ADVANCING AUTONOMY FOR ALL:

Countering future transport exclusion through the inclusive design of shared autonomous vehicles.

Submitted for the Degree of Doctor of Philosophy, Intelligent Mobility Design Centre

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Robin Severs

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ABSTRACT

The emergence of Shared Autonomous Vehicles (SAVs) offers an unprecedented opportunity to reconsider how vehicles and transport systems are designed and begin to address long-standing transport exclusion and inequity. Yet, without early and deliberate consideration of the needs of the whole population, these technologies could perpetuate the transport exclusion already experienced by many or even create entirely new forms of exclusion. This thesis investigates how inclusive design can be applied from the earliest stages of SAV development to ensure equitable access for groups historically marginalised in transport systems, with a focus on exclusion linked to age, disability, and gender.

An inclusive design for transport framework was developed, expanding the traditional scope of inclusive design to fully capture the range of groups and types of exclusion experienced within transport. An inclusive design-led, action research approach was utilised to understand and respond to the needs of excluded groups through exploratory and focused co-design workshops with older people, women, and disabled people; expert interviews with vehicle engineers; and industry engagement through surveys and focus groups. These activities identified needs of various excluded groups throughout an SAV journey, including those relating to psychological and interpersonal factors as well as physical, informational, and service-based barriers.

Design concepts were developed iteratively in response to these findings, addressing multiple points of exclusion across vehicle architecture, interior layout, exterior design, and information systems. Prototyping in full-scale mock-ups and virtual reality environments enabled participants to evaluate and refine concepts, ensuring feasibility and relevance. The outcome is a single, holistic SAV design configuration capable of serving a broad user base without reliance on specialised vehicles, thereby reducing service-related exclusions caused by limited fleet availability.

The thesis makes three principal contributions:

1. A comprehensive, multi-dimensional framework for inclusive design in transport

2. Empirical insights into the mobility needs and barriers experienced by transport-excluded groups in relation to SAVs
3. A set of actionable, industry-relevant vehicle and service design concepts.

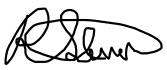
These outputs provide practical starting points for manufacturers, service operators, and policymakers seeking to ensure the inclusivity of SAV development.

By embedding inclusion into the process of designing an SAV, this research demonstrates that it is possible to create vehicles and services that meet the needs of excluded people groups while retaining their utility to the rest of the population. In doing so, it offers a replicable model for the design of future transport systems that are not only technically innovative but also socially inclusive from their inception.

DECLARATION

This thesis represents partial submission for the degree of Doctor of Philosophy at the Royal College of Art. I confirm that the work presented here is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

During the period of registered study in which this thesis was prepared the author has not been registered for any other academic award or qualification. The material included in this thesis has not been submitted wholly or in part for any academic award or qualification other than that for which it is now submitted.



Robin Severs

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SUPPORTING MATERIALS

This thesis represents partial submission for the degree of Doctor of Philosophy and should be considered alongside an accompanying design practice document Designing Autonomy for All. References to this document are made, where relevant, throughout this thesis.

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'For in much wisdom is much vexation, and he who increases knowledge increases sorrow.' Ecclesiastes 1:18

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LIST OF ABBREVIATIONS

AV: Autonomous Vehicle

BSL: British Sign Language

DRM: Design Research Methodology

DRS-ER: Dynamic Ride-Sharing En-Route

DWP: Department for Work and Pensions

eHMI: external Human-Machine Interface

HMI: Human-Machine Interface

IDfT: Inclusive Design for Transport framework

OD-DRS: Origin-Destination Dynamic Ride-Sharing

OEM: Original Equipment Manufacturer

SAV: Shared Autonomous Vehicle

TRSE: Transport-Related Social Exclusion

VR: Virtual Reality

WAV: Wheelchair-Accessible Vehicle

1 INTRODUCTION

1.1 RESEARCH CONTEXT: INCLUSION AND FUTURE MOBILITY

1.1.1 A FORK IN THE ROAD

'We're at a fork in the road.' In the book, *Three Revolutions*, this is how Daniel Sperling (2018) describes a world on the brink of an upheaval of one of the foundational aspects of human life… movement. Sperling describes how our response to the emergence of a trifecta of transport revolutions – electrification, shared mobility, and automation – could lead society down one of two roads.

One road leads to a transport 'dream'; a utopian vision of sustainable, affordable and accessible mobility for all. A shift to electric vehicles results in cleaner air. Shared transport services allow affordable access to a suitable vehicle for every journey, reducing the space and energy inefficiencies of large, privately-owned vehicles and freeing up space for safer active transport and micromobility. Autonomous vehicles (AVs) meet the needs of all people and allow for affordable shared journeys, providing door-to-door transport to those for whom it was previously unattainable.

Down the other road is a transport 'nightmare', a dystopia of increasing disparity and exclusion. Costly, privately-owned autonomous vehicles become the preserve of the wealthy, who shift away from public transport services leaving them underutilised and underfunded. As a result, the mobility of lower income families diminishes. To make the most of their expensive AVs, owners use them for unnecessary journeys, opting to send their vehicles home empty rather than pay for parking, and using them to run errands during the day. This profligacy results in increased congestion, more demand on local space, and increased energy consumption.

While neither of these extremes may be fully realised, it is clear that the three revolutions offer an unprecedented opportunity to shape the future of transport and move ever closer to a transport dream-come-true.

1.1.2 THE PRESENT DAY TRANSPORT NIGHTMARE

For many, the prospect of the transport nightmare is not so far-fetched. The existing transport landscape already fails to meet people's needs with an over-reliance on

private vehicles which are unattainable for many, and alternative transport services presenting a range of issues including insufficient provision, inaccessible vehicles and infrastructure, and poor security. This transport exclusion is felt by people groups across the spectrum of age, gender, ethnicity & nationality, disability, income, and location and can have severe knock-on impacts on people's lives – limiting access to employment, education, and healthcare. The potential for transport exclusion to curtail access to activities that are considered to be fundamental rights, has led many to argue that transport itself should be considered a right (Coggin and Pieterse, 2017; Logan et al., 2018; Sanchez et al., 2018).

While growing awareness of this exclusion has prompted positive changes, transport modes and vehicle typologies have remained broadly the same for over a century and the legacy of a less inclusive past lingers in an infrastructure that is complicated and costly to adapt. An example of this is seen in the London Underground network, whose age and complexity presents challenges to adapting stations for wheelchair access (Ferrari et al., 2014) resulting in costs of up to £100m to provide step-free access for one station (Greater London Authority, 2022).

The three revolutions may offer a more inclusive future afforded by a ground-up rethink of the transport landscape. However, early examples of such mobility innovations give troubling indications that this may not be a priority. New ride-hailing services create fleets with a lower proportion of wheelchair accessible vehicles than traditional taxi services (Transport for All, 2024) and incorporate features that enable drivers to discriminate based on the race of prospective passengers (Ge et al., 2016). Electric vehicle charging presents barriers of inaccessible public charging points (Ricardo, 2020), and price disparity between those living in homes which allow home charging and those forced to rely on public charging infrastructure (Malabanan et al., 2025). Shared micromobility services such as bike and e-scooter schemes are not accessible to many disabled people (Goralzik et al., 2022), and obstruct pavements creating difficulties for disabled pedestrians such as visually impaired people and wheelchair users (Bennett et al., 2021). To achieve a future where the nightmare of transport exclusion gives way to an inclusive transport dream, mobility innovations need to consider transport exclusion from the very start – addressing existing barriers and anticipating emerging ones.

1.1.3 Shared autonomous vehicles: A silver bullet?

The epitome of the three revolutions is the shared autonomous vehicle (SAV). Variously referred to as robotaxis, driverless pods, shuttles, and more, these vehicles incorporate innovations from across the three revolutions utilising electric drivetrains, autonomous technology, and ways of sharing with a view to creating clean, convenient, and cost-effective mobility. For some, SAVs appear to be a mobility silver bullet, a solution to end all transport woes.

No area seems to better demonstrate this SAV optimism than that of transport exclusion. Indeed, for many excluded groups SAVs do appear to offer obvious solutions to the barriers they face. Those who are unable to drive due to disability, or age can experience the freedom of on-demand mobility. Those who were previously unable to own a private vehicle due to cost or lack of parking can enjoy door-to-door travel. Rural communities, previously unserved by public transport services, can access a flexible service that adapts routing and timings to meet their needs. However, despite the obvious benefits SAVs offer to certain excluded groups, the danger of complacency looms. Some appear to consider these existing benefits, combined with some limited and arguably tokenistic inclusive features, to be sufficient to market a vehicle as inclusive or accessible, while more concerted efforts to improve the inclusivity of SAVs often appear to be considered as a task for a later date.

Reassuringly, this apparent lack of urgency around inclusion in SAVs is not universal. Research has been conducted which begins to identify the needs and attitudes of excluded groups as they pertain to SAVs. Efforts have also been made in developing SAVs which address issues of transport exclusion – albeit in specific and limited ways relying on retrofitting accessibility features to existing SAV prototypes (e.g. Accessible Olli (Local Motors, 2018)) or proposing operating models for existing SAVs to meet the journey needs of specific excluded groups (e.g. Muji's Gacha (MUJI, 2021)).

While SAVs promise certain benefits to transport excluded groups and work is being done to develop more inclusive vehicle features and service models, it is apparent that more focused efforts are needed to address the needs of transport excluded people groups from the very first stages of SAV design and development. If we do not fully consider the needs of excluded groups from the start, it seems inevitable that many will be left behind in the wake of the three revolutions.

1.2 RESEARCH AIMS

This PhD project seeks to advance our understanding of how SAVs might be designed to better meet the needs of groups who experience transport exclusion. By describing the SAV-related needs of excluded groups and presenting concepts designed to address them, it is intended that this body of work might prompt further research, design, and decision-making which ultimately results in more inclusive SAV vehicles and services. For stakeholders directly involved in the design of these vehicles and services, concepts presented in this body of work may be validated, applied, and adapted to specific use cases. For those involved in more high-level decision making (e.g. policy makers), these concepts provide a sense of what is possible and may be used to inform guidance and regulation to ensure wider inclusion as SAV services are introduced.

To achieve this aim, this project utilises an inclusive design approach which seeks to:

1. **Understand** the groups that experience transport exclusion, the transport barriers they currently face, and the potential barriers that SAVs could create for them.
2. **Respond** to these identified needs through the identification of key SAV design areas, and the creation of a range of design concepts which seek to address them.

To ensure further consideration and application of the insights generated and design responses created during the project, attention has also been paid to how these findings and future inclusive design research in this space, might best be shared with stakeholders in positions to influence the inclusivity of SAV services, particularly designers.

1.3 THESIS OUTLINE

The areas of **understanding** and **responding** inform the main body of research presented in this thesis.

Chapter 2 details a review of existing literature seeking to understand the current extent of transport exclusion including the groups who experience it, its impacts, and the ways in which it is experienced. This literature review also seeks to understand the existing state of inclusive transport design and the ways in which an inclusive design approach may be used in the development of more inclusive transport. Chapter 2 also gives an overview of SAVs including their various typologies, use cases and

operating models, as well as a review of existing SAV research and design work focusing on inclusion. The chapter concludes with a theoretical framework for inclusive transport design which presents a high-level overview of the full extent of transport exclusion and the ways in which inclusive design development might be used to address it.

Chapter 3 builds upon this understanding of inclusive transport design and presents a more detailed description of the methodology applied to further understand people's transport needs, respond to them through inclusive design, and consider how they might be shared with stakeholders.

Chapter 4 contributes to a more complete understanding of the ways in which SAVs could be designed to reduce transport exclusion. It presents an overview of exclusion that might be experienced within a typical SAV journey detailing:

- The needs of transport-excluded groups – informed by existing and anticipated barriers identified through research workshops with excluded groups, and a review of literature.
- The opportunities for these needs to be addressed through design interventions – informed by suggestions from participants in co-design workshops, and an analysis considering the areas of design that might address the identified needs and barriers.

Chapters 5 and 6 describe the development of a range of design concepts, created in response to key areas of exclusion identified in the previous chapters and informed by co-design research workshops with members of transport-excluded groups. These chapters detail potential inclusive interventions related to the design of the vehicle itself (Chapter 6), as well as the design of supporting information and interactions (Chapter 5). A more detailed description of the design process and its outcomes can be found in the accompanying **practice document**, *Designing Autonomy for All.*

Chapter 7 draws upon a survey of people working in the design and development of vehicles, and a focus group with members of a design team at an automotive OEM, to inform discussions of the barriers to applying inclusive design in an industry context and how knowledge about the needs of transport excluded groups and inclusive SAV design concepts might best be shared with key stakeholders.

Chapter 7 also expands the framework for inclusive transport design presented in Chapter 2, incorporating learnings and reflections on the inclusive design approach taken during the project and detailing the ways in which different disciplines can contribute to creating inclusion in the design of future vehicles and transport services.

Finally, Chapter 7 contains a summary of the original contributions to knowledge made during this research. This conclusion also includes recommendations for additional research and inclusive design development to further understand and respond to the needs of transport-excluded groups and ensure progress towards achieving a more inclusive future for transport.

2 LITERATURE REVIEW

This chapter draws upon the literature to define the scope of this research according to three key areas:

- *Shared autonomous vehicles* – Detailing current understanding and future expectations for SAV typologies and service models and defining the SAV explored in subsequent research and design.
- *Transport-related social exclusion* – Exploring who is excluded from transport and how this exclusion occurs.
- *Inclusive design* – Discussing how design can create more inclusive products and services.

The chapter concludes by describing an *Inclusive Design for Transport Framework,* summarising groups experiencing exclusion, types of exclusion, and how exclusion impacts their use of transport services.

2.1 SHARED AUTONOMOUS VEHICLES

2.1.1 DRIVING AUTOMATION

Automated vehicles assist drivers or replace driving tasks through automation (SAE International, 2021). SAE (2021) describes five levels of driving automation, from automating elements of driving (levels 1 and 2), through automating the entire driving task at certain points (level 3), to automating the entire journey in specific locations (level 4) or in any scenario in which traditional vehicles operate (level 5). This project explores Level 4 and 5 vehicles, with the term autonomous vehicle used to distinguish these vehicles – with no driver – from level 1-3 automated vehicles, where driver input is required.

2.1.2 SHARING AUTONOMOUS VEHICLES

Autonomous vehicles that operate as part of a passenger transport service are called Shared Autonomous Vehicles (SAVs). SAVs are often positioned as bridging the gap between the door-to-door convenience of private cars and the efficiency of transport services (Ohnemus and Perl, 2016).

Impacts of SAVs

Based on a review of literature, Narayanan et al. (2020) detail seven areas where SAVs might have significant impacts on transport:

Traffic and safety: Reducing traffic and accidents caused by human drivers.

Travel behaviour: Replacing private vehicle use, reducing ownership, and increasing occupancy, but potentially increasing vehicle miles due to empty trips and trip length.

Economy: Saving costs through efficient sharing models, optimised services, reduced staffing, and advertising revenues.

Transport supply: Increasing road capacity, transport provision, and accessibility. Although some locations may be underserved by SAVs.

Land use: Reducing land use by reducing the need for parking spaces.

Environment: Reducing energy consumption and emissions through electric powertrains.

Governance: Providing better transport systems through the potential for public-private cooperation and integration with existing systems.

Operation of SAVs

Narayanan et al. (2020) note that many SAV benefits depend on how the service is configured, particularly in terms of managing journey sharing. Several models for sharing within SAV services have been proposed, with different approaches to passenger sharing, service access, and vehicle routing.

Sharing models

Clayton et al. (2020) describe two ways SAVs might be shared between users:

Asynchronous: Allowing different passengers to use the SAV privately, one after the other, similar to existing car-sharing schemes (Clayton et al., 2020).

Synchronous: Allowing multiple passengers to share a vehicle simultaneously and occupy the same interior space (Clayton et al., 2020). Synchronous SAVs are more analogous to public transport and ride-pooling services.

Synchronous sharing models offer efficiency benefits over asynchronous alternatives in reducing congestion (Narayanan et al., 2020), but may be less acceptable due to concerns over sharing space with strangers (Clayton et al., 2020). These concerns

can impact particular transport-excluded groups (e.g. women) and may be addressed through inclusive vehicle design (Wang et al., 2020).

The benefits of synchronous SAV services coupled with the challenges they present for excluded groups necessitate more in-depth design consideration than asynchronous models. Thus, a synchronous SAV service was used as the basis for this PhD research.

Booking/ calling the SAV

Narayanan et al. (2020) identify 3 categories of SAV booking systems: *on-demand* – passengers call for the SAV when needed, *reservation-based* – passengers book in advance, and *mixed*. Research has also explored spontaneous access, such as gesture-based hailing (Mastouri et al., 2023). No specific system for accessing SAVs was defined at this stage of the project to allow open exploration of the inclusivity of a range of solutions throughout the research.

Shared journey routing

With synchronously shared SAVs, the service must determine the efficient routing of passenger journeys. Gurumurthy and Kockelman (2018) discuss two models for this:

Origin-destination dynamic ride-sharing (OD-DRS): Passengers are matched by common origin and destination and share the entire journey.

Dynamic ride-sharing en-route (DRS-ER): Multiple passengers with different origins and destinations join and depart at different points along a shared route.

DRS-ER significantly increases the number of shareable trips in SAV services (Gurumurthy and Kockelman, 2018). This efficiency makes it promising for future routing but introduces the potential for complex interactions and choices regarding sharing that could create difficulties for some transport-excluded groups. Where relevant, research activities throughout this PhD have assumed a DRS-ER system to explore these challenges.

SAV typology

The physical dimensions of SAVs are partly dictated by their operating models. Smaller, 2-4 seat vehicles, such as Dromos, Verne, and Zoox, are designed for asynchronous robotaxi services where sharing space is not required (Dromos GmbH, n.d.; Verne, 2024; Zoox. Inc., 2024). Larger, shuttle-type vehicles seating 8-12 people such as WeRide's robobus, Holon's Mover, and Ohmio's Lift, are intended for

synchronous sharing models (HOLON GmbH, n.d.; Ohmio, n.d.; WeRide.ai, 2022). This PhD focuses on the latter category to allow inclusive design considerations for shared spaces and to explore the inclusion of groups that smaller vehicles may not accommodate, such as wheelchair users.

2.1.3 *Definition of the SAV explored in this PhD*

The type of SAV explored through subsequent research activities and the development of inclusive design responses can be defined as follows:

A level 4/5, 8-10 seat autonomous shuttle suitable for use in a synchronously shared, dynamic ride-sharing en-route service.

2.2 Transport-related social exclusion

The concept of transport-related social exclusion (TRSE) emerged in the UK during the late 1990s and the early 2000s as policymakers and academics explored transport disadvantage and its relation to social exclusion in low-income communities (Lucas, 2012). Kenyon et al. (2002) define transport exclusion as 'The process by which people are prevented from participating in the economic, political and social life of the community because of reduced accessibility to opportunities, services and social networks, due to insufficient mobility in a society built around the assumption of high mobility.'

2.2.1 *Impacts of transport exclusion*

The Social Exclusion Unit (2003) identifies how exclusion from transport negatively impacts people's lives and perpetuates social exclusion by reducing access to work, learning, healthcare, food shops, and social, cultural, and sporting activities. As these consequences of transport exclusion are far-reaching and cause further exclusion, it is vital that the mobility needs of transport-excluded groups are met in designing future transport systems such as SAVs.

2.2.2 *Transport excluded groups & causes of exclusion*

Transport-related social exclusion affects various groups of people due to factors such as age, disability, gender, location, income, and ethnicity (Lucas, 2012). While providing an exhaustive list of excluded groups is challenging, Table 1 lists commonly cited transport-excluded groups and examples of exclusion that they may experience.

