach was practical in terms of time restrictions related to VR fatigue, it may have restricted the relevance of the scenarios to certain participants' protected characteristics, potentially underestimating the range of challenges faced. For example, participants with vision impairments may not have experienced scenarios where lighting or visual cues were essential. Future iterations of this research could have longer sessions, space the scenarios over several sessions or hand pick scenarios for participants based on their self-identified dominant protected characteristics.

Assumptions: In the *Pedestrian interaction scenario*, participants often assumed that the VR pedestrian avatar was male, despite it being designed as gender-neutral avatar. This bias likely influenced their responses, particularly among participants whose protected characteristics intersect with gender dynamics, such as women or LGBTQ+ individuals. Such assumptions may have skewed the findings in this study, highlighting the importance of future studies designing avatars with explicitly diverse gender identities or appearances to examine how visual cues affect participant perceptions and responses. However, this approach was out of scope for this study.

Generalised responses over self-reflection: Participants frequently spoke on behalf of others rather than focusing on how their own protected characteristics influenced their experiences, for example imagining what an older person, or pregnant person may feel in relation to that emergency when they themselves were young or male. This generalised or humanistic approach often led to the dismissal of participant's own protected characteristics like race or religion in favour of advocating for universally inclusive solutions. While such advocacy is an interesting finding (and heartening to see people considering others' experience above their own), it obscured the unique needs of individuals with specific protected characteristics who had been invited to take part to find out how the scenarios would impact them personally. It also supports the finding that some protected characteristics genuinely did not introduce any specific concerns or needs. To mitigate this, without leading the participant as to what kinds of things they 'should' say, future research could provide more detailed instructions to participants at the start to ensure the study design encourages self-reflection rather than generalisation.

Competing protected characteristics: All of us have multiple protected characteristics, but some may be more 'dominant' in self-identity than others, which can mean some characteristics are ignored or dismissed. Findings showed that older male, white, heterosexual participants overwhelmingly did not consider their age, sex, race or sexuality to be a defining factor in any emergency scenario, even if asked directly how it could impact their experience of being in an emergency without a driver present. Other participants prioritised one single protected characteristic over others when describing their experiences. For instance, a participant with both ADHD and a speech impediment might focus on the cognitive challenges their ADHD presented them with during an emergency, such as stimulus overload while neglecting discomfort with using voice-activated technology to talk with an operator. Although moderators used gentle probing to try and draw out a consideration of their protected characteristics, if a participant did not consider it relevant, they moved on to the next scenario. In future studies, participants could be required to complete a questionnaire a week after their involvement in the study based on each scenario they encountered and asked to provide a suggestion for each of their protected characteristics to see if any further relevant information comes to mind.

Representativeness and tailoring: Representativeness emerged as a challenge, as participants noted that while they may not personally experience difficulties in a scenario, individuals with similar or more severe impairments might encounter significant challenges. This emphasises the need for broader user testing and systems that allow individuals to tailor their experiences based on their protected characteristics.

Exclusion of cognitive impairments: The exclusion of participants with cognitive impairments, such as Alzheimer's disease, prevented the study from fully exploring age-related challenges like memory loss or navigation difficulties. Including such participants in future studies would provide more comprehensive insights into the needs of older adults in self-driving taxis. There are complex ethical considerations for including people who cannot give informed consent, and it was assumed that these people would not be regularly using transport independently so were therefore not the target audience for this study. But nevertheless, the technology might improve their transport experiences, so including them in future studies designed specifically for this population would be appropriate with the correct ethical considerations in place.

Overrepresentation of older participants: Older participants were often more vocal and descriptive in their feedback than younger participants, mainly due to confidence and possibly experience, particularly in the Social trials, which may have skewed findings toward older age-related concerns. While these insights were valuable, they may have overshadowed the experiences of younger or less articulate participants. To address this, future research should ensure balanced representation across demographics or consider running single-age Social focus groups. Innovative methods to encourage more diverse contributions in the focus group sessions inside the virtual world could be explored, such as annotating the virtual taxi with suggestions before discussing them together as a group. This practice could guarantee that everyone was equally contributing to the discussion.