TABLE 1 EXCLUDED POPULATIONS (UK/ ENGLAND & WALES) AND EXAMPLES OF TRANSPORT EXCLUSION

Excluding factor	Specific group	Population in UK (millions of people)	Examples of transport exclusion
Age	Older people	12.9 (over 65s) [1]	Lack of technology access for digital mobility services [8]
	Children and young people	15.7 (under 19s) [1]	Lack of independent mobility if transport services unavailable e.g. in rural locations [9]
Disability (impairment type according to Department for Work and Pensions (DWP) classification [2])	Mobility	7.7 [2]	Unreliable wheelchair access to bus services due to faulty ramps [10]
	Stamina/ breathing/ fatigue	5.8 [2]	Poor attitudes and low awareness of invisible disabilities from fellow passengers [11]
	Dexterity	4.0 [2]	Driving controls safety concerns due to reduced dexterity [12]
	Mental health	5.4 [2]	Anxiety caused by interactions with other passengers [13]
	Memory	2.6 [2]	Remembering route information [14]
	Hearing	1.9 [2]	Unable to hear announcements at stations [15]
	Vision	1.9 [2]	Difficulty navigating vehicle interior [16]
	Learning	2.5 [2]	Complex rules and regulations around ticketing [17]
	Social/behavioural	1.9 [2]	Difficulties interacting with other passengers [18]
	Other	2.7 [2]	
Gender	Women	34.8 (females) [1]	Feeling unsafe/ at risk using shared transport [19] Routing favouring journeys more likely to be taken by men [20] Anthropometric differences impacting safety and ergonomics [21]
Location	People living in rural areas	9.7 (England only) [3]	Poor transport provision in small towns [22]
Income/ financial	Low income	11.4 (in relative low poverty) [4]	Less likely to have access to a private car, more reliant on lower-cost transport services [23]
	Unbanked	1.1 [5]	Reduced access to services requiring card payment [24]
Ethnicity, culture, language	Ethnic minorities	10.9 (Census data for people in England and Wales with non-white ethnicities) [6]	Digital profiles resulting in racial discrimination in ride-hailing services [25]
	People with English as a second language	1.0 (Census data for people in England and Wales who could speak no English or could not speak English well) [7]	Language barriers making communication with drivers difficult [26]

Sources

[1] Mid-Year Population Estimates, United Kingdom, June 2023 (Office for National Statistics, 2024)

[2] Family Resources Survey, financial year 2022 to 2023 (Department for Work & Pensions, 2024)

[3] Statistical Digest of Rural England: 1 – Population (Department for Environment Food & Rural Affairs, 2024)

[4] Poverty in the UK: Statistics (Francis-Devine, 2024)

[12] (Remillard et al., 2022)

[13] (Mackett, 2021)

[14] (Bennett and Vijaygopal, 2024)

[15] (Fürst and Vogelauer, 2012)

[16] (Park and Chowdhury, 2018)

[17] (Mackett, 2017)

[18] (Deka et al., 2016)

[19] (European Commission, 2014)

[5] UK Payment Accounts: access and closures (Financial Conduct Authority, 2023)

[6] Ethnic group, England and Wales: Census 2021 (Office for National Statistics, 2022a)

[7] Language, England and Wales: Census 2021 (Office for National Statistics, 2022b)

[8] (Goodman-Deane et al., 2021)

[9] (Storey and Brannen, 2000)

[10] (Velho, 2019)

[11] (Hale et al., 2024)

[20] (Gill, 2018)

[21] (Perez, 2019)

[22] (Allen, 2020)

[23] (Social Exclusion Unit, 2003)

[24] (Brakewood and Kocur, 2013)

[25] (Ge et al., 2016)

[26] (Dabelko-Schoeny et al., 2021)

Several taxonomies summarise how people across these groups experience exclusion (Church et al., 2000; Lucas, 2012; Mackett and Thoreau, 2015) and how it might be addressed (Bjerkan and Øvstedal, 2020). These categorisations describe similar challenges faced by excluded groups, with variations in category specificity and the scope of exclusion. Table 2 compares the categories from the four taxonomies and groups them into four high-level categories related to how people experience these types of exclusion.

Church et al.'s (2000) ' exclusion from facilities' was not included as its description relates more to transport exclusion impacts – reducing access to facilities – than what excludes people from transport. Also notable is Church et al.'s (2000) absence of a category about the impact of information on transport exclusion, which may be attributable to increased dependence on digital information in more recent years.

TABLE 2 COMPARISON OF TAXONOMIES OF TRANSPORT EXCLUSION

Publication	**Transport and social exclusion in London (Church et al., 2000)**	**Transport, social exclusion and health (Mackett and Thoreau, 2015)**	**Making the Connections: Final Report on Transport and Social Exclusion (Social Exclusion Unit, 2003)**	**Functional requirements for inclusive transport (Bjerkan and Øvstedal, 2020)**
Publication type	**Journal article**	**Journal article**	**Government report**	**Journal article**
Focus of taxonomy	**Types of exclusion**	**Types of exclusion**	**Types of exclusion**	**Requirements for inclusive transport**
Excluded groups	**Multiple**	**Multiple**	**Multiple**	**Disabled people**
Psychological	Fear-based exclusion	Psychological barriers	Safety and security	Safety and security
Physical	Physical exclusion	Physical barriers	Availability and physical accessibility	Physically accessible design
	Space exclusion	Facilities		
Information and interactions		Information	Travel horizons and information	Accessible, centralised information
				Reduced administration

Publication	Transport and social exclusion in London (Church et al., 2000)	Transport, social exclusion and health (Mackett and Thoreau, 2015)	Making the Connections: Final Report on Transport and Social Exclusion (Social Exclusion Unit, 2003)	Functional requirements for inclusive transport (Bjerkan and Øvstedal, 2020)
Publication type	**Journal article**	**Journal article**	**Government report**	**Journal article**
Focus of taxonomy	**Types of exclusion**	**Types of exclusion**	**Types of exclusion**	**Requirements for inclusive transport**
Excluded groups	**Multiple**	**Multiple**	**Multiple**	**Disabled people**
Service – cost	Economic exclusion	Cost	Cost of transport	Economic predictability
Service – timing and operation	Time-based exclusion			Short, predictable travel times
				Flexibility
				Reliability
Service – location and routing	Geographical exclusion	Availability of transport	Location of services	
External	Exclusion from facilities			

2.2.3 *FIVE TYPES OF TRANSPORT EXCLUSION*

The categorisations in the previous section provide a helpful overview of how transport exclusion is experienced. However, within these groupings, the way exclusion is experienced and its cause might relate to different categories. For example Mackett and Thoreau's (2015) 'psychological barriers' being experienced due to 'cost' exclusion prohibiting access to more secure transport modes.

To structure explorations of the needs of excluded groups, a taxonomy of transport exclusion should describe exclusion according to how it is reported by those experiencing it. Based on the above taxonomies and the range of exclusion identified in the literature, five types of transport exclusion were identified. These types broadly reflect the categories in the above taxonomies, with the addition of *interpersonal exclusion*, a notable theme throughout the literature and one that is particularly relevant to *shared* AVs. Table 3 details the specific barriers from an initial literature review according to exclusion type and affected group. The five types are defined as follows:

Psychological: Exclusion experienced as a feeling or emotion, including fear, stigma, and the need for confidence and control when using transport. The criterion for classifying exclusion as psychological is based solely on how a person experiences it and *does not* indicate that an individual's psychology is the cause of the exclusion.

Much psychological exclusion is caused by others' behaviours (seen in the worry experienced by autistic people from anticipated and actual passenger behaviours (Deka et al., 2016)) or by knowledge and experiences informing evidence-based fear (e.g. women's fear when sharing transport with men, given knowledge of sexual assault prevalence). Psychological exclusion, therefore, includes fear caused by perceived threats regardless of whether they are ultimately realised and may be addressed through interventions which improve perceptions of security and (more importantly) directly remove the risks.

Interpersonal: Exclusion caused by other people's behaviours or actions encountered during a journey. Barriers include poor awareness of exclusion, exclusionary behaviours of passengers and staff, social interactions, and dangerous passenger behaviours. Some exclusion that begins as psychological may become interpersonal when perceived threats manifest as abusive or dangerous behaviour.

Physical: Exclusion experienced due to an inability to use the physical features of the transport service and surrounding infrastructure. These barriers include those related to moving and navigating in and through spaces, occupying and using spaces (e.g. sitting onboard the vehicle), and actions required to use the physical elements of the vehicle or service.

Information & interactions: Exclusion experienced due to difficulties in receiving information about a journey and interacting with information systems. This type of exclusion includes barriers that may arise from an increasing reliance on digital interfaces to use transport services, including the availability of information, reliability of interfaces, ability to interact with interfaces, and ability to perceive and understand information.

Service: Exclusion experienced due to decisions made regarding the administration and operation of the transport service, including barriers related to cost and payment, whole network accessibility, service availability, reliability, operation, maintenance, and staffing.

TABLE 3 EXISTING TRANSPORT BARRIERS & NEEDS A RANGE OF EXCLUDED GROUPS ACCORDING TO THE 5 TYPES OF TRANSPORT EXCLUSION

	Psychological	Interpersonal	Information & Interactions	Physical	Service
Visually impaired people [1] Fürst and Vogelauer, (2012) [2] Park and Chowdhury (2018)		Lack of awareness of disability and knowledge about white canes among drivers, staff, and other passengers [1,2]	Poor visibility of information and interfaces due to poor contrast, and small sizes. [1,2] Unavailable/ inaudible audio information [1,2]	Difficulties navigating built environment and transport hubs due to obstructions, lack of tactile navigation and contrast markings. [1,2] Difficulties boarding and navigating vehicles due to large gaps between vehicle and platforms, high floors, internal steps, lack of consistency in layout, lack of contrasting colours. [1,2]	
Hearing impaired people [3] Fürst and Vogelauer (2012)		Lack of awareness of disability among drivers, staff, and other passengers [3]	Lack of visual alternatives to information and interfaces for emergencies, arrivals, departures, and alerts [3]		
Mobility impaired people [4] Park and Chowdhury (2018) [5] Velho (2019)	Stigma from negative responses to ramp alarm [5]	Poor driver attitude and awareness of disability, bus not stopping for mobility impaired people and wheelchair users [4.5]		Difficulties navigating built environment and transport hubs due to obstructions, steep gradients and a lack of lifts [4] Difficulties boarding and moving on vehicles due to gaps between vehicle and platform, lack of bus kneeling functionality, narrow aisles, internal steps, and poor wheelchair restraints. [4]	Lack of accessible parking provision [4]
Cognitively impaired people [6] Iwarsson and Ståhl (2012)		Crowding causing stress [6] Poor driver communication and provision of information, driver not stopping [6] Car drivers – lack of awareness and communication with pedestrians [6] Embarrassment at not doing things quick enough, 'looking stupid' [6]	Difficulties understanding and remembering information including wayfinding, timetables, audio announcements, and bus numbers [6] Difficulties buying a ticket and handling payment [6] Difficulties planning journeys: relying on others, poor automated telephone planning services [6]	Difficulties moving in built environment and transport hubs due to uneven surfaces, poor placement/ location of road crossings [6] Difficulties boarding and moving onboard vehicles – High steps, kneeling function not used, stopping away from kerb, heavy breaking and acceleration [6] Poor visibility of outside to know when to disembark [6]	Driving behaviour, hard breaking etc. [6] Poor positioning of terminals and stops for their needs [6]

Autistic people [7] Deka, Feeley and Lubin (2016)	Worried about exclusion e.g. passenger behaviour, finding a seat etc. [7]	Behaviour of other passengers and driver [7]	Difficulties with planning journeys [7]	Poor seat availability [7]	Costly fares [7]
Women [8] European Commission. Directorate General for Mobility and Transport. (2014) [9] Gill (2018) [10] Perez (2019)	Fear when alone, at night, in car parks, underground stations and railway platforms, and on crowded vehicles [8]			Vehicle safety and comfort impacted by failure to account for women's anthropometrics [8,10]	Routing and pricing structures favouring travel patterns more common among men [9]
Ethnicity, culture, nationality [11] Schachter and Liu (2005) [12] Ge et al. (2016)		Driver – communication in second language, racism [11] Ride-hailing service profiles allowing drivers to discriminate based on race [12]	Language barrier creating difficulties with unclear audio announcements and ticket machine instructions [11]		Transport routing not considering connections between immigrant communities [11]
Location excluded [13] Velaga et al. (2012) [14] Allen (2020)			Poor access to/ lack of real time passenger information systems [13]		Poor and worsening service provision [13.14] Rising costs of transport services [14]
Financially excluded [15] Bostock (2001) [16] Brakewood and Kocur (2013)	Reliance on walking – poor security & safety when walking with children [15]		Unbanked passengers unable to use contactless payment systems [16]	Reliance on walking – Poor condition of built environment [15]	
Older people [17] Gilhooly, Hamilton and O'Neil (2002) [18] Centre for Ageing Better (2019)	Personal security at night [17]	Poor passenger behaviour [17]	Lack of clear signage [18] Over-reliance on tech-based booking, payment and ticketing [18]	Mobility difficulties – getting to vehicle [18] and carrying luggage [17] Lack of facilities including toilets, seating etc. [18]	Existing transport routes designed for commuting, rather than journeys older people might make [18] Use of more costly flexible modes of transport [18] Difficulties with delays, cancellations, long wait times, and mode changes [17]

2.3 INCLUSIVE DESIGN

The British Standards Institute (2005) defines Inclusive Design as 'the design of mainstream products and/or services that are accessible to, and usable by, as many people as reasonably possible ... without the need for special adaptation or specialised design.' Inclusive Design aims to produce products usable by the entire population, including older and disabled people. It emerged in the UK as a 'synthesis of initiatives, experiments and insights dating back to the 1960s and beyond' (Clarkson and Coleman, 2015). It developed alongside legislative changes like the Disability Discrimination Act (1995), shifting from a medical model to a social model, where inadequate design disables people (Clarkson and Coleman, 2015). While initially focused on older and disabled people, Inclusive Design benefits all users, as shown by OXO's Good GripsTM kitchen utensils (Gheerawo, 2016).

The Inclusive Design Cube

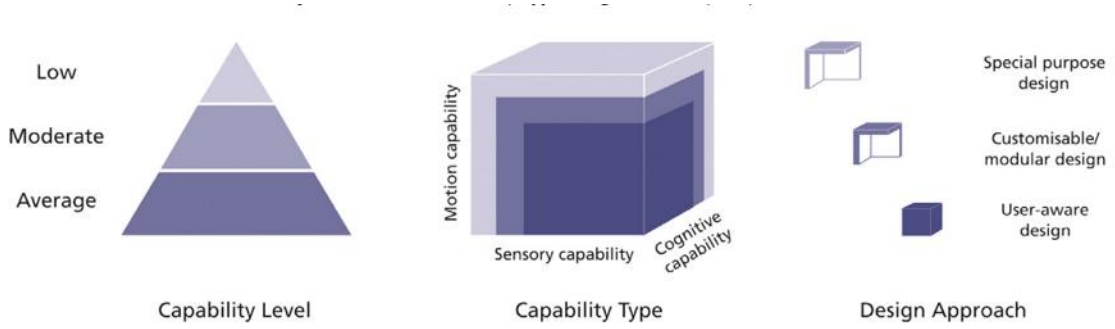

FIGURE 1 THE INCLUSIVE DESIGN CUBE (CLARKSON AND KEATES, 2003).

The Inclusive Design Cube (Figure 1) demonstrates capability variation among disabled people and common design approaches to address their needs (Clarkson and Keates, 2003). This model expands on Benktzon's (1993) User Pyramid by incorporating variations in motion, cognitive, and sensory capabilities. The model includes three design approaches: user-aware design for mainstream products addressing wider population needs, customisable/modular design allowing product adaptation, and special purpose design for niche products meeting specific user needs. The British Standards Institute (2005) definition of inclusive design excludes special purpose products.

In transport contexts, special purpose designs are unlikely to be viable because of cost and service constraints. Ford's Focus designers utilised a user-aware design

approach, donning ‘third age suits' to simulate older people's impairments (Gheerawo, 2016), while Toyota uses customisable design for incorporating vehicle adaptations for disabled people (Persson et al., 2015).

Socially Inclusive Design

Recent work has expanded inclusive design to include more excluded groups. Gheerawo (2016)discusses how 'people-centred techniques developed by Inclusive Design can address the needs of other marginalised and underserved groups beyond the age-ability construct.' This includes groups excluded because of gender, culture, language, economic status, and location, reflecting the groups experiencing transport exclusion discussed in 2.2.2.

Inclusive Design beyond usability

Design for excluded groups often focuses solely on function, neglecting aesthetics. This can cause stigma by limiting the self-expression of disabled people through product styling (Bichard et al., 2007). While assistive products often seek to address stigma by reducing their visibility (e.g. hearing aids and contact lenses), others are seen as fashion accessories or badges of honour (e.g. glasses and walking sticks) (Newell, 2003; Pullin, 2007). Additionally, stigma can arise from conspicuous interactions drawing unwanted attention to those using assistive features, for example, wheelchair users when bus ramp alarms sound (Velho, 2019). To provide equity of use and a destigmatised experience, Inclusive Design should seek not just to overcome barriers, but to do so in style.

2.4 Shared Autonomous Vehicles and Inclusion

Autonomous Vehicles (AVs) have the potential to improve the mobility of disabled people (UK Autodrive, 2016), and several calls have been made for Inclusive Design in AV development (Allu et al., 2017; Bennett et al., 2019a). Focus group and survey studies have examined the attitudes of older and disabled users towards autonomous vehicles (Bennett et al., 2020, 2019a, 2019b; Brinkley et al., 2020), and reports have considered the impact of AVs on disabled people and recommended key areas of accessibility for design intervention (Bayless and Davidson, 2019; Claypool et al., 2017). Research has also explored how belonging to an older generation increases the likelihood of late adoption of self-driving vehicle technologies, among a group who may benefit significantly from such technology

(Ruggeri et al., 2018). This highlights a need for inclusive SAV design which seeks to promote adoption and remove barriers to use among older generations.

Several previous projects have considered the role of inclusive design in AV development. The Flourish project (Shergold et al., 2019) explored the mobility needs and expectations of older people in relation to AVs to maximise the potential benefits that these vehicles offer to older passengers. Several studies have focused on the inclusive design of AV human-machine interfaces (HMIs), including external interfaces to communicate vehicle activities and intentions to pedestrians (Colley et al., 2020; Karina A Roundtree et al., 2020) and interior interfaces designed for cognitively impaired people (Eskandar et al., 2022; Park et al., 2024, 2023), to be intuitive for older people (Gluck et al., 2020), and to allow the inclusive operation of AVs (Amanatidis et al., 2018). Personal digital devices have also been explored as a means of meeting the SAV-related needs of excluded groups, with studies exploring the design of smartphone apps to generally improve accessibility (Martelaro et al., 2022; Wiles, 2023), specifically meet the needs of visually impaired passengers (Bhalearo et al., 2022; Fink et al., 2024), and improve security for women (Schuß et al., 2022). Some studies have also focused on the physical accessibility of AVs for older and disabled people, including the ingress and egress of the vehicle and the interior layout (Tabattanon et al., 2020, 2019), with some providing detailed design guidelines for multiple physical aspects of the SAV (Klinich et al., 2022).

Vehicle manufacturers and SAV providers are considering the needs of excluded groups through concepts and trials of inclusive vehicles with wheelchair ramps and lifts (Etherington, 2019; Local Motors, 2018; Ohmio, n.d.), accessible interfaces for visually and hearing-impaired passengers (Lyft, 2019; Waymo, 2021), and serving older populations (DeNA Co., 2021; MUJI, 2021; Navya, 2020). While these projects provide a good basis for creating more inclusive SAVs, many are limited in achieving inclusion due to existing vehicle limitations, such as the floor height of the May Mobility shuttle (Etherington, 2019), resulting in an impractically long and steep wheelchair ramp.

2.4.1 THE NEED FOR MULTIVARIATE INCLUSIVE SAV DESIGN

While existing explorations of SAV-related inclusion in academic and industry contexts provide a reassuring outlook for inclusive SAVs, much work considers inclusion in isolation, with solutions narrowly targeted at meeting the needs of a

specific group. Although this approach can highlight ideal solutions, outcomes may tend towards the idealistic, failing to identify potential conflicts, where solutions for one group result in the exclusion of another, and pragmatic considerations that impact application in real-world contexts. For example, the design consultancy Layer's Joyn concept (Layer, 2024) focuses on dividing interior space to improve security but reduces the openness that might allow for a wheelchair space to be incorporated.

Failure to consider the wider user base when designing inclusive SAV features may result in limited uptake in real-world contexts, where designers must meet the needs of the general population. Where such "niche" features may be considered too costly or compromising for general-purpose SAVs, decision-makers may be tempted to limit complete inclusivity to a subset of vehicles within the fleet. In existing transport services, this approach creates a two-tier provision where non-excluded groups, who can use any vehicle, benefit from regular transport access but excluded groups, who can only use specific vehicles, face longer wait times or service inaccessibility. A key example is Uber's UberWAV (wheelchair-accessible vehicle) service, with one study showing that wheelchair users receive significantly worse service with lower vehicle availability than Uber's standard service and 4.5 times the average wait time (Hassanpour et al., 2021).

To maximise inclusion and provide equitable transport services, inclusive SAV design should address the needs of multiple excluded groups, resolve conflicting priorities, and be integrated into standard vehicle and service offerings, thereby reducing reliance on special-purpose vehicles. This project seeks to present design responses that address the needs of various excluded groups within a single SAV design and service offering.

2.5 Introducing the inclusive design for transport framework

As transport services combine multiple physical, informational, infrastructure, and service elements, a clear framework for transport exclusion would support designers and decision-makers in navigating the complexities of inclusive transport research and design. This section describes an *Inclusive design for transport framework (IDfT)*. An earlier version was published in *Side-stepping future transport exclusion via an expanded inclusive design approach* (Severs et al., 2022). The framework comprises three dimensions to consider when applying inclusive design to transport services:

1. The groups affected by transport exclusion.
2. The types of exclusion that these groups may experience.
3. The levels at which people experience exclusion within a transport service.

As transport inclusion research often uses qualitative methods such as workshops (Gheerawo and Harrow, 2013), semi-structured interviews (Velho, 2019), and co-design (Brewer and Kameswaran, 2018), the *Inclusive design for transport framework* helps in the planning of such activities to ensure that participants and areas of exploration represent a wide range of potential exclusion.

The framework can be illustrated as a 3-dimensional space which defines the extents of transport exclusion (Figure 2). The inclusivity of a given vehicle or transport service might be evaluated by the volume of this space where exclusion can be considered to have been addressed, i.e. the number of groups, types, and levels of exclusion that have been considered in its design.

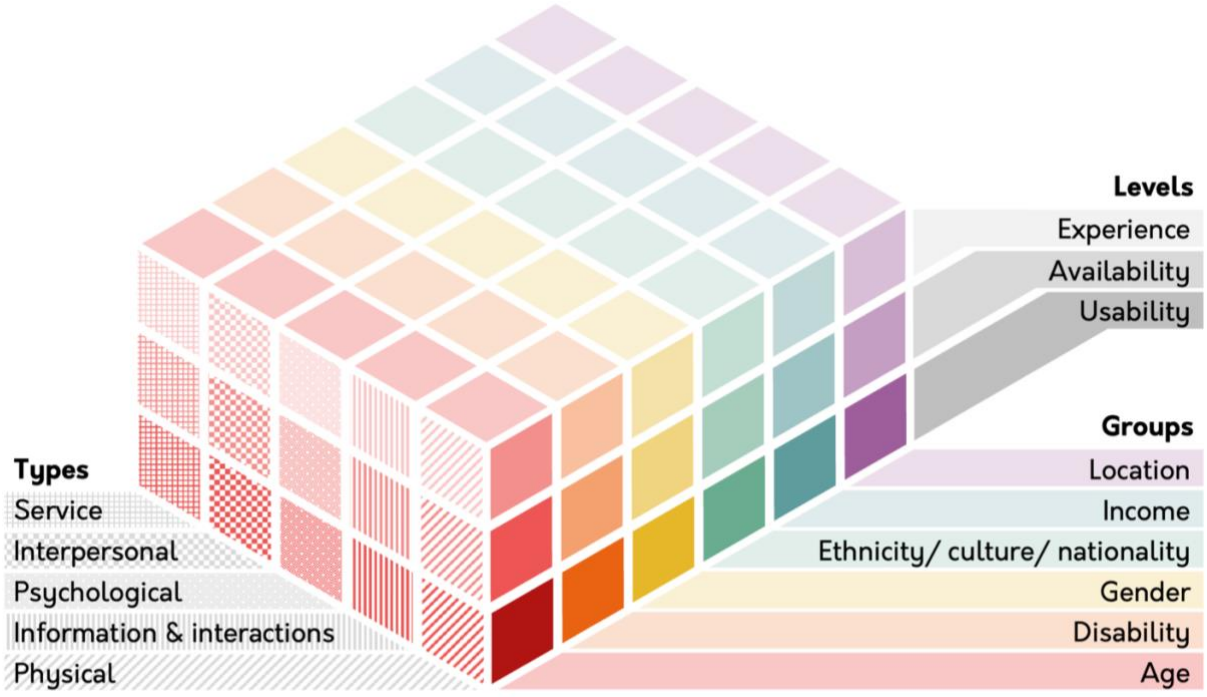

FIGURE 2 THE INCLUSIVE DESIGN FOR TRANSPORT FRAMEWORK

2.5.1 THE 1ST DIMENSION OF THE INCLUSIVE DESIGN FOR TRANSPORT FRAMEWORK: GROUPS AFFECTED BY TRANSPORT EXCLUSION

The first dimension highlights that inclusive design for transport must address the needs of a range of groups whose mobility is impacted by age, disability, gender,

location, income, and ethnicity/culture/nationality-related factors. A socially inclusive approach (Gheerawo, 2016) to transport design would better serve to address these groups affected by transport exclusion.

To create inclusive vehicles and transport services, designers and decision-makers should use this dimension as a starting point for research and design, seeking to understand the existing and anticipated needs and barriers of people across this range of groups.

2.5.2 *The 2nd dimension of the inclusive design for transport framework: Types of transport exclusion*

The second dimension comprises the five types of transport exclusion detailed in 2.2.3. These types of transport exclusion may be used by designers and other decision-makers to structure research activities and questions, ensuring a complete investigation of the range of exclusion that excluded groups experience.

2.5.3 *The 3rd dimension of the inclusive design for transport Framework: Levels of transport exclusion*

Some areas of transport exclusion may not be addressed through traditional usability-focused design (e.g. barriers related to the availability and administration of services). The IDfT incorporates three levels of transport exclusion to define the breadth of ways in which inclusion can be improved: *availability*, *usability*, and *experience*. Figure 3 shows how these levels can be arranged according to their impact on the use of a service by a transport-excluded person.

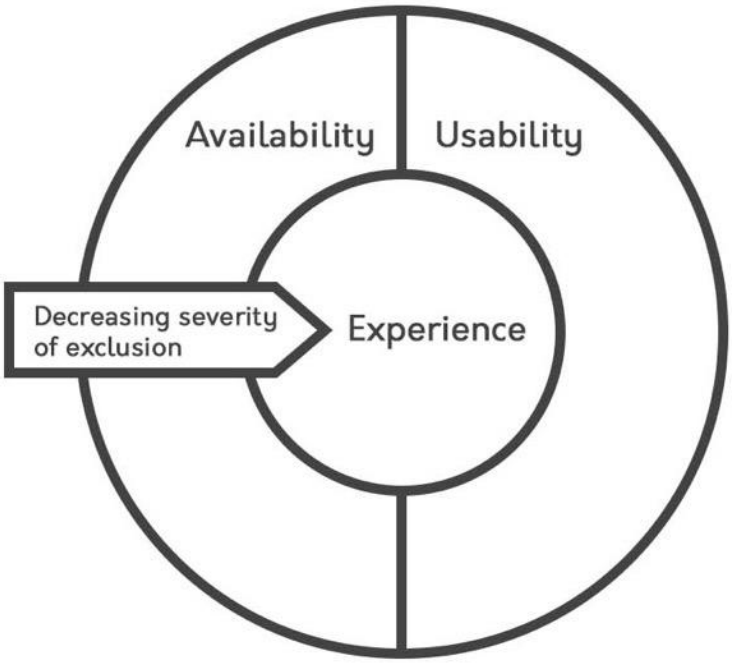

FIGURE 3 LEVELS OF TRANSPORT EXCLUSION FOR THE INCLUSIVE DESIGN OF TRANSPORT *(SEVERS ET AL., 2022)*

Availability

Availability pertains to the presence of a transport service that an individual can use to access a desired location in a given scenario. Several exclusionary factors may make a service less available to an excluded user, including:

- *Cost*: The lack of a transport service to the desired destination at an affordable price, affecting financially excluded users.
- *Location*: The lack of a transport service to the desired destination from the users' location, affecting geographically excluded users and mobility impaired people who may be unable to engage in active transport to the journey start point.
- *Time*: The lack of a transport service to the desired destination within the users' time constraints, affecting those who experience time poverty.

Severe availability-level exclusion may result in complete isolation and an inability to travel. Less severe forms can lead to longer wait times, increased walking distances at journey start/end, and reduced transport mode choice. Availability-level exclusion is typically addressed through service design, implementation, and policy decisions, rather than design-related interventions.

Usability

Usability relates to the ability of people to use transport services due to disability-related barriers, such as the lack of audio information for visually impaired people or barriers relating to context (e.g. lack of information in a user's language or lack of level boarding for parents with pushchairs). Some excluded people may still use transport services with poor usability by relying on assistive devices, assistance from others, and strategies to overcome usability issues, such as wheelchair users jumping between underground platforms and trains (Velho, 2019). In severe cases, transport services with poor usability may completely exclude certain groups, forcing them to rely on less convenient and costlier alternatives.

Experience

Excluded groups' experiences of transport services should be equitable to non-excluded users. While a service may be available to a particular excluded group, they may experience exclusion due to poor user experience of assistance features and their preferences not being accounted for in the non-functional elements of the transport service. The design of assistive features in vehicles can focus too much on function while neglecting aesthetics or user experience, resulting in the stigmatisation of disabled people and other excluded groups (Bichard et al., 2007; Velho, 2019). As the experience-based needs of excluded transport users are not as urgent as usability and availability needs, they may be overlooked by researchers and excluded groups themselves, who often prioritise discussions about more severe aspects of accessibility and exclusion.

Using these three levels of transport exclusion, designers and decision-makers can ensure that research with excluded groups incorporates experiential and availability-related explorations alongside usability-related discussions. While wheelchair users in semi-structured interviews may initially focus on physical access issues (Velho, 2019), an interview structured around the three levels may encourage individuals to discuss how their journey can be made more pleasant beyond the need for good access.

2.5.4 USE OF THE INCLUSIVE DESIGN FOR TRANSPORT FRAMEWORK

The inclusive design for transport framework bridges the gap between traditional inclusive design and the needs of people experiencing transport-related social exclusion. Figure 4 shows how this framework expands the inclusive design approach to include groups beyond the age-ability construct and address transport-related

social exclusion beyond usability by considering availability barriers and excluded groups' experiential preferences.

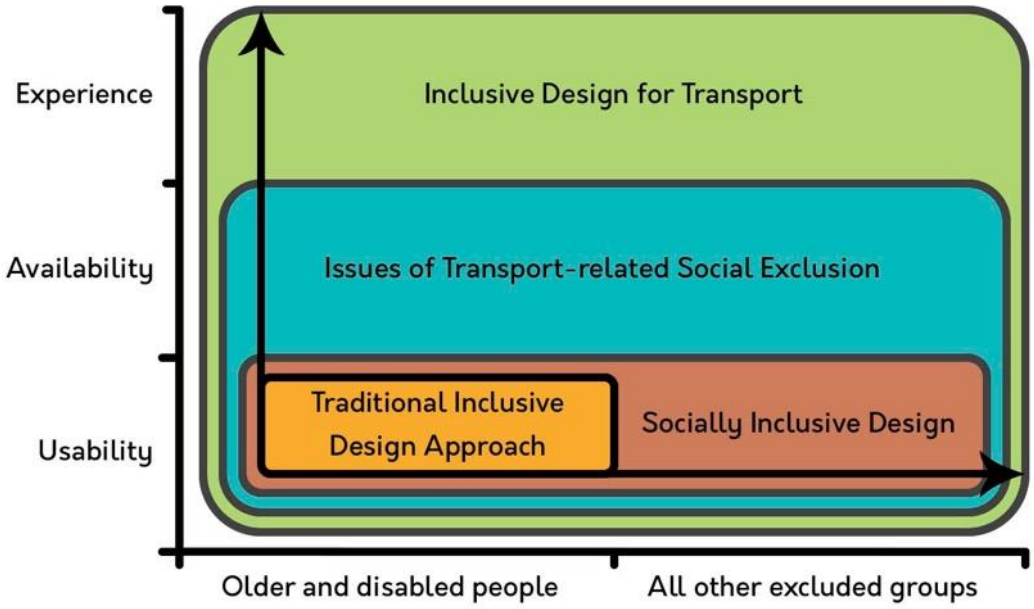

FIGURE 4 INCLUSIVE DESIGN FOR TRANSPORT FRAMEWORK COMPARED WITH INCLUSIVE DESIGN, SOCIALLY INCLUSIVE DESIGN, AND THE BARRIERS OF TRANSPORT-RELATED SOCIAL EXCLUSION *(SEVERS ET AL., 2022)*

A key use case of the framework is the development of future vehicles and transport services. While the existing experiences of excluded groups may help develop new solutions, there is a need to anticipate the barriers that future vehicles may create. The unfamiliarity of research participants with novel transport modes (such as SAVs) may hinder the use of participatory methods in anticipating future barriers. However, using the five types of transport exclusion as a starting point allows for more focused explorations based on hypotheses drawn from excluded groups' current experiences. Discussions of specific scenarios according to these types of exclusion may help participants better envisage barriers caused by novel vehicles and transport services and provide insights into how these issues can be "designed out".

While many excluded groups may benefit from inclusive design interventions, the extent to which design might address each exclusion type varies, and groups experiencing less design-dependent exclusion might be less likely to be included through design alone. Groups and exclusion types addressable through design may

be identified early in an inclusive transport project to define the focus of subsequent research and practice.

As design typically focuses on human-product interactions, Information & interactions, and physical exclusion are often the most suitable for design intervention. However, other types may be indirectly addressed through design, such as psychological exclusion addressed through safer space design or service exclusion addressed through interior designs which maximise occupancy and increase service efficiency. For Location, Income/financial, and Ethnicity/culture/language excluded groups, service-related exclusions are common, with service/policy decisions having the biggest impact and fewer opportunities for design. For age, disability, and gender, more design opportunities exist owing to the prevalence of physical and informational barriers and the potential for interventions to address interpersonal interactions and psychological exclusion through the design of spaces.

As age, disability, and gender offer most opportunities for inclusive transport design interventions, this project focused on how SAVs might address the needs of older people, women, and disabled people. To consider intersectional exclusion, the research recruitment included participants who might also be excluded because of the other three factors.

3 METHODOLOGY

3.1 THE APPROACH: INCLUSIVE DESIGN IN A RESEARCH CONTEXT

To fulfil this project's aim of creating a range of SAV design concepts to respond to multiple exclusions, it is necessary that the methodology used is well placed to gather detailed understandings of excluded groups' transport needs and creatively explore how they might be responded to.

This PhD project seeks to answer the following primary research question:

How might an inclusive design approach be used to further Shared Autonomous Vehicle design to better meet the needs of people who experience exclusion from transport?

The application of an inclusive design approach has a significant impact on the overall methodology of this project. Inclusive design has been described as:

'a framework and growing body of practice within which business decision-makers and design practitioners can understand and respond to the needs of diverse users' (Clarkson, 2003)

According to this definition, inclusive design is not tied to any particular research methodology. In fact, inclusive design was originally intended for application in an industry context, with inclusive design research historically focused on creating practical methods and tools for designers in these contexts (Keates et al., 2000). While not prescribing a specific methodology, the above description of an inclusive design approach necessitates a methodology that allows the researcher to both understand and respond to the needs of excluded groups.

3.1.1 DESIGN RESEARCH

Responding to people's needs through design sets inclusive design research apart from other disciplines and significantly impacts the methodology of such projects.

The field of design research is generally concerned with "design practice". Archer (1995), a pioneer of design research, distinguishes 'research about practice', 'research for practice', and 'research through practice', with the last being most relevant here. On research through practice, Archer argues that constructing or

enacting something is sometimes the best way to explore or test propositions, describing an approach of Action Research as systematic inquiry through practical action to test new information and generate knowledge.

Action Research is well suited to inclusive design research which negotiates the complexity of transport exclusion, equipping the researcher to engage in constructive action which leads to a depth of understanding of and practical design responses to people's needs. It is also suited to researching nascent technologies, like SAVs, with a limited knowledge-base regarding people's needs and how they might be met. While Archer (1995) acknowledges Action Research's limitations in creating generalisable findings, he emphasises its value in providing insights for further studies. It is my hope that the findings in this thesis provide such valuable insights to inform future inclusive SAV research. As well as providing stimuli for future investigation, Boyd Davis and Vane (2022) note that design practice also helps to externalise ideas during the research process, improving researcher understanding, allowing iteration, aiding participant communication, and informing research direction.

Related research approaches share Action Research's view of the researcher as an active practitioner. Real world research takes a pragmatic approach to produce workable solutions (Robson and McCartan, 2016), while Design Science (Johannesson and Perjons, 2014)structures design research as scientific investigations emphasising rigor and generalisability.

While Action Research is a useful, general approach to research through design, it is helpful to consider more specific approaches to understanding and responding to the needs of excluded groups and, ultimately, to how responses might be *shared* with those in positions to influence inclusion.

Understanding

To address exclusion issues, we must go beyond understanding needs to examine how barriers manifest and can be addressed. In inclusive design, qualitative and participatory methods are often chosen to allow those with lived experiences of exclusion to describe barriers in detail, providing rich insights (Clarkson, 2003).

Responding

Translating insights into designs involves the researcher/designer's creative process. Inspiration, intuition, experience, and prior knowledge form a "black box" of design

activity. This complexity limits precise documentation of decisions and justifications, a challenge that increases with the multivariate nature of holistic vehicle design, requiring constant prioritisation between groups' needs.

Sharing

While this project focuses on understanding and responding to excluded groups' needs, sharing findings with industry is explored to increase impact. Sharing with knowledge users is a key inclusive design aim (Clarkson and Coleman, 2015). Methodologies like design research methodology (DRM) (Blessing and Chakrabarti, 2009) focus on sharing through creating support to improve design practice - what Archer (1995) calls 'Research for the purposes of practice'.

3.2 THE RESEARCH PARADIGM: POSITIONING THE RESEARCHER

A designer-researcher with a practical, solutions-focused approach might consider theoretical discussions of research foundations to be a distraction. However, Robson and McCartan (2016) argue that 'real world' researchers should have a foundational understanding of the theory behind their research.

3.2.1 INCLUSIVE DESIGN AND RESEARCH PARADIGMS

The 'basic set of beliefs that guide [a researcher's] action' can be summarised as a research paradigm (Guba, 1990). Guba and Lincoln (1994) describe how paradigms incorporate views on ontology (understandings of reality), epistemology (how reality can be known), and methodology (how researchers obtain knowledge) and outline four main research paradigms: positivism, post-positivism, critical theory, and constructivism, none of which adequately summarise an inclusive design researcher's approach.

An inclusive design approach is precluded from objectivist epistemologies because of its value-driven nature. It assumes a critical realist ontology, where exclusion exists but is incompletely apprehensible due to complex needs, variations within excluded groups, and intersectionality. The iterative nature of design research also aligns with critical realism, assuming that design responses improve with iterations that better apprehend the reality of exclusion. Although the transformational nature of inclusive design has been described as a type of critical theory (D'souza, 2004), its pragmatic approach to creating change through design differs from critical theory's aim of

changing worldviews, although the sharing of inclusive design findings may affect the perspectives of knowledge users (Clarkson and Coleman, 2015).

3.2.2 A *PRAGMATIC PARADIGM*

The pragmatism of inclusive design means the paradigm guiding such research can only be described by how it combines elements of different paradigms to serve understanding and responding to excluded groups' needs through "what works". Robson and McCartan (2016) describe 'a pragmatic approach' common among researchers aiming to 'get the job done'. Johnson and Onwuegbuzie (2004) discuss a pragmatic paradigm offering 'a practical and outcome-oriented method of inquiry that is based on action'. This pragmatic approach explains how projects can borrow from different paradigms, rejecting traditional dualisms and embracing views that adherents of any of Guba and Lincoln's (1994) four paradigms may deem paradoxical.

This pragmatism is key in 'Design Science' projects where different paradigms inform research phases. Activities to understand needs might assume a less objectivist epistemology where findings emerge through researcher-participant interactions before a positivist stance is applied to evaluate designs (Johannesson and Perjons, 2014).

3.2.3 *SUMMARY OF THE RESEARCH PARADIGM*

This project adopts a pragmatic research paradigm to generate workable descriptions of excluded groups' needs to inform practical design responses. Ontologically, it applies critical realism where knowledge about excluded groups' needs can be imperfectly apprehended and assumes designs created in response may be broadly beneficial in addressing these needs. Epistemologically, it accepts that knowledge is constructed through dialogue with participants, is value-driven, and that there is an extent to which research and participant might influence each other and the knowledge created. However, it assumes this knowledge presents an imperfectly apprehended view of reality that can reasonably inform the design of effective solutions. The methodology is dialectical, using dialogue between investigator and participants to understand and respond to needs, while incorporating elements of more experimental/ manipulative methodologies for testing designs. This approach differs from traditional paradigms concerned with explaining how things are, rather than affecting change.

3.3 The methodology: an inclusive design research process

3.3.1 *Methodological frameworks for design and research*

While researcher positioning in inclusive design projects may not align with typical research paradigms, methodological approaches to understanding and responding to needs are well documented across industry and academic contexts.

These approaches include stages through which needs are understood and responses created, using divergent and convergent thinking to drive exploration, ideation, problem definition, and design refinement. The design science method framework by Johannesson and Perjons (2014) outlines five such stages: explicate problem, define requirements, design and develop artefact, demonstrate artefact, and evaluate artefact. The industry-focused double diamond diagram (Figure 5) presents four similar stages: discover, define, develop, and deliver (Design Council, 2023).