5.3 Recommendations for future APS design to meet user needs

The absence of a human driver in self-driving taxis introduces unique challenges for passengers, particularly in emergencies where tasks typically managed by a driver must now be performed by the passengers themselves. The findings highlight that barriers faced during such scenarios are not only practical—rooted in physical, sensory, or cognitive limitations—but also shaped by passengers' perceptions of safety, often influenced by their protected characteristics. Individuals with disabilities, older adults, and younger passengers are most likely to encounter significant obstacles, while factors such as race, religious beliefs, gender, or sexual orientation can impact users' willingness to seek help or perform necessary actions.

To address these challenges, this section outlines recommendations for future automated passenger service (APS) designs, focusing on ensuring inclusivity and safety by prioritising features that support diverse user needs in the absence of a driver. These recommendations are structured around the tasks passengers must perform during emergencies and consider how systems can mitigate the absence of a human mediator.

Prioritising Inclusive and Adaptive Design

Accessible Vehicle Design
Physical accessibility becomes paramount when passengers must manage their own safety. Key design elements could include:

- Manual overrides for door locks to ensure egress during power failures.
- Weather-resistant ramps and clear, unobstructed pathways for individuals with mobility impairments.
- Adjustable seating configurations and ergonomic features for older adults, pregnant passengers, or those with disabilities.
  Emergency exits should be intuitive and accessible, with mechanisms that function reliably even during system malfunctions.

Multimodal Communication Systems
Effective communication is critical in the absence of a driver to mediate emergencies. Systems should accommodate sensory and cognitive needs by offering voice, text, and visual instructions. Simple, step-by-step guidance and universally recognisable icons can help passengers make decisions under stress. Features that dynamically adjust communication methods based on user profiles—such as combining audio instructions for vision-impaired users with calming, structured text for neurodivergent users—address intersecting needs and enhance usability.

Personalised Safety Features
Without a driver, passengers must rely entirely on the system to adapt to their needs. Personalised interfaces that allow users to pre-fill information about their protected characteristics, preferences, and requirements during booking can help the system dynamically adjust features. For instance, automated systems could tailor emergency guidance or accessibility settings to support users with physical disabilities or neurodivergent conditions. This approach reduces cognitive load and ensures a more tailored response to emergencies.

Proactive Emergency Planning
Proactive features could compensate for the absence of a human driver's intervention during emergencies. Systems could integrate:

- Embedded medical tools, such as first-aid kits and defibrillators.
- AI-powered evacuation plans tailored to passengers' characteristics and real-time conditions.
- Features like automated hazard detection and live operator connections to guide passengers safely through emergencies.

Addressing Perceptions of Safety
The absence of a driver amplifies some users' fears of prejudice or misjudgement, particularly for those who belong to marginalised groups. For example, LGBTQIA+ users or individuals from visible minority backgrounds may hesitate to seek help due to concerns about bias. High-quality real-time video and audio monitoring, combined with automated alerts, can provide reassurance by promoting accountability and reducing reliance on passenger-led interactions. These systems should ensure that assistance is unbiased and equitable, fostering trust among diverse user groups.

Cultural and Religious Sensitivity
Designing with cultural and religious sensitivities in mind enhances comfort and inclusivity. For example, providing gender-specific communication or seating preferences could align with faith-based norms. Automated systems with multilingual support and non-verbal cues further accommodate passengers from diverse backgrounds, ensuring their safety and dignity are prioritised.

System Responsibilities and Design Considerations

In self-driving taxis, the absence of a driver places the burden of safety and decision-making on passengers and the automated system. To overcome the key barriers faced by users during emergencies self-driving taxi systems should prioritise inclusivity, accessibility, and safety.