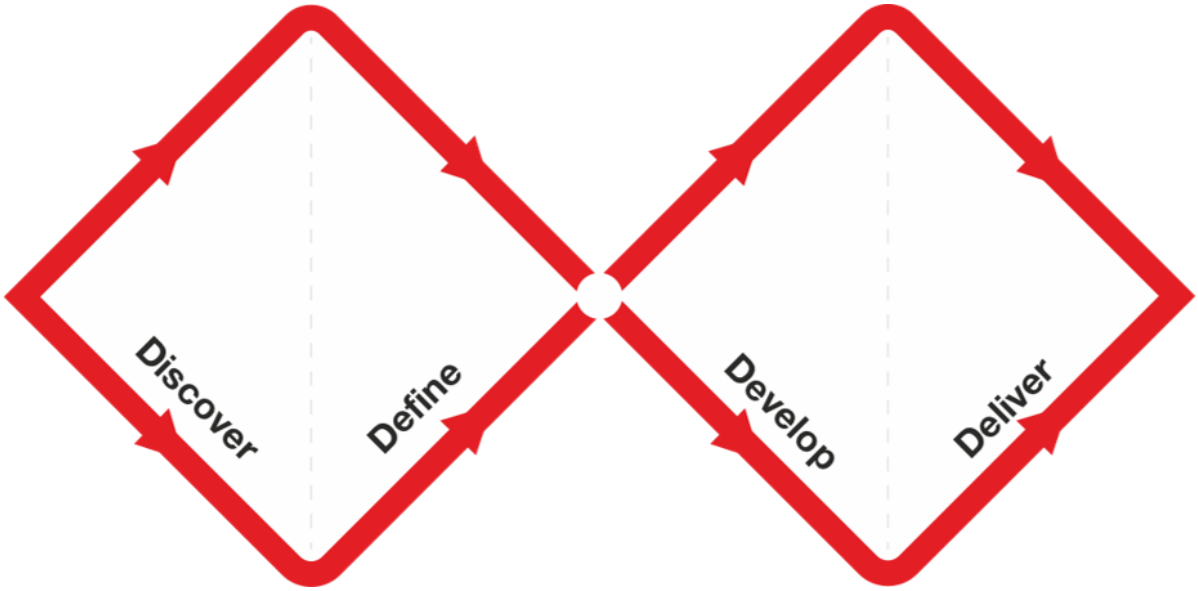

Figure 5 The Double Diamond (Design Council, 2023)

The stages of the Double Diamond and design science approaches can be applied in an inclusive design context with different stages corresponding to two overarching inclusive design "phases" of understanding and responding, each with divergent and convergent sub-stages. Table 4 demonstrates this relationship between inclusive design, Double Diamond and design science approaches.

TABLE 4 COMPARABLE STAGES OF INCLUSIVE DESIGN, DOUBLE DIAMOND, AND DESIGN SCIENCE APPROACHES

Inclusive design	Double diamond	Design science
Understand	Discover	Explicate problem
	Define	Define requirements
Respond	Develop	Design and develop artefact
	Deliver	Demonstrate artefact
		Evaluate artefact

3.3.2 *METHODOLOGICAL FRAMEWORK FOR THIS PROJECT*

The main stages of this research project correspond to the double diamond as follows:

Discover – Transport exclusion is explored with barriers and needs identified through a literature review and workshops.

Define – Specific groups and focus areas are selected from identified barriers. Early concepts are developed, and workshops are conducted to define the design challenges.

Develop – Design concepts are further developed through focused workshops and expert consultations to understand technical feasibility.

Deliver – Concepts are combined into a single vehicle design with visualisations and illustrations produced.

Although these stages broadly outline the research and design activities conducted during the project, the linearity of this model does not accurately represent the messy reality of design research. Throughout the project, the researcher engaged in ongoing design practice or Action Research (Frayling, 1994). This design practice formed the backbone of the project, creating stimuli for ongoing participatory research activities and responding to challenges emerging from this research. Research activities involved collaborations with two types of experts: people with personal experience of transport exclusion or "lived experience experts", and automotive industry experts with experience of designing vehicles and technical knowledge relevant to SAV design. This iterative structure blurs the lines between understanding and responding to needs, a characteristic of design-based research (Johannesson and Perjons, 2014) and exemplifying design-led externalisation (Boyd Davis and Vane, 2022).

To inform the future dissemination of findings, inclusive design in the automotive industry was explored through research seeking to understand how information might be shared with stakeholders responsible for vehicle development. Reflecting the early stages of the Design Research Methodology (Blessing and Chakrabarti, 2009), a focus group and industry survey sought to:

- Understand barriers to inclusive design application in automotive industry.
- Understand how automotive designers prefer to receive inclusive design information.

Figure 6 shows the methodological framework, demonstrating research activities undertaken with industry professionals and excluded groups, iterative loops of design practice informing research activities and vice versa, and how these activities ultimately inform key project outcomes. Individual research activities are detailed in the following section.

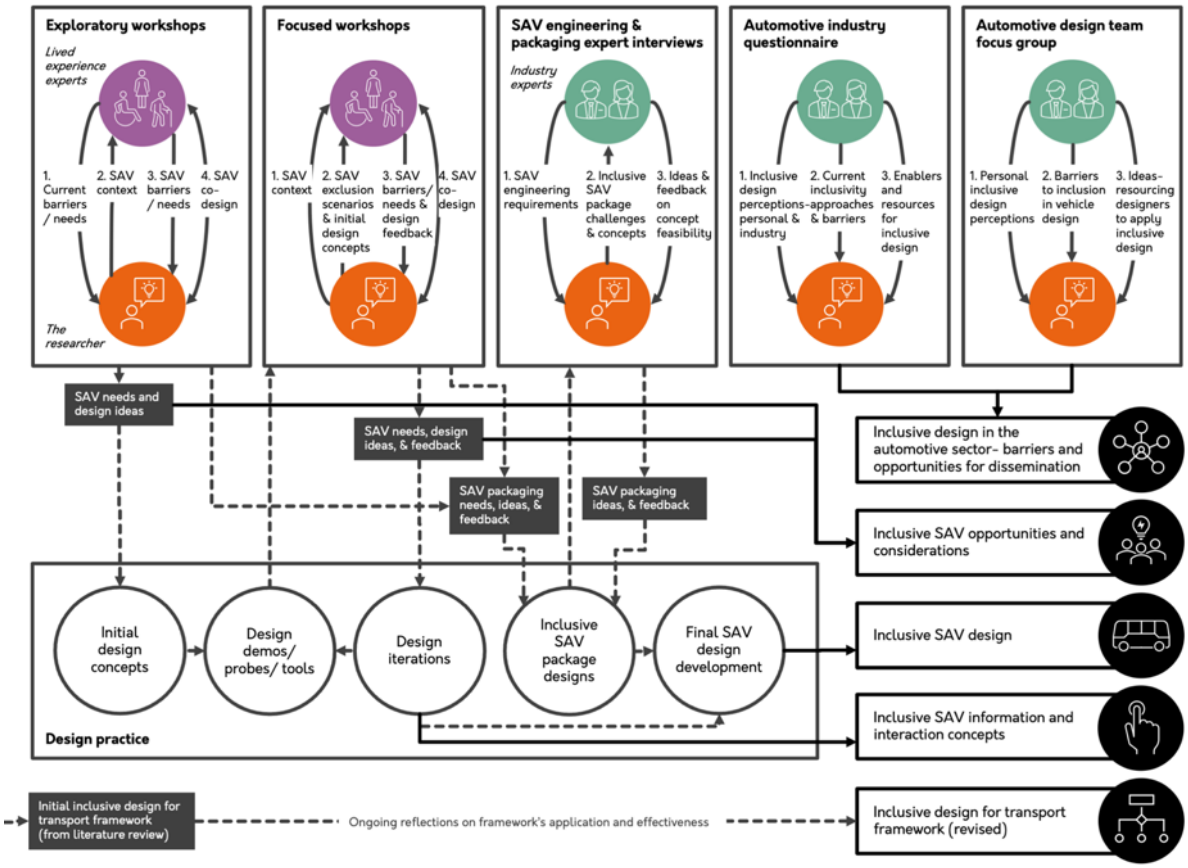

FIGURE 6 METHODOLOGICAL FRAMEWORK

3.4 THE METHODS: DATA GATHERING, ANALYSIS, AND DESIGN

3.4.1 *EXPLORATORY WORKSHOPS*

Initial *exploratory workshops* were conducted with excluded groups to understand their current experiences of exclusion and the potential for exclusion when using SAV services and to generate ideas for inclusive design solutions.

The workshops used a 'Future Workshops' methodology, enabling participants to consider future scenarios through existing experiences by combining a 'critique of the current situation' with 'fantasy/implementation' phases to collectively imagine improvements (Victor and Vidal, 2005).

The critique stage involved a journey mapping activity to consider the end-to-end experiences of excluded groups, an approach that has previously been used in similar contexts as an advocacy tool for disabled people (Crosier and Handford, 2012). Participants completed a booklet outlining the key stages of a typical transport journey, with questions about their experience and space to record thoughts at each stage (Table 5).

Before the second stage, the participants engaged in an SAV introduction discussion, learning about autonomy and viewing images of vehicle designs and use cases (Figure 7). Visually impaired participants examined a 3D printed SAV model to understand the potential design and layout (Figure 8). The discussion continued until the participants demonstrated a clear understanding.

The fantasy/implementation phase used collaborative co-design (Sanders and Stappers, 2008), focusing on addressing barriers through the SAV design. The participants enacted journey activities in the SAV mock-up (Figure 9). Design ideas were tested by reconfiguring the layout and creating props. Props (Figure 10) served as 'design probes' (Gaver et al., 1999) to prompt discussions of functional features and experiential aspects of inclusion.

FIGURE 7 WORKSHOP INTRODUCTION SLIDES TO EXPLAIN THE CONCEPT OF SAVS AND THE POTENTIAL VARIATION IN THEIR DESIGN AND OPERATION

FIGURE 8 TACTILE SAV MODEL

FIGURE 9 SAV MOCK-UP

FIGURE 10: FOAMBOARD PROPS

TABLE 5 STAGES AND QUESTIONS FROM JOURNEY MAPPING TOOL

Stage	Question number	Question
1. Booking and planning	1	How do you plan your journey?
	2	Do you book in advance?
2. Preparing for the journey	3	How do you remember the details of your journey?
	4	What items are you taking with you?
3. Getting to the vehicle	5	How do you get to the vehicle?
	6	Where do you board the vehicle?
4. Waiting	7	How long do you have to wait?
	8	What waiting facilities are available?
5. Getting on the vehicle	9	How easy is it to board?
	10	How do you find your seat?
	11	Where do you put your luggage/ other items?
6. On the journey	12	What do you do while on the journey?
7. Getting off the vehicle	13	How easy is it to exit the vehicle?
	14	Where do you exit the vehicle?
	15	Where do you put your luggage/ other items?
8. From the vehicle to your destination	16	How do you travel from the vehicle to your destination?
	17	How far do you travel from the vehicle to your destination?
	18	How do you navigate from the vehicle to your destination?

Participants and recruitment

Eleven participants attended four exploratory workshops, recruited through mailing lists, social media, and word of mouth. The participants represented groups excluded because of age, gender, and disability (previously identified as likely to be addressed through design interventions). The workshops included women (N=4), older people (N=3), physically disabled people (N=2), and those with neurodiversity/mental health conditions (N=2). To discuss interactions between excluding factors, participants were selected to represent diversity in other areas, including ethnicity and location (Table 6).

TABLE 6 EXPLORATORY WORKSHOP PARTICIPANTS

Workshop	Participant ID	Age	Gender	Ethnicity	Disability/ Health condition / Neurodivergent	Location
Disabled people	P1	25-34	M	Asian or Asian British	Blind/ visually impaired	Urban – Major city
	P2	65-74	M	White	Deaf/ hard of hearing	Rural – Town
Neurodivergent/ Mental health/ Learning Disability	P3	25-34	F	Asian or Asian British	Neurodivergent, Jawbone Syndrome (TMJ)	Urban – Major city
	P4	55-64	M	Asian or Asian British	Mobility impaired (not wheelchair user), Chronic illness /long – term health condition, Mental health condition	Urban – Major city
Older people	P5	65-74	M	White	Deaf/ hard of hearing	Suburban
	P6	65-74	M	White	Non-disabled	Urban – Major city
	P7	75-84	M	Asian or Asian British	Blind/ visually impaired, Mobility impaired (not wheelchair user)	Suburban
Women	P8	25-34	F	Asian or Asian British	Non-disabled	Urban – Major city
	P9	25-34	F	Mixed	Prefer not to say	Rural – Village
	P10	45-54	F	Black/African /Caribbean/ Black British	Chronic illness /long – term health condition	Urban – Major city
	P11	55-64	F	White	Mobility impaired (not wheelchair user), Reaching, stretching or dexterity impaired	Urban – Major city

3.4.2 FOCUSED WORKSHOPS

Following the exploratory workshops and throughout the inclusive design practice, *focused workshops* were conducted to investigate specific areas of exclusion

identified in previous research and respond to challenges during the design process. Areas of focus were selected based on relevance and impact on SAV design and to provide examples of inclusive design addressing the needs of groups excluded due to age (older people), gender (women), and disability (wheelchair users and visually impaired people).

Participants and recruitment

Participants were recruited through mailing lists, social media posts, and word of mouth. A total of 19 participants joined 10 workshops with groups of women (N=7), visually impaired people and their assistants (N=6), wheelchair users and their assistants (N=3), and older people (N=3). The details of the participants are presented in Table 7. The participant IDs listed relate to the workshop focus, specific workshop attended, and participant number. Some participants from the exploratory workshops returned for the focused workshops, as indicated by their Participant ID from Table 6 (in parentheses). In women's workshops, some participants from earlier focused workshops (1-3) returned for subsequent workshops (4 and 5) to explore additional topics and provide feedback on the developed designs. Returning participants are indicated by their ID from the first workshops (in parentheses).

TABLE 7 FOCUSED WORKSHOP PARTICIPANTS

Workshop	Participant ID	Age	Gender	Ethnicity	Disability/ Health condition / Neurodivergent	Location
Women 1	W1P1	18-24	F	Asian or Asian British	Non-disabled	Urban – Major city
Women 2	W2P1	18-24	F	Asian or Asian British	Non-disabled	Urban – Major city Urban – Town
	W2P2		F	Asian or Asian British	Non-disabled	Urban – Major city
Women 3	W3P1	25-34	F	Asian or Asian British	Non-disabled	Urban – Major city
Women 4	W4P1(W1P1)	18-24	F	Asian or Asian British	Non-disabled	Urban – Major city
	W4P2	45-54	F	White	-	Urban – Major city
	W4P3	-	F	-	-	-
Women 5	W5P1	18-24	F	White	Non-disabled	Urban – Major city
	W5P2(W3P1)	25-34	F	Asian or Asian British	Non-disabled	Urban – Major city
	V1P1	55-64	F	British Pakistani	Blind/VI	Urban – Major city

visually impaired people 1	V1P2	65-74	M	UK	Blind/VI	Urban – Major city
	V1A	Assisting participants				
visually impaired people 2	V2P1	45-54	F	White British	Blind/VI	Urban – Major city
	V2P2	45-54	F	White British	Blind/VI	Rural -Town
	V2P3	45-54	F	Caribbean British Asian (Indian)	Blind/VI	Urban – Major city
Wheelchair users 1	WU1	55-64	M	White British	Wheelchair user	Urban – Major city
Wheelchair users 2	WU2	45-54	F	African Caribbean	Wheelchair user Reaching, stretching or dexterity impaired Chronic illness /long – term health condition	Urban – Major city
	WU2A	Assisting participants				
Older people	OP1(P5)	65-74	M	White	Deaf/ hard of hearing	Suburban
	OP2(P6)	65-74	M	White	Non-disabled	Urban – Major city
	OP3	65-74	M	White European	Blind/ VI Chronic illness /long – term health condition	Urban – Major city

Workshop focuses and activities

Co-design activities (Sanders and Stappers, 2008) explored specific exclusions participants anticipated from SAV introduction, tested early design concepts, and created ideas to inform design development. All workshops included the same SAV introduction discussion, presentation, and Q&A as the exploratory workshops.

The workshop structure varied according to the range of topics and groups, with activities selected based on suitability for the group, topic focus, and maturity of ongoing design practice. The activities fell into three main categories:

Creative discussions of SAV journeys – Including journey mapping activities (Crosier and Handford, 2012) and illustrated scenarios (Carroll, 2000) created to prompt discussion and ideation related to specific barriers.

Collaborative enactment and co-creation using specialised tools – For some workshops, participants used virtual reality (VR) headsets to explore and suggest improvements to a full-scale, virtual SAV design shown using Gravity Sketch VR (Gravity Sketch, 2024). The VR SAV matched the location of seating and steps onboard the physical SAV mock-up, allowing participants to understand the scale and test physical elements. A "pass-through" feature enabled participants to see physical obstacles and other people's movements. The researcher occupied the

same virtual space and responded to suggestions by creating 3D volumes and sketches and moving existing design elements (for seating layout changes, seats were moved accordingly). More confident participants collaborated using the basic pen tool in Gravity Sketch. VR has been used in participatory design to demonstrate designs and provide reality and scale not possible through sketches or models (Loyola et al., 2019) and for collaboration among expert designers (Novoa et al., 2022). However, it is not evident that previous work has used this technology in similar expert-participant co-design activities or workshops.

For visually impaired participants and others uncomfortable with VR technology, physical tools were used for vehicle-related co-design. Physical tools are commonly used in co-design to allow non-experts to engage in design (Borum et al., 2014), and configurable scale vehicle models have previously been used in inclusive mobility design research (Dhaundiyal and Sharma, 2023). A 3D-printed SAV scale model was used to allow the participants to demonstrate their ideas (Figure 15). This model differed to the one used in the exploratory workshops, incorporating moveable seats which allowed it to function as a design tool for participants to illustrate ideas, rather than simply a means of familiarising participants with SAVs. Full-scale physical co-design activities were also conducted using the SAV mock-up and marked-out floor areas (used by wheelchair users to avoid exertion from constant boarding ramp use) with seating and other physical props configured to illustrate and test ideas.

Critical evaluation and iteration of design concepts – Where design concepts had been developed from previous workshops, they were presented to participants for feedback as potential solutions to the exclusion being discussed. These concepts were presented as physical mock-ups – demonstrating tactile interfaces, vehicle features, and surfacing to visually impaired people; VR SAV interior designs – demonstrating interior layouts and features; and images – including illustrations and concept interface designs.

Table 8 details the specific topics and activities of each of the ten focused workshops, with Figure 11 – Figure 18 showing some of the tools used in these workshops.

TABLE 8 FOCUSED WORKSHOP TOPICS AND ACTIVITIES

Workshop	Workshop focus	Workshop activities
Women 1, Women 2, Women 3	Fear-based exclusion How might SAVs be designed to address fear-based exclusion experienced by women during a journey?	Journey scenarios – Fear-based exclusion storyboard images (Figure 11). VR co-design – Vehicle interior in Gravity Sketch VR (Gravity Sketch, 2024) (Figure 12).
Women 4, Women 5	Fear-based exclusion How might the division and layout of SAV interior spaces be designed to reduce fear-based exclusion experienced by women sharing an SAV with strangers? How might SAV-related information and interfaces be designed to foster an end-to-end sense of security for women when travelling?	Image-based design evaluation and iteration – Interface and interaction concepts shown to participants in a printed booklet allowing for annotation (Figure 13). VR design evaluation and iteration – Vehicle interior layouts and concepts for the division of space presented and iterated in Gravity Sketch VR (Gravity Sketch, 2024) (Figure 14).
Visually impaired people 1, Visually impaired people 2	Physical exclusion and information and interactions exclusion How might SAVs be designed to enable easy boarding and interior navigation for visually impaired people? How might SAVs be designed to allow visually impaired people to interact with the service and access the information they need?	Journey scenarios – Information and interaction preferences for booking and pre-boarding, at the vehicle, in the vehicle, and end of the journey. Physical enactment and co-design – using configurable SAV scale model (Figure 15) and full-scale mock-up Physical evaluation and iteration – testing 3D printed tactile map concept, tactile surface swatches, and navigable vehicle layout with continuous outside-inside guide rail (Figure 16).
Wheelchair users 1	Physical exclusion How might SAVs be designed to enable easy boarding and interior navigation for wheelchair users?	Physical and VR enactment and co-design – using marked floor space and VR vehicle interior model (Figure 12) to co-design interior layouts and door positioning.
Wheelchair users 2	Physical exclusion How might SAV vehicles and services be designs to offer whole journey exclusion for wheelchair users?	Journey mapping activity – mapping exclusion and ideating potential solutions throughout an SAV journey (Figure 17).
Older people	Information & interactions exclusion How might SAV information and interactions be designed to allow older people to access the service?	Journey scenarios – Storyboard images of different SAV journeys to prompt co-design of interactions to access the service. Interaction cards to prompt discussions of multiple potential interaction types (Figure 18).

FOCUSED WORKSHOP TOOLS

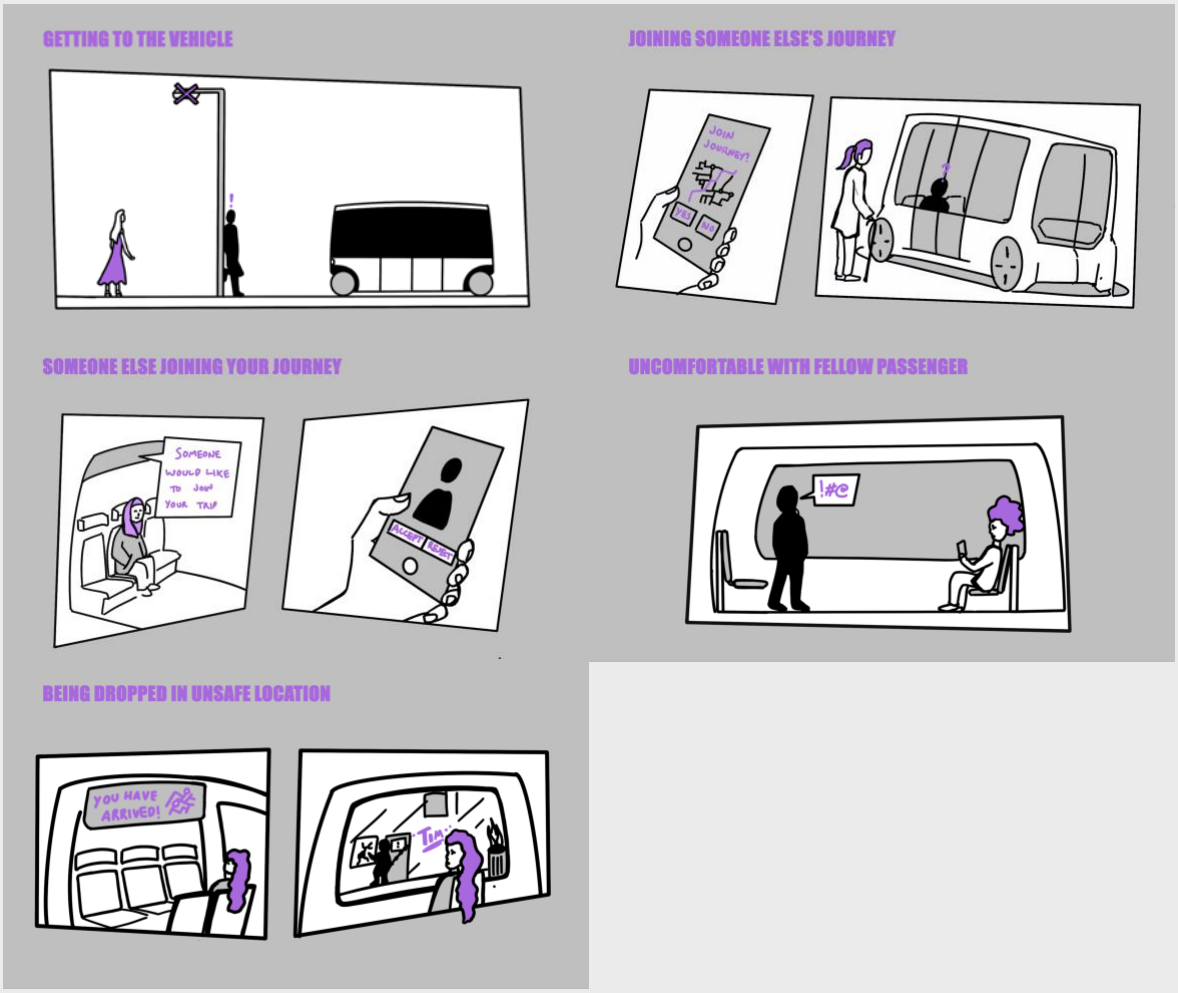

FIGURE 11 WOMEN'S WORKSHOPS SCENARIO STORYBOARDS

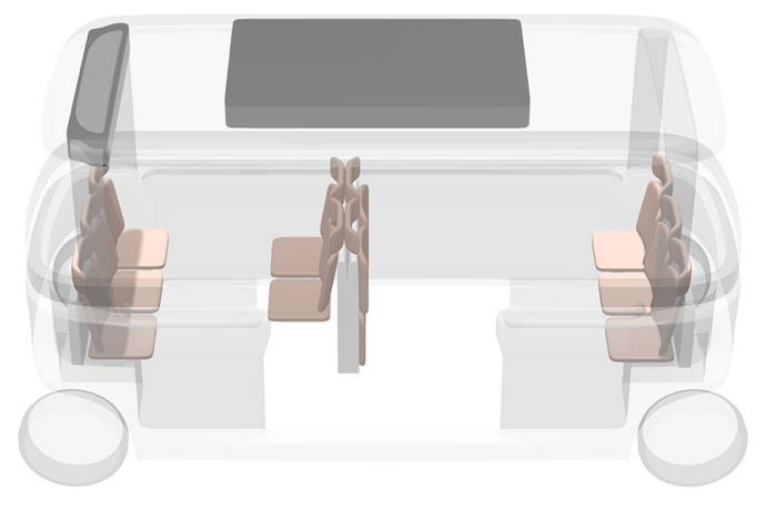

FIGURE 12 FOCUSED WORKSHOP GRAVITY SKETCH VR INTERIOR LAYOUT

FIGURE 13 BOOKLET PAGES FROM WOMEN'S WORKSHOPS 4 & 5

FIGURE 14 INTERIOR DESIGN CONCEPTS AND SHARING SCENARIOS FROM WOMEN'S WORKSHOPS 4 & 5

FIGURE 15 CONFIGURABLE TACTILE MODEL OF SAV INTERIOR (LEFT) AND ITS USE IN VISUALLY IMPAIRED PEOPLE'S WORKSHOPS (RIGHT)

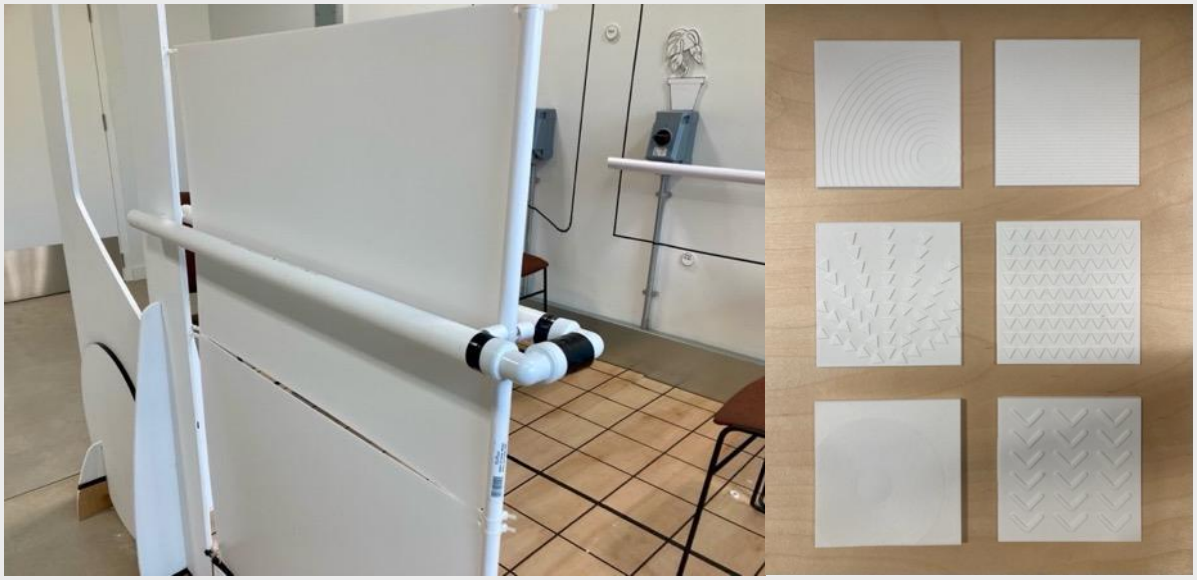

FIGURE 16 MOCK-UP GUIDE RAIL BASED ON P1'S SUGGESTION AND TACTILE DIRECTIONAL SURFACE SWATCHES

FIGURE 17 JOURNEY MAP FROM WHEELCHAIR USERS 2 WORKSHOP

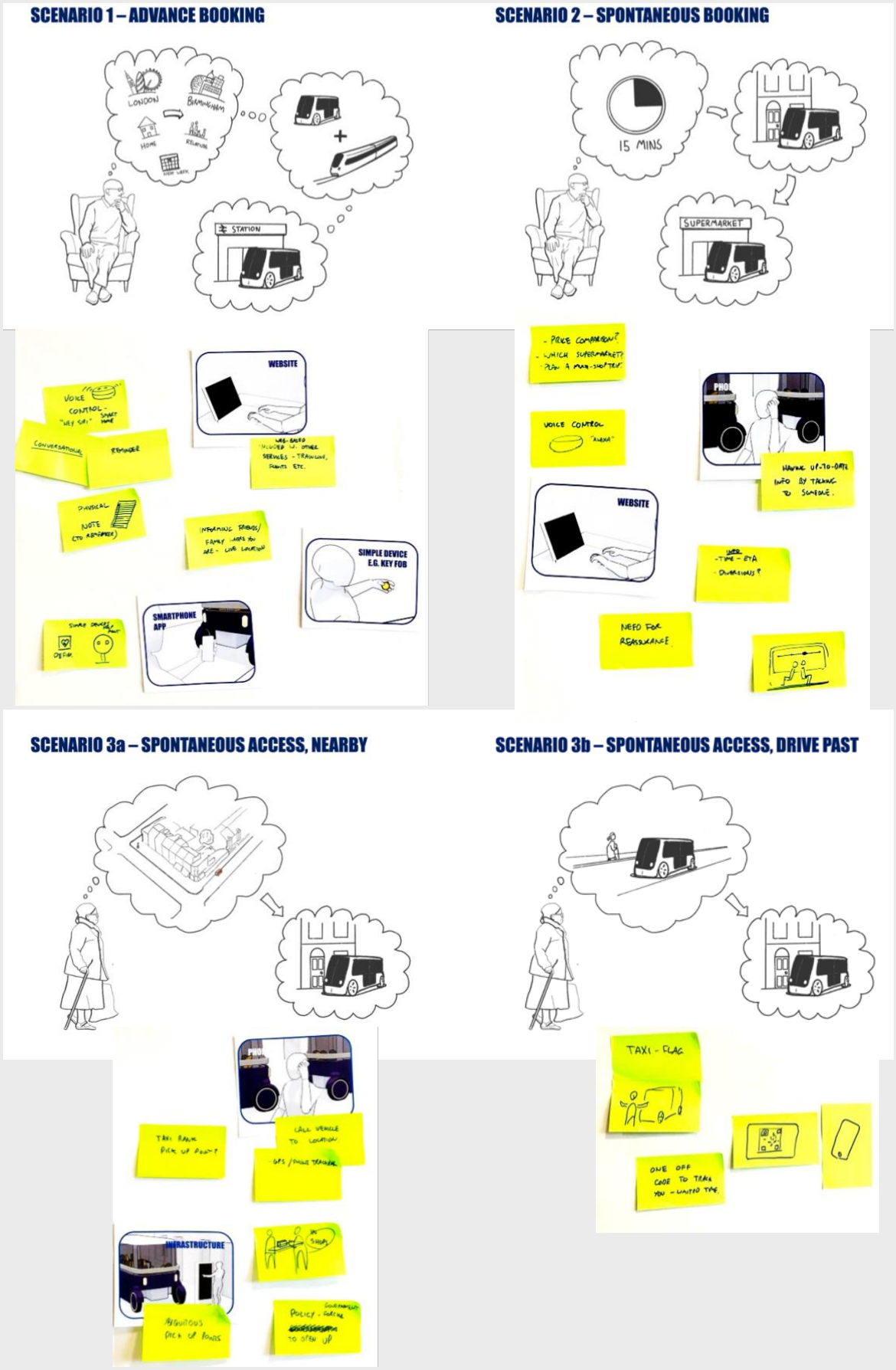

FIGURE 18 SCENARIOS AND STICKY NOTES FROM OLDER PEOPLE'S WORKSHOP

3.4.3 *Exploratory and focused workshops analysis and synthesis: From barriers to opportunities*

An inductive thematic analysis approach (Braun and Clarke, 2006) was used to analyse workshop outputs and transcripts, alongside video footage and images of co-created design outputs. The analysis focused on coding current and anticipated future barriers, needs, and design solutions.

These coded barriers, needs, and solutions were grouped within six journey stages:

1. *Before using the SAV service for the first time*
2. *Planning the journey and accessing the service*
3. *Pre-boarding*
4. *Boarding*
5. *Onboard*
6. *End of the journey*

Within each stage, subgroups were created for specific journey activities, related tasks, and needs.

As detailed insights emerged through focused workshops, they were added to the journey overview to inform the picture of exclusion. Structured tables detailing all identified needs throughout the workshops are presented in Appendix 1.

This approach allowed design opportunities to be identified which address multiple barriers experienced at similar journey stages, increasing the potential universality of designs in these areas. Figure 19 illustrates how the needs of excluded groups have been grouped, synthesised, and classified into opportunities and considerations for inclusive design responses. To help stakeholders identify opportunities that match their expertise, these have been grouped by SAV design area: vehicle, information and interactions, and service (detailed in the tables in Chapter 4, pp. 99, 102, 109).

A thematic analysis approach was also applied to create high-level themes for summarising results in Chapter 4, avoiding repetition of similar barriers and needs that would occur in journey stage-structured narratives.

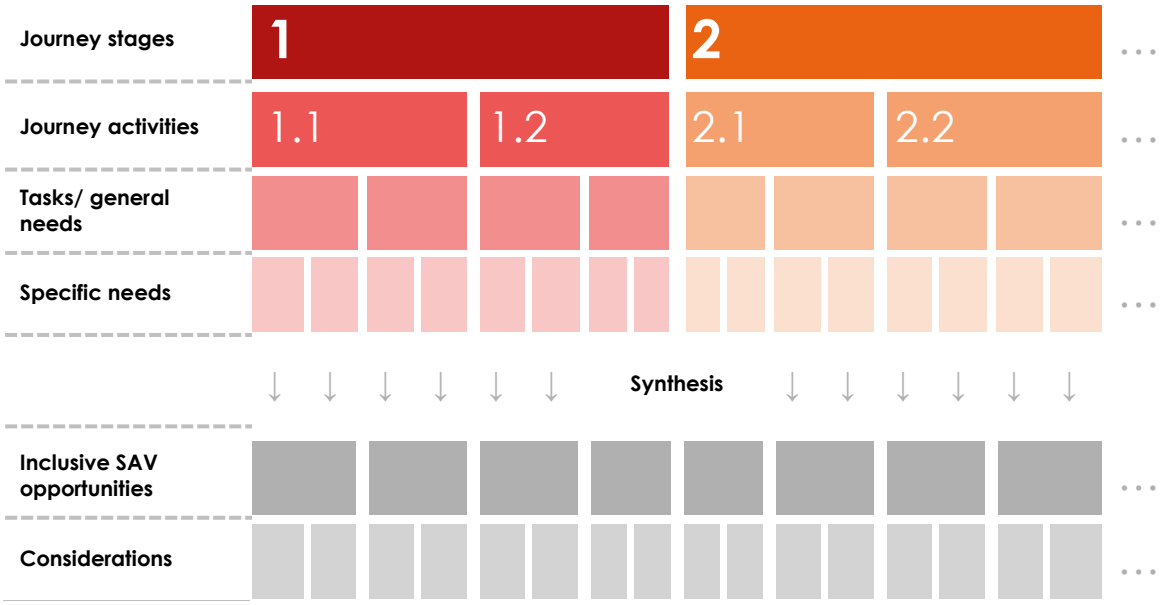

FIGURE 19 STRUCTURE OF JOURNEY NEEDS DATA AND INCLUSIVE SAV OPPORTUNITIES

3.4.4 *EXPLORATORY AND FOCUSED WORKSHOPS: LIMITATIONS*

For the exploratory workshops, small group sizes were selected to allow open discussion of sensitive topics and the safe use of the SAV mock-up. A high drop-out rate among older and disabled invitees due to Covid-19 resulted in fewer attendees than the six people initially recruited for each workshop. While smaller samples reduce the generalisability of barriers mentioned by participants, detailed discussions in smaller groups provided sufficient depth to inform design responses.

As focused workshops addressed emerging design challenges throughout the design practice, small groups and one-on-one workshops enabled multiple sessions to be arranged at short notice. For some workshops, VR co-design activities limited the group size to three to allow the safe use of VR headsets within the SAV mock-up.

While efforts were made to ensure that the groupings represented diverse backgrounds, some workshops were less representative due to low response rates among certain groups and non-attendance. This is most noticeable in the lack of diversity in ethnicity and gender among older people and the overrepresentation of city-dwellers due to research activities taking place in London.

As discussed previously, the design research approach may sacrifice a degree of generalisability in its results as it prioritises the depth of insight and creativity of design outputs achievable through qualitative research activities with smaller sample sizes

and a more subjectivist epistemological approach. As such, the barriers identified through these workshops (detailed in Chapter 4) and the resultant design concepts (presented in Chapters 5 and 6) are not intended as definitive solutions to exclusion. Instead, they present research-informed starting points to prompt further validation of the concepts and future development in this field.

3.4.5 *Expert interviews*

To ensure the feasibility of the engineering-related concepts developed during the design practice, three semi-structured expert interviews were conducted with two engineers specialising in vehicle packaging. The interviews focused on understanding key decisions in the vehicle packaging process and opportunities for novel SAV package designs to address inclusion issues, including discussions of emerging design concepts. The first expert (E1), who participated in two interviews early in the project, was an expert in designing vehicle platforms for mass-market electric vehicles at an automotive OEM. The second expert (E2) was directly involved in SAV vehicle packaging development in his role at an automotive engineering consultancy. Insights from these experts are referenced in the discussions of vehicle package development in Chapter 6.

3.4.6 *Automotive and transport Industry survey*

To inform the future dissemination of thesis findings and understand the barriers affecting inclusive innovation in the automotive and transport sectors, a short survey was circulated. A complete list of questions and results is provided in Appendix 2.1.

Responses were gathered through an online form via mailing lists and LinkedIn posts to professionals involved in vehicle design and development (N=34). Of the respondents, most (N=22) worked for car manufacturers, seven worked in design consultancies, two in commercial vehicle development, and three in other related fields. The participants represented various areas of expertise: eight in vehicle engineering, six in exterior design, three in interior design, three in UI/UX design, three in design management, three in quality, four in product planning and research, and four in other related roles. The results of this survey are discussed in Chapter 7.

3.4.7 *Automotive design team focus group*

For a deeper exploration of how inclusive design might be applied in the development of vehicles, a focus group was conducted with members of a design

team at an automotive OEM (N=9). This discussion explored designers' understanding of inclusive design, the potential barriers to its application in the industry, and the tools and resources that might assist designers in applying inclusive design principles in their work.

Thematic analysis (Braun and Clarke, 2006) of this focus group and written answers from the industry survey were used to generate the themes which form the discussion in 7.2. The focus group discussion guide can be found in Appendix 2.2 .

4 UNDERSTAND: THE EXCLUDING JOURNEY – IDENTIFYING OPPORTUNITIES FOR INCLUSIVE SAV DESIGN

4.1 INTRODUCTION

The introduction of SAVs creates opportunities for the ground-up design of vehicles, services, interfaces and infrastructure that meet specific needs of excluded groups and create a more universal transport mode. To inform inclusive SAV development, an integrated approach to understanding people's needs has been applied, exploring common and unique needs of multiple groups throughout the whole journey. This approach ensures design responses better encompass synergies and trade-offs arising from different needs – essential for service-based vehicles where niche, inclusion-specific vehicles could result in longer wait times and lower availability.

This chapter summarises the needs and barriers of transport-excluded groups throughout an SAV journey. As an emerging transport technology with few real-world examples, this chapter discusses potential exclusion in SAV services by drawing upon:

- Existing transport exclusion, identified in literature and through *exploratory workshops.*
- Exclusion people anticipate *might* be caused by SAVs, based on *exploratory* and *focused workshops.*
- Exclusion that is *likely* to result if the design of SAVs does not address exclusion, based on physical interactions with mock-ups and prototypes in workshops.

The chapter concludes with opportunities where inclusive SAV design might address such exclusion.

4.2 RESULTS: SAV-RELATED NEEDS, AND BARRIERS

This section details the anticipated SAV-related needs of excluded groups represented in research workshops. Findings are grouped thematically according to the following needs:

- Feeling secure

- Feeling confident: familiarisation, information, and control
- Traveling with/ being assisted by others
- Other people: attitudes, behaviours and interactions
- Journey comfort, enjoyment and productivity
- Moving, navigating, and locating
- Accessible physical features and spaces
- Concessionary pricing and priority services
- Configuration, customisation and planning to meet needs
- Using interfaces and understanding information

A more detailed summary of transport exclusion and needs at each journey stage can be found in Appendix 1.

4.2.1 *FEELING SECURE*

Many people experience exclusion when using transport services, due to fear of violence or harassment in public spaces before and after boarding, and when sharing vehicles with strangers. Factors like being alone, travelling at night, and poorly lit spaces can exacerbate fear (European Commission, 2014). This exclusion often relates to women's experiences of transport (European Commission, 2014), but can result from racial discrimination and affect other groups including older people (pteg, 2010).

Existing products, services, and strategies may help people feel safer while travelling including safe navigation apps like WalkSafe – allowing pedestrians to identify safe spaces and share location with friends and family (Chaperhome Ltd, 2024), and safety features of ride hailing services such as Uber which allow live location sharing and notify passengers if drivers deviate from the correct route (Boman, 2024).

In SAVs, security concerns may worsen due to the absence of staff to manage dangerous passenger behaviour and smaller vehicles creating confined spaces with fewer passengers who might intervene during assault or harassment (Schuß et al., 2021). However, access to door-to-door SAV services could improve security by reducing waiting time in public places and walking distance at journey start and end points.