Inclusivity: Tailored interfaces, inclusive training for operators, and proactive engagement with user groups can help ensure APS systems meet the needs of passengers with a wide range of characteristics and vulnerabilities. Operators could provide interfaces and alerts that cater to diverse sensory and cognitive needs such as customisable user profiles for pre-configured accessibility settings and preferred communication methods in the event of an emergency.

Safety: Advanced communication systems, robust monitoring tools, and accessible vehicle features would provide passengers with the confidence to navigate emergencies independently. Robust safety mechanisms, including emergency door releases, panic buttons, and automated hazard alerts should be prioritised together with accessible egress options, such as wide doors, ramps, and ergonomic seating. Solutions include manual overrides, multimodal communication, and automated hazard detection to ensure safety even in the absence of a driver.

Trust and comfort: Features like real-time monitoring, automated assistance, and cultural sensitivity can reduce barriers to adoption and ensure passengers feel supported and respected during their journeys. Calming and structured guidance, both inside the vehicle and via remote assistance can reduce distress without impeding task performance. This is especially critical for neurodivergent users or those with heightened anxiety in emergencies.

6. Conclusion

This study has highlighted that individuals with certain protected characteristics, such as disabilities, gender, age, and cultural or religious identities, face unique challenges during emergencies in self-driving taxis. These challenges, while significant, also present opportunities to innovate and collaborate with industry to address barriers and ensure that Automated Passenger Services (APS) are safe, inclusive, and adaptable to the needs of all users.

The absence of a driver in self-driving taxis shifts the responsibility for safety and decision-making to passengers and automated systems, creating a unique context for developing user-centred solutions. The study’s goal was to identify tasks passengers may need to perform during emergencies, examine the circumstances in which support is most required, and propose design considerations to meet these needs. By leveraging these insights, the development and implementation of APS can align with the principles of inclusivity and safety.

The absence of a driver also provides a distinctive opportunity to reimagine how support is offered during emergencies. Without the presence of a human figure to provide guidance or mediate interactions, automated systems will be required to take on a more proactive and dynamic role in addressing users' needs. This shift encourages a deeper exploration of how technology can create equitable and reliable systems that respond to physical, cognitive, and emotional challenges.

The overall goal of this study was to identify tasks that passengers may need to perform during emergencies and consider their needs for accomplishing these tasks. The findings suggest that inclusive design—through personalised, adaptive HMIs, robust communication systems, and proactive emergency planning—offers significant opportunities to improve passenger safety and trust.

As the APS sector evolves and the implementation of the Automated Vehicle Act 2024 progresses, collaboration with industry stakeholders is crucial. By engaging with user groups, transport operators, and technology providers, these insights can inform the design of systems that integrate inclusivity into the core of self-driving taxi services. This approach not only enhances safety and accessibility but also sets a standard for user-centred innovation in emerging transport technologies.

By aligning design and service provision with the specific needs of diverse users, APS systems can ensure that all passengers, regardless of their characteristics or vulnerabilities, can navigate emergencies with confidence. This study provides a foundation for further collaboration with industry stakeholders to refine processes, develop innovative solutions, and embed inclusivity into the core of APS design and implementation.

This study employed an innovative approach using virtual reality (VR) simulations to examine emergency scenarios in the context of a newly emerging transport technology. By leveraging VR, it was possible to study self-driving taxi systems in a controlled yet realistic environment, enabling the identification of safety and accessibility needs ahead of widespread rollout. This method ensured that potential challenges could be addressed proactively, promoting systems that meet the needs of all passengers, including those with protected characteristics.

The inclusion of voices often overlooked in transport planning, such as those of individuals with disabilities, neurodivergent conditions, and gender- or faith-based concerns, underscores the study's commitment to inclusivity. This approach not only provided richer insights into user needs but also highlighted the importance of designing transport systems that consider the full diversity of their users. By integrating these perspectives, the study lays the groundwork for self-driving taxis to become a truly equitable and trusted mode of transport.