Previous work has explored how SAV features might improve security through human-like digital companions (Schuß et al., 2024), providing information about

other passengers (Flohr et al., 2024), providing an emergency button for reporting of different levels of danger (Schuß et al., 2022), and encouraging passengers to look out for each other through app-based buddy systems (Schuß et al., 2022).

Passenger information & secure sharing choices

Women in workshops discussed how sharing an SAV with strangers (primarily men) could make them feel unsafe. To improve security, they suggested making sharing choices according to app-based information about other passengers including age, gender, passenger rating, sharing duration, and passenger numbers – to avoid crowding. Providing passenger information and women-only vehicles have previously been suggested to address fear-based exclusion of women using SAVs (Schuß et al., 2022).

Women also suggested that knowing fellow passengers' seating positions could help in making secure seating choices:

> *'It would be nice to know, within the layout of the vehicle, who's sitting – it's a male, 35, or [a] middle aged man – who's sitting inside a vehicle, and sitting where? If I'll be comfortable sitting with those people.' – W3P1*

Making choices about sharing is most applicable to origin-destination dynamic ride-sharing models where sharing passengers are known before the journey. In dynamic ride-sharing en-route models, passengers cannot anticipate who might join, and allowing onboard passengers to decide if others can join could be problematic if passengers have conflicting time/ cost priorities. However, passenger information may still improve security, as shown by Flohr et al. (2024).

While improving security perceptions, providing this information could exclude other groups such as men – for whom the availability of shared journeys would likely drop, and groups experiencing discrimination (e.g. people of colour) – where others' prejudices could be reflected in passenger ratings. Despite concerns about the implications of such systems, women's safety remained their priority:

> *'We will always choose what's safest for us even if it may mean that it is prejudiced or rude. Even though you shouldn't, you don't want to give it the benefit of the doubt because you don't*

want to be like 'maybe they're nice' because it's your security.' – W2P1

Stricter personal sharing criteria could also disadvantage those experiencing fear-based exclusion by limiting suitable shared journeys – causing longer wait times and reducing cost-saving potential. P8 described how low taxi availability at night creates similar trade-offs between longer waits in unsafe locations or sharing with potentially unsafe strangers.

Given the importance of accurate passenger information for security, participants discussed validation methods including using official ID documents for service registration and passenger reporting of suspected false information alongside CCTV validation.

Although beneficial for security, participants were reluctant to share personal data with the service due to privacy concerns. They noted the trade-off between accessing benefits and features versus retaining data privacy, with some willing to forfeit access to some features for their privacy and others prepared to forfeit privacy in favour of security.

The complexity of decision-making based on detailed passenger information concerned participants. To address security and complexity concerns, one suggested simpler, anonymised recommendations for shared journeys with personalised "safe" passenger groups calibrated through a questionnaire:

'If you have a questionnaire where you can fill out your preferences. When you call this vehicle, the app can decide for you.' – W2P1

Security in public places: walking, wheeling, and waiting

Alongside concerns about SAV sharing, participants discussed security in public spaces before and after leaving vehicles.

Women discussed factors affecting safety perceptions including poor lighting, late night travel, being alone, and knowledge of previous crimes. Security barriers included unsafe taxi pickup locations and theft when using smartphones to navigate. Participants discussed services and strategies to reduce fear including

CCTV cameras, sharing location with friends, and safety apps like WalkSafe (Chaperhome Ltd, 2024).

Participants suggested ways an SAV app could provide end-to-end security when traveling to and from vehicles. Suggested features included:

- Information regarding the safety of an area.
- Sharing live location and starting calls with friends, or family while walking.
- A home-safe button requiring confirmation of safe arrival and alerting contacts/ authorities if not pressed.
- A journey rating system for safety feedback and service improvements.

SAVs' onboard camera systems were also suggested to promote security by monitoring streets and identifying emergencies.

> *'The tech in the vehicle can adjust to recognise a potential dangerous scenario and go slowly through that route to see if anyone is in danger, if anyone needs help.' – W3P1*

Participants discussed how fear increases during extended waiting periods for vehicles at the roadside, with delays and cancellations compounding this fear. Fixed SAV stops and infrastructure were suggested to improve security.

> *'But if it has spots where it stops, and it's publicly known, then I wouldn't mind waiting there for five minutes or so. Because I know that space is designated for that vehicle.' – W3P1*

Accurate SAV arrival information can improve security for women and reduce waiting times in unsafe locations (Schuß et al., 2022). Women discussed how this information could allow them to time their exit from safe spaces to coincide with vehicle arrival.

> *'And you will know in how much time that vehicle is coming. So mostly, if it's a restaurant or something, you'll probably stay inside the restaurant until it comes.' – W3P1*

To further reduce time at the roadside, women discussed how exterior lighting would improve safety by enabling immediate identification of the SAV, suggesting a system where exterior lighting matches a unique colour code in an app.

To avoid unsafe drop-off locations, women suggested SAV interface features to adjust end points and ensure safer walking routes. Similarly, Schuß et al. (2022) mention that SAV routing information can help women avoid unsafe areas. Some suggested selecting drop-off points away from home to prevent fellow passengers seeing where they live while others preferred the vehicle to wait until they were safely indoors.

Security inside the vehicle

While passenger information and sharing choices might improve feelings of security related to other passengers, discussions also explored how vehicle features might ensure passengers feel secure inside an SAV and reduce antisocial or abusive behaviours. Discussed examples of such behaviours included sexual assault, vandalism, drunkenness, and theft.

Controlling entry was suggested by many including older people, women and visually impaired people. With suggestions for preventing 'tailgating' (unknown people following others onto the vehicle) and stopping people commandeering pre-booked vehicles. Suggested validation methods included biometrics (considered unreliable by some visually impaired participants), unique passenger codes, smartphone apps with QR codes and travelcards linked to accounts.

Without a driver, CCTV monitoring of the vehicle interior was seen as essential for security. One participant noted female staff members may help women feel safer and, while crowding may increase fears, having some fellow passengers was seen as beneficial to security.

To reduce negative interactions, participants discussed dividing the interior space using floor-to-ceiling walls, curtains, semi-transparent dividers, and seat-based dividers. In women's focused workshops, participants preferred partial or semi-transparent dividers, providing separation while allowing monitoring of other passengers. Full-height, opaque walls created claustrophobic spaces which could be dangerous when shared with threatening passengers. Seat division was viewed positively with participants suggesting the addition of armrests, headrests and

moveable dividers. Participants also suggested interior mirrors to improve security through greater awareness of others' actions.

If passenger behaviour becomes dangerous, participants suggested a panic button system for emergency response. P3 discussed how a 'Stop Thief' button might stop and lock the vehicle during theft, while P6 suggested driving offenders directly to the police. Participants noted the button should be concealed to allow discreet activation. An emergency button allowing reporting of multiple emergency levels has been suggested previously (Schuß et al., 2022).

Participants suggested an onboard passenger reporting system allowing anonymous feedback on behaviours and consequences for offenders. To prevent the potential prejudice discussed above, participants suggested using reporting only for serious incidents, with CCTV used to verify reported incidents.

4.2.2 Feeling confident: Familiarisation, information, and control

For many who experience exclusion, negative past experiences may reduce confidence when using transport services, and those accustomed to private mobility may feel a lack of control when using shared services.

Disabled people often rely on accessibility information for confidence to overcome journey barriers (Sartori do Amaral et al., 2019). People also lack confidence in knowing how to use transport services, including older people who struggle with unfamiliar digital interactions (Pangbourne et al., 2010). Older people can feel a loss of control when age-related disability or circumstances lead to driving cessation and increased reliance on other transport modes (Musselwhite, 2011; Shrestha et al., 2017).

Some of these feelings may be addressed through SAVs' functions (e.g. providing door-to-door on-demand journeys similar to cars), or features addressing the exclusion that causes them (e.g. guaranteeing accessibility). However, building confidence, providing control, and reassuring excluded passengers that their needs are met throughout the journey may improve these groups' experiences, as shown by studies on older and disabled peoples' attitudes towards SAVs (Golbabaei et al., 2024; Hassan et al., 2021; Miller et al., 2022). Providing control in SAVs through minor interactions (e.g. confirmation to start the journey), and giving passengers information to improve situational awareness have been identified as key means of

improving disabled people's confidence when using SAVs (Brewer and Kameswaran, 2018; Martelaro et al., 2022).

Many workshop participants expressed concerns about confidence and control when using SAVs and discussed how the provision of education, information, and interactions might improve their experiences.

Education & familiarity

Lack of confidence in knowing about SAVs and their use can be a barrier for disabled people (Miller et al., 2022) and was discussed by participants across several other groups. To address this lack of confidence, participants suggested ways to educate themselves before their first journey including: seeing them operate, reading media coverage, viewing images, and having test drives.

Older participants, who noted difficulties learning new services, suggested building familiarity into SAV services through standardised vehicle design, similarity to existing transport modes, and predictable, fixed routes. Similarity to existing transport has previously been suggested to benefit disabled people using SAVs (Miller et al., 2022). Familiar and scheduled routing was also important for participants, with some describing how they opt for expensive taxis to avoid the burden of planning unfamiliar journeys (e.g. visually impaired people – P1).

Routing control

Allowing choices when planning and selecting SAV routes has been suggested to improve the sense of control for excluded groups, including disabled people (Martelaro et al., 2022).

In several workshops, older people discussed concerns that automatic SAV routing might reduce the sense of control they have when using their own expertise to plan journeys e.g. ignoring directions where the service's information conflicts with their knowledge.

While prior knowledge can provide confidence and control, older people discussed how *'blithely obeying'* (P6) digital journey planning services reduces their ability to build this knowledge:

'To get here today, it was quite complicated… I looked up on Transport for London... I've come 3 different ways… I still don't know the most efficient way of getting here.' OP2(P6)

Pre-journey information

For unfamiliar journeys, passengers may require information before boarding, ensuring they feel confident in the vehicle's arrival and have time to respond to disruption. While delays, cancellations, and route changes frustrate all passengers, excluded groups experience these difficulties more acutely due to fewer alternatives and specific needs. Participants expressed how a lack of this information causes stress:

'If I don't have any information coming my way, then I start to think 'well, what's happening?' My stress levels go up. So, I need that regular information […] some reassurance that things are okay.' – P2

Participants discussed needs for information prior to boarding the SAV including accurate ETAs and location information through smartphone apps, display boards and announcements.

Several groups (particularly older people) discussed reminding themselves of key journey details before boarding. Accessing information through offline means was seen as essential, with many describing their use of physical tools – maps, tickets, and notes (handwritten and braille) – and offline digital information – stored in notes or emails and readable using visually impaired people's screen readers. While an app could provide this information, these examples and discussions about smartphone inaccessibility may indicate a need for alternatives.

On-journey information

Participants discussed essential on-journey information that should be provided including arrival time, routing, and alerts about diversions and disruption. Visually impaired people mentioned that knowing their current location helped improve their situational awareness.

Knowing about and responding to emergencies without a driver was a common concern, with suggested needs including:

- Controlling the vehicle to drive it to safety.
- Contacting the SAV service in emergencies (crashes, breakdowns, or medical emergencies) with simple buttons or voice commands activating an onboard phone system.
- Updates on arrival of replacement vehicles.
- Information to help visually impaired people navigate to emergency exits.

Some visually impaired participants expressed concern about missing their stop and suggested audio announcements and vibrotactile seat feedback could ensure awareness of the vehicle stopping. Similar seat-integrated haptic feedback has previously been demonstrated to aid in alerting drivers of automated vehicles (SAE level 3) of safety-critical take-over requests (Peters et al., 2025).

4.2.3 *TRAVELING WITH/ BEING ASSISTED BY OTHERS*

For many disabled people, reliance on transport staff and passengers during travel is key to their journey experience. While transport staff may be helpful, discussions of transport exclusion detail how poor awareness of disability and communication can impact disabled people including autistic people and those with cognitive, visual, hearing and mobility impairments (Deka et al., 2016; Fürst and Vogelauer, 2012; Park and Chowdhury, 2018; Risser et al., 2012). Workshop participants discussed barriers caused by failures to accommodate those with personal assistants and lack of access to transport staff.

Accessing assistance

Access to staff at transport nodes was essential for some participants. Visually impaired people discussed relying on staff to guide them to vehicles, although assistance unavailability can lengthen and disrupt journeys:

> *'With the National Rail, they give confirmation somebody will assist you. But by the time you reach there, there's nobody' – P1*

One visually impaired participant discussed how absence of assistance can result in denied access to transport:

> *'If somebody's not there, they won't let you get on the train.' – P7*

Participants discussed the value of communicating with staff at transport hubs for emergency assistance and information. However, a hearing impaired participant raised communication difficulties experienced when interacting with staff:

> *'You [P1] can verbalise, which I can't do so you can actually speak to the person and explain. what can I do? I can't use my voice.' – P2*

Beyond poor disability awareness, participants discussed racial prejudice from transport staff including taxi drivers refusing young black men, and bus drivers refusing to stop for East Asian people during the Covid-19 pandemic. Racial exclusion by transport staff has been identified as a barrier to immigrant communities' mobility (Schachter and Liu, 2005).

As SAVs are less likely to provide fixed transport nodes and staff, consideration is needed for how essential tasks requiring assistance might be aided through alternatives. Several examples are described in these results e.g. staff-assisted booking services within other businesses such as local shops.

Sitting with others

Seating arrangements can restrict disabled people's ability to communicate with and be assisted by travel companions. Wheelchair users suggested SAVs should allow conversation by providing seating near the wheelchair space:

> *'That seat would flip down if I needed it for a friend' -WU2*

A hearing impaired participant noted facing seating is necessary for lip reading and British sign language (BSL). For some disabled people, space is also required for assistance dogs, as mentioned by visually and hearing impaired participants:

> *'Yeah, if I had the hearing dog with me, of course that might be difficult. You know, finding a place for the dog.' – P2*

4.2.4 Other people: attitudes, behaviours and interactions

While the presence of others can improve inclusion, exclusion may be caused by attitudes and behaviours of others. Disabled people can experience abuse,

unwanted "assistance", and difficulties contesting with passengers for priority spaces (Wayland et al., 2022). Poor attitudes of other passengers can also lead to disabled people feeling stigmatised when using certain inclusive features e.g. wheelchair ramps (Velho, 2019). Poor disability awareness, unpredictable passenger behaviour, and crowding create barriers for autistic people and those with cognitive, visual and hearing impairments (Deka et al., 2016; Fürst and Vogelauer, 2012; Park and Chowdhury, 2018; Risser et al., 2012).

As dangerous passenger behaviours were discussed above, this section details other exclusionary behaviours experienced by excluded groups and their relevance to SAVs.

Excluding behaviours: pedestrians and road users

Others' behaviours can create barriers when getting to a vehicle. Unpredictable driving is a barrier for cognitively impaired pedestrians (Risser et al., 2012), while lack of disability awareness can make other pedestrians impatient towards mobility impaired people (discussed by P11) and stigmatise disabled people:

> *'…holding my cane and going with my headphones. People might be thinking it's kind of funny that this person can't see and [is] using headphones, listening [to] music.' – P1*

Excluding behaviours: other passengers

For some disabled people, fellow passengers' lack of awareness and failure to engage in inclusive behaviours can create barriers e.g. by obstructing wheelchair spaces.

For cognitively impaired people, fear of judgment when doing things slowly can deter them from traveling (Risser et al., 2012). Poor public knowledge regarding assistive devices and assistance dogs were also cited by visually and hearing impaired participants as barriers they encounter when using public transport. Those with less visible disabilities discussed how lack of awareness leads to people refusing to vacate priority seating unless the disability is obvious:

> *'Not having a badge saying I am disabled. People just assume you don't need [a seat].' – P11*

Crowding

Crowding creates difficulties for disabled groups, including cognitively impaired people for whom it can cause significant stress (Risser et al., 2012) and crowded vehicles may increase likelihood of sexual assault of women (European Commission, 2014). Crowding also makes navigation challenging for visually impaired people and can worsen symptoms for those with conditions and disabilities causing pain:

> *'I don't want to get pushed by people […] because when you have a physical pain, you're being fragile, so you want to protect yourself' – P3*

Participants noted that pre-booked journeys and flexible routing in SAVs will limit occupancy to the number of available seats, addressing onboard crowding issues.

Social interaction with other passengers

Social interactions with fellow passengers were discussed positively and negatively by different participants and some noted how different contexts might impact their propensity for socialising on journeys:

> *'Depends on the day. If you feel friendly you may just keep talking about whatever you want. You just woke up or you had a bad day, you don't want to talk that much.' – P8*

While these preferences are often unrelated to exclusion, and more dependent on individuals' personalities, some excluded groups may have different characteristics and needs which impact these interactions.

For some older people, public transport can be seen as an opportunity for social interaction where regular contact with others might not be common (Roberts, 2008) – although some older workshop participants preferred a degree of privacy.

To address differing preferences for social interaction, participants suggested different seating layouts. Facing seating was seen as conducive to positive social interaction by some but was too intimate for those that favour privacy – who preferred seating configured in rows. A combination of facing and row-based seating may allow passengers to select a seat according to their preferred level of interaction.

4.2.5 *JOURNEY COMFORT, ENJOYMENT AND PRODUCTIVITY*

While participants generally prioritised discussions of more severe needs and preferences, conversations across research workshops allowed for discussion of more experiential elements of journeys – as encouraged by the *Inclusive design for transport framework.* These discussions rarely indicated specific exclusion-related desires, focusing on inclusive access to more generally desirable features.

Waiting facilities

While SAV services might be unlikely to incorporate waiting facilities, some discussions related to the desire for pleasant journey experiences focused on positive and negative experiences of waiting facilities. Phone charging facilities were discussed as useful and could reduce anxiety around battery life when using smartphone-reliant services. Comfortable and warm indoor facilities were also suggested to improve journeys, however concerns about vandalism, littering, and closure of these facilities were common across all groups.

Interior condition and environment

The lack of a driver to deter littering and vandalism, and to ensure the vehicle is cleaned, caused concern for several participants. Hygiene was also a common priority, particularly among disabled people discussing the use of public transport in the aftermath of the Covid-19 pandemic. Participants suggested crowd-sourced reporting could be used to notify the service of maintenance needs.

Comfort

Climate control and opening windows, controlled from the seat, were suggested to ensure passengers' comfort with older participants even discussing the potential for a convertible roof! Climate controls have also previously been suggested as a means of improving disabled passengers' sense of control in SAVs (Martelaro et al., 2022). Smooth driving style, pleasant lighting designs (notably discussed by visually impaired participants) and window blinds – allowing privacy and control of natural lighting – were also suggested.

Participants discussed many preferences for comfort when seated including sufficient leg room, forward facing seating (to avoid motion sickness), and standing, perch-type seating. As comfort is dependent on personal preferences, inclusive comfort might be achieved with a degree of adaptability. It is important to note that for some disabled people, a lack of comfort may exacerbate the impacts of

their symptoms e.g. uncomfortable ride quality causing pain for those with spinal injuries (Rojas, 2020).

On-journey activities

Participants discussed and suggested many other features that could enhance their personal journey experiences including:

- Facilitating the use of personal devices such as phones and laptops with onboard charging and folding tables.
- Monitoring passenger health.
- Location sharing to update friends and family on ETA.
- Providing food and drink – including cocktail cabinets, refrigerators, and complementary snacks.
- Entertainment – including free newspapers.

While some suggestions might not be feasible or relevant to all passengers, older participants suggested that a degree of modularity could tailor the vehicle to be enjoyed by different groups (and generations!).

4.2.6 *MOVING, NAVIGATING, AND LOCATING THE VEHICLE*

Mobility impaired people and visually impaired people experience many barriers related to moving and navigating through spaces both inside and outside of a vehicle. While challenges with visual navigation of a space and physical movement in a space are experienced differently by the affected groups, these challenges are often created by similar causes e.g. unexpected obstructions on a path causing a collision risk for visually impaired people and an obstacle for wheelchair users (Fürst and Vogelauer, 2012; Park and Chowdhury, 2018). Certain solutions to these barriers may also address both navigation and physical movement e.g. railings offering physical support to mobility impaired people and guidance for visually impaired people.

Getting to the vehicle

Disabled people can experience physical barriers navigating the built environment including uneven pavements, obstructions, poor lighting, and poor visibility (Fürst and Vogelauer, 2012; Park and Chowdhury, 2018; Risser et al., 2012). Similarly, steep ramps, gaps between trains and platforms, and a lack of lifts can create difficulties with moving through transport hubs (Park and Chowdhury, 2018).

Navigation before boarding a vehicle also presents challenges for groups, including autistic people (Deka et al., 2016) and visually impaired people (P1, P7). Unclear or absent signage, markings, and tactile paving can create navigational challenges for visually and cognitively impaired people at transport hubs (Fürst and Vogelauer, 2012; Risser et al., 2012). For visually impaired people, previous work has considered how app-based navigation might address these difficulties by incorporating vibration, haptic feedback, and audio instructions (Bayless and Davidson, 2019; Bhalearo et al., 2022; Fink et al., 2024).

During the workshops, visually impaired people discussed the importance of familiarity with routes to bus stops and pick-up points, particularly when navigating using a cane. Navigational familiarity was also discussed by other participants, concerned that apps do not allow them to build this independent knowledge of an area (P10, P11). Overall, participants expressed an enthusiasm for SAVs' potential to offer door-to-door services that reduce or eliminate the requirement to navigate the built-environment.

Locating the vehicle

Difficulties with locating and identifying vehicles were commonly discussed by visually impaired people who may currently be unable to read external vehicle information e.g. bus numbers. In the context of SAVs, many other groups also discussed the importance of being able to easily locate the vehicle and, as SAVs become more ubiquitous, to distinguish it from others.

For pre-booked SAVs, visually impaired people need to be able to locate the vehicle on the roadside. Visually impaired participants suggested the use of audio-based smartphone apps, bright lighting, and audio beacons to locate the vehicle. One suggested that Navilens (a camera app that scans and reads data from unique codes, at a distance) could be used to recognise a code on the vehicle and guide people to it.

To locate an SAV for spontaneous access, older and visually impaired participants discussed dedicated, familiar locations for accessing vehicles such as bus stops and taxi ranks. Older people suggested a bus-like SAV service running a fixed route between known boarding locations, which could meet demand by swarming to common locations e.g. a station when a busy train arrives.

The need to distinguish SAVs from each other was a common topic across multiple groups. P2 (a hearing impaired person) suggested displaying his name (or an anonymous alias) on the vehicle, so that it is visible above other cars – addressing his difficulties reading number plates of ride-hailing vehicles. In the same discussion, P1 (a visually impaired person) suggested a unique audio signature to identify his vehicle, as he cannot rely on visual information.

The security implications of being able to quickly locate a vehicle on the roadside were also discussed by women in the workshops (discussed in more detail in section 4.2.1).

Boarding the vehicle

For visually impaired people, locating vehicle doors presents a challenge when boarding. While some rely on guide dogs, staff, or others to locate doors, such assistance isn't always available. Driverless, low occupancy SAVs are likely to further reduce this availability of assistance. Visually impaired people noted that bright, contrasting colours help distinguish doors and lighting can indicate door location through colours and flashing patterns. Sounds can guide them to doors alongside vehicle-mounted handles, rails and tactile features.

More generally, disabled people face barriers when boarding vehicles including: large gaps between vehicle and kerb/platform, high steps, and steep ramps (Fürst and Vogelauer, 2012; Park and Chowdhury, 2018; Risser et al., 2012).

Participants discussed solutions to boarding challenges including:

- *Physical support* – Provided through handles and railings, as suggested in existing inclusive SAV design guidance (Klinich et al., 2022).
- *Obvious and locatable steps/ramps* – P1 noted difficulties locating steps with his cane; visually impaired people suggested bright lighting to highlight steps.
- *Short step-in distance/height* – Beneficial for visual and mobility impaired people. Solutions included low vehicle height, raised kerbs, and stopping SAVs near kerbs.

Wheelchair users discussed challenges with boarding vehicles, including stigma from longer boarding times and alarms (as noted by Velho (2019)). Wheelchair access in SAVs was discussed in the context of three common solutions:

- *Ramps* – These were the most suggested solution, prioritising gentle angles and unobstructed deployment. Participants suggested automatic ramps which are operated with a travel card. Previous work has proposed obstacle-avoiding automated ramps (Wiles, 2023), gentle gradients (<4.8°) (Klinich et al., 2022), and app-based ramp information (Martelaro et al., 2022).
- *Lifts* – These allow boarding from street-level without kerbs and are used in some SAV designs like Ohmio's Lift (Ohmio, n.d.). While suggested in inclusive design guidance (Klinich et al., 2022), lifts can require more time and space to deploy than ramps.
- *Level boarding* – This was considered ideal for SAV access due to efficiency and reliability. However, it requires raised kerbs due to vehicle floor heights. Level boarding is enabled by low floors, kneeling suspension and specially designed kerbs (Kantor et al., 2006).

Moving in the vehicle

Once onboard, disabled people can experience difficulties moving to seats due to obstructions like steps (Park and Chowdhury, 2018) and vehicles departing before they are seated (Risser et al., 2012). Visually impaired people struggle to navigate vehicles and locate stop buttons, seating, and other passengers, often relying on assistance.

Wheelchair users need clear space with minimal obstructions to manoeuvre (Klinich et al., 2022). Requirements include non-slip floors, wide aisles, and minimal turning to get into position (Klinich et al., 2022). Workshop participants noted folding seats' utility in creating wheelchair space but stressed that they should automatically return to folded positions when vacated. Participants also suggested announcements could encourage passengers to remove obstructions from wheelchair spaces and aisles – also suggested by visually impaired people.

For mobility impaired people, moving at standing height improves movement ease with workshop participants responding positively to the height of the SAV mock-up. Stability while moving is also challenging, especially during vehicle motion with visually impaired and wheelchair users requesting interior handles to steady themselves while moving (also suggested by Klinich et al. (2022)) and interfaces to begin the journey once seated.

Given the unfamiliarity of SAVs, visually impaired people anticipated layout navigation challenges as they currently rely on known vehicle layouts, and variations create difficulties (Gallagher et al., 2011). Participants suggested publicly available tactile models and mock-up walkthroughs could aid familiarisation. Placing priority seating near doors may also help navigation (Gallagher et al., 2011).

Visually impaired people recommended intuitive tactile navigation and standardised layouts across SAV services. Solutions discussed included directional tactile surfaces, handles, guide rails, and tactile flooring. Some suggested continuous guide rails could lead them from the outside of the vehicle to their seat, while others preferred vertical handles. For those with partial vision, contrasting colours were suggested to highlight the layout.

More changeable interior elements like passenger location and configuration may require active communication of their status for safe onboard navigation. Visually impaired people suggested interior layout and occupancy information should be communicated before vehicle arrival (also suggested to improve security) and an audio description given when boarding.

'As you're going on it says: "seats 1, 7 and 8 are free".' – V2P2

Interior navigation could also be improved through seat-based audio beacons as suggested by Bhalearo et al. (2022).

When leaving the vehicle, disabled people may take longer to exit due to navigational barriers with P1 describing how buses sometimes depart before he can exit. Wheelchair users also noted concerns about faulty ramps blocking their exit, delaying other passengers, and requiring route diversions to a suitable exit location.

Getting from vehicle to destination

Visually and mobility impaired people face difficulties navigating after departing. Visually impaired people suggested the vehicle provide brief audio directions to their destination as they depart.

Disabled people also emphasised the need for accessible drop-off points. Visually impaired people preferred locations with fewer obstructions and road crossings, suggesting vehicle-based audio announcements to warn about external obstacles. Wheelchair users noted that SAVs might provide more consistently accessible

disembarking by eliminating human error in drop-off location selection. Offering a choice of drop-off point (already suggested in the context of security in section 4.2.1) could also address these concerns.

4.2.7 ACCESSIBLE PHYSICAL FEATURES AND SPACES

Disabled participants discussed how their physical needs and capabilities are not often accounted for in the design of the spaces they use during journeys, particularly seating and luggage storage.

Waiting facilities providing for physical needs

While most physical barriers related to being onboard vehicles, some participants discussed issues with waiting facilities including poorly located shelters, obstructed seating, and unavailable toilets. As SAV journey endpoints are flexible, workshop discussions on dedicated waiting facilities were limited.

Wheelchair occupancy

Wheelchair users noted wheelchair spaces are often occupied or obstructed. Limited space in SAVs could worsen this as wheelchair spaces are required to serve multiple functions. Wheelchair users emphasised spaces should be reservable and suggested SAVs accommodate multiple wheelchairs (a challenge given the limited interior space), with unnecessary use/ obstruction of spaces discouraged through announcements and locking folding seats.

Wheelchair restraints can be problematic, requiring assistance to use and feeling unsafe when loose. Vehicles without restraints often require uncomfortable rear facing positioning, forcing choices between safety and comfort. WU1 discussed his refusal to use restraints in taxis, instead risking his safety by facing forward and holding on to a handle.

Placing luggage

To ensure items do not cause obstructions inside the vehicle, suitable storage should be provided. Participants discussed storage of luggage, shopping, pushchairs, and bikes. Excluded groups can have specific storage needs related to the location of storage spaces and moving luggage onboard the vehicle.

Visually impaired people discussed keeping their items close, ensuring they are safe from theft and easily locatable upon departure.

> *'[I keep my bag] next to my seat. Because when I get off, I can't see… That's why I keep in mind where I left it.' – P1*

Similarly, some women mentioned keeping their bag visible and nearby to avoid theft.

People with strength and mobility impairments may struggle with carrying and loading luggage, especially with overhead racks. Participants discussed how wheelchair ramps could make boarding easier for passengers with wheeled luggage.

Priority disabled space

While many at-seat needs discussed throughout this chapter are unlikely to be met at every seat in a given SAV, some priority seats in accessible locations could provide a complete selection of inclusive features.

4.2.8 Concessionary pricing and priority services

While service provision and pricing were not common barriers raised by participants, concessionary SAV pricing was discussed as a driver of transport use. Although a universal service was favoured, some participants mentioned desire for women-only vehicles and priority services for disabled people.

Older and disabled participants discussed benefits from free transport and wanted similar schemes for SAV services:

> *'I can lose any other card except my freedom pass… To be given freedom is a wonderful gift. I'm sure it won't last, but I just think it keeps people in touch, and it actually creates communities.' – OP2(P6)*

Some disabled people noted that priority pricing access could lead to false registrations and suggested using existing disability allowance documentation for validation.

The integration of SAVs with transport services could help fill existing exclusion gaps. For example, for wheelchair users unable to use London's Underground, operators could prioritise and subsidise SAVs for equivalent journeys. Similarly, Bhalearo et al.

(2022) suggest prioritising visually impaired users for SAV journeys. Discounting and prioritisation could also address inequities like women's increased likelihood to travel on underserved routes and pay higher prices due to less regular travel patterns (Gill, 2018).

4.2.9 *CONFIGURATION, CUSTOMISATION AND PLANNING TO MEET NEEDS*

As many potential solutions to exclusion depend on adaptable services targeting solutions at those who need them, some participants discussed how passengers might ensure access to and control of such features.

Accessing exclusion-specific benefits

Where provisions for specific excluded groups might be broadly desirable (e.g. discounted pricing) or require validation of information (e.g. gender to control access to women-only services), participants discussed the necessity for passenger accounts and validation enabled through apps or travel cards.

Providing detailed choices and control

Some disabled people rely on comprehensive journey planning to access necessary accessibility features, which can be time consuming and mentally challenging.

Additional planning requirements and reduced transport access can compound disruption when cancellations and delays occur. Disabled people described planning habits to mitigate disruption including advance planning, preparing alternative routes, and allowing extra journey time.

Despite the complexity of additional planning, participants suggestions often required additional choices during journey planning. Journey planning for inclusive SAV features has been explored through an app concept tailoring provision based on wheelchair dimensions and allowing reservation of vehicles with specific accessibility features (Martelaro et al., 2022). The provision of security-related choices has already been discussed in section 4.2.1.

Disabled participants discussed how SAV interior choices may meet their physical needs. Wheelchair users wanted pre-booking to ensure wheelchair space availability and give them 'peace of mind' (WU2). Pre-booked seating may also reduce anxiety for other groups e.g. autistic people (Deka et al., 2016). As adaptable features are likely to account for a significant portion of inclusive SAV

design, reservation and configuration of any these features may be beneficial to excluded groups.

To enable control over inclusive features without complex planning, participants suggested registering needs with the service to automate features (similar to suggestions for a security calibration questionnaire in section 4.2.1). Wheelchair users proposed using travelcards pre-loaded with needs to trigger automated adaptations. This concept was well-received by many participants as a means of communicating access needs, including determining information and interface modality for visually and hearing impaired people.

Physical configurability

Certain physical elements of an SAV may require manual manipulation rather than automatic operation. For example, seating configurations requiring folding and adjustments may not suit automatic electromechanical actuation due to cost constraints in service-based vehicles. Disabled people, particularly wheelchair users, noted difficulties with folding chairs and suggested using simple buttons or weighted self-folding seats to enable them to clear the wheelchair space.

4.2.10 USING INTERFACES AND UNDERSTANDING INFORMATION

Exclusion when using transport-related interfaces can currently be caused by language barriers (Schachter and Liu, 2005), illegible visual information (Fürst and Vogelauer, 2012; Park and Chowdhury, 2018), inaccessible formats (Fürst and Vogelauer, 2012), and difficulties locating interfaces (Park and Chowdhury, 2018). As much of the exclusion discussed previously is related to and may be addressed by the use of interfaces, the inclusivity of information and interactions is essential. Excluded groups anticipated barriers arising from increased use of digital interfaces for future mobility.

Accessibility

Disabled workshop participants regularly discussed the inaccessibility of digital interfaces, particularly smartphones, including:

- Reliance on visual information, or screen readers – visually impaired people.
- No tactile feedback from touchscreens – visually impaired people.
- Fine motor skills required for touch screens – dexterity impaired people.

More inclusive interfaces have previously been suggested utilising automation, multimodality and adaptability to assist disabled people when planning SAV journeys (Amanatidis et al., 2018; Bhalearo et al., 2022; Martelaro et al., 2022).

Understandability

Non-disabled excluded groups may experience barriers to understanding interfaces due language barriers (Schachter and Liu, 2005), and a lack of familiarity or proficiency with their use (prevalent among older people (Goodman-Deane et al., 2021)).

Older participants expressed that the novelty of SAV designs could present difficulties when learning to use them. Some older people already have difficulties with the complexity of features in new vehicles – evidenced by P6's exasperation at his new car:

> *'You don't need half the bloody stuff' – P6*

Participants also discussed how the safety-critical nature of vehicle controls could result in dangerous consequences of unfamiliarity, suggesting simulators could teach older people to use them. Although SAV interactions are unlikely to be safety-critical, existing barriers indicate a need for simplicity and learnability of vehicle functions.

Reliability

For those comfortable with digital interfaces, reliability was a concern. Poor battery life, connectivity, and faulty devices contributed to wariness of transport services relying on such interfaces.

Although the portability, connectivity, and customisability of smartphones enable features and innovations to improve inclusion, consideration should be given to designing SAV services for those who are not able to access this technology.

Interaction simplicity

Simplifying interactions can ensure ease of SAV use for excluded groups. Participants discussed automating features through travel cards pre-loaded with passengers' needs. Tapping these cards could adapt personal interfaces – turning on audio-information for visually impaired people, or haptic alerts for hearing impaired people – and customise at-seat information.

Accessing the service

Perhaps the most severe impact of excluding interfaces and interactions is its effect on SAV service access. Participants discussed these concerns, with the older people's focused workshop exploring inclusive access methods for those less confident with digital interfaces.

On-demand access

Smartphone apps were assumed to be the default means of accessing SAVs on-demand, even by participants describing usability challenges with such devices. However, phone unreliability, poor battery life and connectivity caused concern for participants, particularly women – perhaps due to the role phones play in providing security while traveling. Participants suggested SAV access through both apps and alternative means.

Disabled and older participants proposed more low-tech ways of utilising a phone for service access, using email, SMS and phone calls. Older participants emphasised the need for human phone operators rather than frustrating automated systems.

For SAV access without personal devices, participants discussed using public booking interfaces. Similar interfaces currently present several barriers: inaccessibility to visually impaired people (Fürst and Vogelauer, 2012; Park et al., 2014), language dependence (Schachter and Liu, 2005), unreliability, and unavailability. Older people suggested locating booking interfaces in local businesses – providing staff assistance and generating income – as street-based interfaces can be vulnerable to vandalism. The complexity of suggested interfaces ranged from simple call buttons to touch screens while visually impaired participants suggested that travelcards could communicate their details to interfaces, avoiding complex interactions.

Some participants suggested SAV-specific devices for access. P7 (visually impaired) proposed a handheld device to call vehicles without complex phone interactions.

Spontaneous roadside access

Participants discussed familiar means of accessing SAVs spontaneously without booking. Some suggested an interface-free method of boarding at the roadside, similar to using buses or car sharing services.

> *'It would be like a bus you just get on it, that's it. It would be public transport really.' – V1P2*

Older people proposed hailing vehicles with hand gestures but expressed concerns about gesture ambiguity and misuse by pranksters unnecessarily stopping vehicles. They suggested using travelcards to ensure SAVs stop for genuine passengers and noted the need for clear information about approaching SAVs' accessibility and availability. While familiar interactions can aid understanding, care must be taken to avoid replicating existing exclusion while creating this familiarity. For vehicle hailing, visually impaired people would need suitable non-visual information to avoid current difficulties with timing gestures to stop approaching buses.

Spontaneous SAV access would require inputting journey information at the vehicle. External interfaces for this purpose were viewed negatively by participants due to weather, crowding, safety concerns, and vandalism. Interior at-seat interfaces were preferred with participants suggesting travel cards to store information (e.g. regular destinations) and communicate it to the vehicle, reducing complex interactions.

Payments

Participants discussed how card and digital payments are not available to all e.g. unbanked people who often have low incomes (Brakewood and Kocur, 2013). While some discussed the convenience of existing app-based ticketing, others were frustrated at the need to download multiple apps.

A travelcard was suggested as a universal solution to streamline payment and access, potentially helping groups who struggle with payment complexity e.g. cognitively impaired people (Risser et al., 2012). Although use of a travelcard is similar to contactless payment modes, the potential for cash-based top-ups makes them a viable solution for unbanked people.

On-journey interfaces

Workshop participants (particularly disabled people and older people) expressed preferences regarding the design and modality of on-journey interfaces that meet their physical needs while being easy to understand and interact with.

Several participants preferred physical controls over touch screen interfaces, particularly visually impaired people who suggested large, tactile, and bright buttons would be easier to locate.

More personal journey information and interactions might require private at-seat interfaces providing a more tailored information and inclusive interface modality – particularly necessary for those unable to access a smartphone for such interactions.

Suggestions for personal interface modality included:

- Voice activated interfaces – preferred by visually impaired and some older people.
- Telephone services – suggested as a more reliable alternative to voice interfaces.
- Physical (non-touchscreen) controls – suggested by visually impaired and wheelchair users.
- Audio information – discussed by visually impaired participants, with headphone connectivity suggested to provide privacy.
- Visual information – widely discussed alongside preferences for clarity and visibility.

For more general journey information such as route maps and emergency instructions, participants (particularly older people) preferred large, digital displays with graphical information (e.g. images of locations) instead of text. Visually impaired participants suggested that they would like to access an audio version of this information on-demand at the touch of a button.

Audio announcements were favoured by visually impaired people but posed challenges for neurodivergent people (due to sensory challenges), non-native speakers, and hearing impaired people:

> *'Public transport still relies on announcement and there's no really good visual equivalent about. Especially when there's emergencies, it's usually a sound announcement.' – P2*

Physical interactions

Physical interactions with the vehicle may be necessary to open doors, validate a journey, or authorise payment upon boarding. Validation when boarding was also suggested as a means of triggering automated vehicle adaptations to meet passenger needs. visually impaired participants mentioned that, if physical buttons

are used to open doors, they should be large and tactile to make them easy to locate.

4.3 PRINCIPLES FOR INCLUSIVE SAVS

Based on the barriers discussed in the previous section, the following key principles have been identified to improve inclusion in SAV services, corresponding to the 5 types of transport exclusion from the *inclusive design for transport framework*.

4.3.1 SERVICE

As SAVs have the potential to address barriers experienced by excluded groups while offering a desirable transport option to the public, inclusive SAV services should seek to prioritise availability for those most in need and less able to use alternative modes.

Universal fleet

As excluded groups have specific needs that are challenging to address, services may default to providing a range of SAVs targeted towards different groups. While this enables more tailored inclusion, limited numbers of suitable vehicles in a fleet is likely to result in further exclusion caused by longer wait times (as with UberWAV service (Hassanpour et al., 2021)). Instead, SAV services should employ fleets of universal vehicles, providing equal access for as many excluded groups as possible.

Inclusive implementation and routing

SAVs are likely to exist within transport networks comprising modes that may transport people more efficiently. Inclusive SAVs benefit groups for whom access to other transport modes is challenging e.g. due to poor accessibility for disabled people and limited provision in rural areas. While other services' inclusivity may improve alongside SAVs, some might prove too costly or complex to become truly inclusive e.g. London Underground converting all stations to step-free access. To ensure SAVs serve those needing them most, services might "fill the gaps" by prioritising journeys in underserved locations and for people groups unable to access alternative transport for a given journey.

Inclusive pricing and payment

SAV passengers may be incentivised to share vehicles through reduced costs based on the number of sharers. Some groups might be unable to share due to fear-based exclusion when sharing or space needs, e.g. wheelchair users occupying the space of two seats. SAV services should provide equitable pricing that doesn't penalise those needing more space or force choices between safety and cost. For excluded

groups unable to access cheaper alternative modes, inclusive pricing could discount SAV journeys.

SAV services should ensure financially excluded and unbanked passengers can pay through accessible means beyond bank cards and smartphones – such as cash-based ticketing or travel card top-ups (as suggested by Abdoli et al. (2022)).