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7. Appendices

7.1 Rotation of emergency scenario order

A1	Pedestrian interaction
A2	Medical emergency
B1	Incorrect stopping point
B2	Road closure due to flood
C1	Fire with a door malfunction
C2	Vehicle collision

Rotation 1	Rotation 2	Rotation 3	Rotation 4	Rotation 5	Rotation 6	Rotation 7	Rotation 8
A1	**A1**	**A1**	**A1**	**A2**	**A2**	**A2**	**A2**
B1	**B1**	**B2**	**B2**	**B1**	**B1**	**B2**	**B2**
C1	**C2**	**C1**	**C2**	**C1**	**C2**	**C1**	**C2**

7.2 VR technical design elements

Scenario	Description	3D Object/Mesh	Video	Sound
Pedestrian interaction	Another pedestrian attempts to enter the automated vehicle, creating a potential safety threat for the occupants. The vehicle's security system activates, preventing unauthorised access. The avatar will not behave aggressively, to avoid frightening occupants (such as small children).	Pod vehicle with an obvious door – tinted black door (no animation) Door locked sign <text> on both doors Androgenous avatar on footpath outside trying door handle	360 video of environment City environment Traffic light – car stationary Avatar pedestrians walking around	Fumbling on door handle sound Sound of the road environment
Incorrect stopping point	The automated vehicle stops at the wrong or inaccessible location, causing inconvenience to the passengers. Passengers hear an alert saying “you have arrived at your destination” but the vehicle has halted far from the intended destination, with no clear explanation provided. The VR world can be rendered to show a clearly visible landmark some way away from the vehicles stopping point.	Pod vehicle with an obvious door – no tint/clear window (no animation) Door closed sign <text> on both doors Door open sign <text> on both doors	Vehicle moving City environment Landmark in VRE – urban world with destination Pass the landmark (Library) Vehicle stops with landmark visible in the back window Avatar pedestrians walking around	Sound of the road environment Sound of alert saying “you have arrived at your destination”
Road closure due to flooding	The planned route is obstructed due to unexpected road closures or construction work, causing the automated vehicle to come to a halt. Passengers observe road signs and flooding in the VR world and workmen in the road, indicating the closure and notice workers diverting traffic.	Pod vehicle with an obvious door – no tint/clear window (no animation) Door closed sign <text> on both doors	Vehicle moving Residential street environment Raining Road closure signs Puddles on road that increase in size until before the road closure it is deep Workmen avatars	Sound of the road environment Sound of heavy rain

Vehicle collision	The APS experiences a minor collision, rendering it unable to continue the journey. Passengers notice the vehicle coming to a halt. For ethical reasons, this will only be a small collision, such as the vehicle behind in slow traffic bumping into the APS.	Pod vehicle with an obvious door – no tint/clear window (no animation) Door closed sign <text> on both doors	Pod is moving City environment Stop at amber traffic lights Vehicle behind connects with the back of the APS Push/jump in the video to simulate a shudder/push Pedestrian avatars walking around <after impact – directed attention and stop>	Sound of the road environment Collision sound (metal)
Medical emergency	A passenger inside the automated vehicle experiences a sudden mild medical issue, such as nausea, requiring immediate attention. The passenger expresses discomfort and requests assistance. For ethical reasons this will not be a heart attack or alarming health concern.	Pod vehicle with an obvious door – no tint/clear window (no animation) Door closed sign <text> on both doors Avatar inside the pod, moving to simulate being unwell	Pod is moving City environment Avatar pedestrians walking around	Sound of someone saying “I feel ill”
Fire or smoke emergency with door malfunction	Smoke or flames are detected inside the automated vehicle, indicating a potential fire hazard. However, the VR environment ensures that the simulated fire or smoke is not frightening.	Pod vehicle with an obvious door – no tint/clear window (no animation) Door closed sign <text> on both doors Animation of flames and smoke inside the APS	Pod is moving City environment Avatar pedestrians walking around	Sound of crackle/fire