4.3.2 PHYSICAL

For groups who experience physical exclusion, the design of physical elements of SAV services should seek to be universally usable, easy to interact with, and easy to move in and through, while providing for the activities and tasks that passengers may want to engage in.

Universal > adaptable > modular

To meet the needs of physically excluded groups, physical elements of SAV services should first seek to be universally useable. If a groups' needs cannot be met through a single design, adaptation should be incorporated. If adaptation isn't possible, a degree of modularity may be beneficial, although configuring a service-based vehicle in this way presents significant logistical challenges. Special purpose designed vehicles should only be considered where addressing the needs of a group within the standard SAV is impossible.

Accessible physical interactions

Adaptable features requiring physical manipulation (e.g. folding seating) should be operable by a wide range of excluded groups. The default state should prioritise severely physically excluded users – e.g. folding seats defaulting to a folded position for wheelchair users. Large handles, levers, and electromechanical actuation may all serve to reduce such barriers.

Provision of suitable space

SAVs should provide onboard space that accommodates excluded people and their assistive devices, luggage, and travelling companions (human or animal). This space should also inclusively facilitate additional journey activities passengers may want to engage in.

Easy movement

SAVs and infrastructure should be easy to navigate for excluded groups. Unobstructed manoeuvring space should be provided for wheelchair users, and

guiding features for visually impaired people. Ramps, railings, and handles should also be incorporated to aid movement for disabled people.

4.3.3 INFORMATION AND INTERACTIONS

Multimodal
Various perception, cognition and motor function capabilities across excluded groups necessitate interfaces with multiple modalities. These should provide information in audio, visual and tactile formats while offering various input modes including voice and touch.

Simple
Interfaces which simplify complex interactions could enable people with reduced dexterity to use SAVs. Using imagery, larger text, and simpler language could also help visually and cognitively impaired people, and non-native speakers.

Familiar
The use of new SAV services may cause confusion for some excluded groups. Creating interactions similar to other services may ensure an easier learning curve for these groups.

Automation/ recommendation
SAV services may seek to automate interactions where complex decisions are required. Initial registration of passenger preferences and information linked to a travelcard or app could enable this automation.

Low-tech/ failsafe
Reliance on smartphone apps creates usability and reliability challenges for many excluded groups. SAV services should aim to provide inclusive non-digital or low-tech means of access for these groups.

4.3.4 INTERPERSONAL

Barriers related to other passengers on SAVs may be more challenging to address due to the difficulty of changing people's behaviours. However, the provision of certain information and the design of shared spaces may serve to address some interpersonal exclusion.

Improving awareness of exclusion

SAV services should seek to reduce excluding and discriminatory behaviours by improving awareness of exclusion among passengers e.g. through public information and in-vehicle signage.

Ensuring positive behaviours

SAV services may also encourage positive behaviours through education and physical design cues that promote inclusive use of space and features e.g. clearly marked areas for wheelchair spaces.

Providing for social interaction and communication

Sharing a vehicle may provide some passengers with opportunities for socialisation, while others may prefer privacy. SAVs should accommodate these preferences perhaps through interior layouts that allow passengers to choose a suitably social position.

4.3.5 PSYCHOLOGICAL

Inclusive SAVs should reduce psychological barriers experienced by excluded groups and improve passengers' feelings about using them.

Reduced stigma

Excluded groups may experience stigma when using assistive features in shared spaces. Stigma may be reduced by seamlessly incorporating such features into the vehicle's design and general operation. For example, level or ramped boarding becoming a standard procedure when the vehicle stops, reducing stigma for wheelchair users.

Increased agency

SAV automation may reduce the agency passengers when compared to driving private vehicles, but providing journey choices and control may address this. Inclusive access to SAVs may also generally improve agency for some excluded groups by providing independence not offered by other services.

Increased sense of security

Inclusive SAVs should improve security for groups experiencing fear-based exclusion when sharing vehicles. Interior space division, sharing choices, and passenger monitoring may enhance security.

Reduced uncertainty

The novelty of SAV services may result in uncertainty about their operation becoming a significant barrier. This may be reduced through clear and timely journey information, familiarisation, and standardisation.

4.4 INCLUSIVE SAV DESIGN OPPORTUNITIES

To inform the design of inclusive SAVs and associated services, opportunities and considerations have been collated for relevant areas of design and decision making. Table 9 – Table 11 summarise these opportunities related to vehicles, interfaces, and services alongside exclusions they address and potential solutions suggested during workshops. Discussions of selected opportunities appear in subsequent chapters detailing inclusive design concepts.

4.4.1 *VEHICLE: INCLUSIVE SAV DESIGN OPPORTUNITIES*

TABLE 9 INCLUSIVE SAV DESIGN OPPORTUNITIES AND CONSIDERATIONS – VEHICLE

Opportunity	Consideration(s) What should it do to improve inclusion?	Exclusion What exclusion should it address?	Solutions/ existing strategies (workshop ideas) How might it do this?
Navigable vehicle interior	Incorporates Intuitive, tactile means of guiding visually impaired people through the vehicle Make the location of interior features obvious to visually impaired people Provide support for disabled people when moving in the vehicle	**Physical exclusion** *Navigating in/ through space:* Vehicle interior *Moving in/ through space:* Vehicle interior – worse when vehicle moving **Information & interactions exclusion** *Availability of information:* Lack of interior navigation information	Continuous guide rail Handles Tactile surfaces Tactile flooring Colour – bright and contrasting – seats – contrasting top and bottom colours to make it easy to know if they're folded
Adaptable/ flexible vehicle interior	Allow passengers to reserve and adapt interior space to meet their access needs Adaptable interior automatically returns to default accessible position i.e. clears space for wheelchair users	**Interpersonal exclusion** *Awareness & inclusive/ excluding behaviours:* Occupying seating and wheelchair space **Physical exclusion** *Occupying/ using space:* No priority seating, No wheelchair space *Moving in/ through space:* Vehicle interior	Folding seating – default folded position
Exterior boarding features	Make the location of vehicle doors, steps, ramps, and buttons obvious to visually impaired people Provide means of physical support for disabled people when boarding Guide visually impaired people towards and through vehicle doors Provide ramps, lifts, or steps to ensure ease of boarding in multiple scenarios – including from kerb & road levels Allow automatic deployment of ramp/ lift access for wheelchair users Reliable operation of ramps and lifts to reduce delays and diversions for wheelchair users	**Physical exclusion** *Moving in/ through space:* Vehicle exterior – difficult to step/ wheel into vehicle *Navigating in/ through space:* Vehicle exterior – difficult to navigate to vehicle doors for visually impaired people **Information & interactions exclusion** *Availability of information:* Lack of door location information for visually impaired people **Psychological exclusion** *Stigma:* Slow boarding – feeling of delaying or inconveniencing other passengers	Visual – contrasting colours, lighting – patterns and colours Audio – beacon located by doors Tactile – tactile surfaces, tactile buttons, continuous guide rail from exterior>interior, steps locatable with cane Handles Guiderail Lift Automatic ramp Kneeling suspension

Opportunity	Consideration(s) What should it do to improve inclusion?	Exclusion What exclusion should it address?	Solutions/ existing strategies (workshop ideas) How might it do this?
Vehicle platform	Reduce vehicle step-in height to make entry easier for disabled people Reduce ramp steepness/ allow for level boarding to ensure efficient and independent entry for wheelchair users Reduce protrusions into the interior space to allow unobstructed movement and navigation	**Physical exclusion** *Moving in/ through space:* Vehicle exterior – difficult to step/ wheel into vehicle, Vehicle interior – obstructions *Navigating in/ through space:* Vehicle exterior – difficult to navigate to vehicle doors for visually impaired people, Vehicle interior – obstructions	Kneeling suspension system
Seating	Seating orientation allowing for different levels of social interaction according to preferences Seating orientation allowing forward facing for comfort Seating orientation allowing facing to aid communication for hearing impaired people through BSL and lip reading Seating layout ensuring sufficient leg room for comfort Seating layout divided to improve sense of security from other passengers Seating allowing for multiple preferences for comfort Seating adaptation e.g. folding requiring little strength/ dexterity Adjacent seat division to improve sense of security from other passengers Priority spaces allowing access to inclusive features if not available at every seat	**Interpersonal exclusion** *Social interaction:* Unwanted interaction, Lack of interaction, Unable to communicate (hearing impaired people) *Dangerous/ illegal/ uncomfortable behaviours* **Psychological exclusion** *Fear:* Sharing SAV with strangers **Physical exclusion** *Actions:* Difficulty moving adaptable interior components (e.g. seats)	Adaptability of seating layout Floor-to-ceiling division – walls, curtains, semi-transparent dividers Multiple seating types – Perch seating, regular seating etc. Folding seating – button operated, self-folding Division between seats – armrests, moveable dividers, headrests

Opportunity	Consideration(s) What should it do to improve inclusion?	Exclusion What exclusion should it address?	Solutions/ existing strategies (workshop ideas) How might it do this?
Wheelchair space	Provide access to sufficient wheelchair space(s) Reduce potential for wheelchair space to be occupied Ensure easy, independent use of suitable wheelchair restraints – if required Allow suitable seating for wheelchair users' travelling companions	**Physical exclusion** *Occupying/ using space:* Wheelchair space – unavailable, not reservable *Actions:* Wheelchair restraints not independently usable **Interpersonal exclusion** *Awareness & inclusive/ excluding behaviours:* Occupying wheelchair space *Social interaction:* Unable to have social interaction – no seating near wheelchair space **Psychological exclusion** *Fear:* Feeling unsafe – poor wheelchair restraints	Multiple wheelchair spaces Additional space for buggies etc. which usually obstruct wheelchair spaces Folding seating – unobvious, folded by default, and lockable
Luggage/ assistance animal space	Space for personal items close to seat, in line-of-sight, or in contact with passenger to reduce fear of theft Space for large luggage that doesn't require significant strength to place Space for assistance dogs near to seating	**Psychological exclusion** *Fear:* Theft **Physical exclusion** *Occupying/ using space:* Luggage storage – inaccessible, No space for assistance dogs	Wheelchair ramp used for wheeled luggage
Facilitating on-journey activities	Facilitating use of personal devices and reading Providing useful, pleasant and surprising features to all passengers		Folding table Charging sockets Older people's suggestions from workshops – Drinks cabinet, complementary food, refrigerated shopping section, free newspapers, health monitoring

4.4.2 *Interfaces: Inclusive SAV design opportunities*

Table 10 Inclusive SAV design opportunities and considerations – Interfaces

Opportunity	Consideration(s) What should it do to improve inclusion?	Exclusion What exclusion should it address?	Solutions/ existing strategies (workshop ideas) How might it do this?
Registration process	Collect personal information about passengers, allowing for individuals to choose shared SAV journeys that feel secure. Calibrate security preferences to allow automatic recommendation of SAV journeys that feel secure. Collect information about individuals' access needs to ensure inclusive adaptation of physical features and interfaces during the journey. Register passengers as belonging to specific excluded groups to enable access to priority services and preferential pricing. Validate passenger information. Ensure privacy of personal data.	**Psychological exclusion** *Fear:* Sharing SAV with strangers, Sharing personal information **Information and interactions exclusion** *Perceiving & understanding* *Interacting* **Physical exclusion** **Service exclusion** *Cost & payment* *Network accessibility*	Public passenger profile – age, gender, and passenger rating Simple scenario-based security questionnaire Card/ pass linked to account with saved accessibility needs App – linked to card/ pass Validation – existing entitlements for disabled people (e.g. government benefit eligibility), ID, passenger reporting + CCTV
Journey choices	Allow passengers to make choices about sharing a vehicle to improve sense of safety Allow passengers to reserve and adapt interior space to meet their access needs Allow for control of routing according to passengers' knowledge and preferences	**Psychological exclusion** *Fear:* Sharing SAV with strangers *Confidence & control* **Interpersonal exclusion** *Awareness and inclusive/ excluding behaviours:* Occupying priority seating and wheelchair spaces **Physical exclusion** *Occupying/ using space:* Seating/ wheelchair space	App – showing age, gender and rating of potential sharers App – selecting safe journey based on calibration of safety preferences Ability to select seat for comfort – facing direction of travel

Opportunity	Consideration(s) What should it do to improve inclusion?	Exclusion What exclusion should it address?	Solutions/ existing strategies (workshop ideas) How might it do this?
Personal booking, planning and service access interface	Reliable and usable by multiple excluded groups including those with low digital literacy and disabilities influencing their use of interfaces Provide alternative to inaccessible and unreliable smartphone use for accessing SAV on-demand and in public Provide familiar and intuitive ways of accessing vehicle spontaneously	**Information and interactions exclusion** *Perceiving & understanding:* Inaccessible information modality *Interacting:* Unintuitive and unfamiliar *Reliability:* Unreliability of smartphones (battery, connectivity etc.)	Friends or family assistance Staff to assist, ticket office Telephone service – human, not automated Home voice assistant Simple phone services: email, SMS, Phone call Key fob or similar with location tracking and a button to call SAV Public booking terminals – on-street, inside businesses, simple call points and more detailed interfaces Gesture-based hailing – similar to taxis, holding out card/ pass for journey validation
Public booking, planning and service access interactions	Reliable and usable by multiple excluded groups including those with low digital literacy and disabilities influencing their use of interfaces Provide familiar and intuitive ways of accessing vehicle spontaneously at the roadside	**Information and interactions exclusion** *Perceiving & understanding:* Inaccessible information modality *Interacting:* Unintuitive and unfamiliar *Reliability:* Unreliability of smartphones (battery, connectivity etc.)	Staff to assist Simple public call points Roadside access – similar to boarding a bus

Opportunity	Consideration(s) What should it do to improve inclusion?	Exclusion What exclusion should it address?	Solutions/ existing strategies (workshop ideas) How might it do this?
Pre-journey information	Provide information about vehicle arrival – ETA, notification of arrival for general benefits and to minimise time waiting for vehicle in unsafe location Journey details made available in on-demand, accessible formats Provide information about delays, disruption and alternative routes Provide information about vehicle layout and occupancy to help visually impaired people prepare for navigation Displays and announcements providing information about vehicle arrival at waiting facilities	**Psychological exclusion** *Fear:* Waiting for vehicle in public *Confidence & control:* Extensive planning **Information and interactions exclusion** *Perceiving & understanding:* Inaccessible information modality, Complexity of information *Interacting:* Unintuitive and unfamiliar *Reliability:* Unreliability of smartphones (battery, connectivity etc.) *Availability of information:* Lack of interior navigation information **Service exclusion** *Reliability:* Unexpected changes **Physical exclusion** *Navigating in/ through space:* Vehicle interior	Smartphone app Offline information – stored in notes/ emails on phone – read by screen reader (inaudible in busy locations) Physical maps, tickets, notes (braille and handwritten) Handwritten notes Arrival display board Infrastructure-based audio arrivals information activated by button
Boarding and validation interactions	Validate entry to the vehicle to avoid misuse of service (e.g. tailgating) and reduce fear of sharing with unauthorised passengers Allow simple communication of passenger needs to ensure passenger needs are met when journey is not pre-booked Does not draw passengers' attention to operation of ramps or other boarding features to reduce stigma Allow simple and accessible triggering of door opening reducing need for complex interactions Allow simple and accessible triggering of ramp/ lift access for wheelchair users Validate entry to the vehicle to avoid misuse of service (e.g. tailgating) and reduce fear of sharing with unauthorised passengers Allow simple communication of passenger needs to ensure passenger needs are met when journey is not pre-booked Ensure visually impaired people are aware of layout of interior before moving inside the vehicle – particularly when interior layout may adapt	**Psychological exclusion** *Fear:* Sharing SAV with strangers *Stigma:* Conspicuous disability-specific interactions **Physical exclusion** *Actions:* Reaching and activating door/ ramp controls *Navigating in/ through space:* Vehicle interior **Information and interactions exclusion** *Availability of information:* Lack of interior navigation information	Travel card – tapped on exterior, unique to passenger, linked to account with registered needs – e.g. to ensure ramp is deployed Unique passenger code – e.g. QR code; App Audio – description of interior space

Opportunity	Consideration(s) What should it do to improve inclusion?	Exclusion What exclusion should it address?	Solutions/ existing strategies (workshop ideas) How might it do this?
Inclusive modality of interior interfaces	Provide intuitive, simple interactions inside the vehicle that are easy to use from the first attempt Controls that do not require complex interactions or touchscreens to use Provide a viable alternative to a smartphone app for personal interactions with SAV for those who experience difficulties using smartphones Information made available in audio format Information made available in easy to understand and read visual format Automation of complex input of journey needs and preferences Personal journey information is kept private from other passengers Controls that are easy to locate for visually impaired people	**Information and interactions exclusion** *Perceiving & understanding:* Inaccessible information modality, Complexity of information *Interacting:* Unintuitive and unfamiliar, Inaccessible interaction modality – tactility, dexterity *Reliability:* Unreliability of smartphones (battery, connectivity etc.) *Availability of information:* Lack of interior navigation information **Psychological exclusion** *Fear:* Sharing personal information	
Interior at-seat interactions	Provide simple, comfortable, and safe ways of entering journey information and access needs from inside the vehicle Allow people to choose to start vehicle once seated to reduce instability when moving onboard Allow payment from comfort and safety of seat Allow reporting of unclean or vandalised interior Allow personal control of comfort features e.g. climate control and lighting Allow passengers to share location with those they are travelling to, family etc. Allow passengers to report negative passenger behaviours Notify passenger of journey end Allow selection of safe and/or accessible drop off location Provide a viable alternative to a smartphone app for personal interactions with SAV for those who experience difficulties using smartphones Reachable from wheelchair space	**Service exclusion** *Maintenance* Vandalism **Interpersonal exclusion** *Dangerous/ illegal/ uncomfortable behaviours:* Crowding – outside the vehicle to access exterior interfaces **Physical exclusion** *Moving in/ through space:* Vehicle interior – worse when moving, Built environment – being dropped in inaccessible locations **Psychological exclusion** *Fear:* Sharing SAV with strangers, Sharing personal information, Being dropped off in unsafe locations **Information and interactions exclusion** *Perceiving & understanding:* Inaccessible information modality *Interacting:* Unintuitive and unfamiliar, Inaccessible interaction modality – dexterity, reachable, seated	Entering information at seat using travel card to automatically enter preferences and destinations Crowdsourced reports on interior condition Lighting features; Configurable window blinds Vibrotactile feedback App – Map interfaces, adjusting end point

Opportunity	Consideration(s) What should it do to improve inclusion?	Exclusion What exclusion should it address?	Solutions/ existing strategies (workshop ideas) How might it do this?
Interior emergency interactions	Provide intuitive means of controlling the vehicle if required in emergency scenarios Provide easy means of communicating with service in emergencies Clearly communicate information about service response to emergencies/ breakdowns e.g. arrival of replacement vehicle Provide clear emergency exit navigation information to visually impaired people Provide simple and discreet means of alerting service to dangerous passenger behaviour	**Physical exclusion** *Navigating in/ through space:* Vehicle interior – for visually impaired people in emergencies **Information & interactions exclusion** *Perceiving & understanding:* Inaccessible information modality *Interacting:* Unintuitive and unfamiliar – in emergencies, Inaccessible interaction modality – in emergencies *Availability of information:* Lack of interior navigation information – for visually impaired people in emergencies **Interpersonal exclusion** *Dangerous/ illegal/ uncomfortable behaviours* **Psychological exclusion** *Fear:* Sharing SAV with strangers	Panic button – hidden location; Vehicle responds to panic button by driving to safe location/ locking
Interior journey information	Provide vehicle ETA information Provide vehicle routing information Provide vehicle service updates and alerts Provide current location information for visually impaired people who cannot rely on view of outside	**Information & interactions exclusion** *Perceiving & understanding:* Inaccessible information modality – location for visually impaired people *Availability of information*	
Interior passenger alerts	Reduce likelihood of passengers obstructing vehicle floor space to aid movement and navigation by disabled people Non-audio formats for public alerts and notifications for hearing impaired people	**Interpersonal exclusion** *Awareness & inclusive/ excluding behaviours:* Obstructing interior space **Information & interactions exclusion** *Perceiving & understanding:* Inaccessible information modality – audio and hearing impaired people	Audio – announcements encouraging people to not obstruct interior; Signage – making priority spaces clear Visual alerts and notifications
Interior onward journey information	Communicates exterior environment to visually impaired people when leaving the vehicle Gives directions for onward journey	**Physical exclusion** *Navigating in/through space:* Built environment – visually impaired people	Audio – description of exterior obstacles Audio – onward navigation instructions

Opportunity	Consideration(s) What should it do to improve inclusion?	Exclusion What exclusion should it address?	Solutions/ existing strategies (workshop ideas) How might it do this?
Communication of access needs	Allow passengers to communicate access needs to the service ensuring access throughout journey	**Psychological exclusion** *Confidence & control:* Extensive planning **Service exclusion** *Reliability:* Unexpected changes – inaccessible replacement services	Guided selection of accessibility features using booking app; Automatic use of registered access needs to ensure accessibility; Service-specific travel card to automatically input journey preferences
Inclusive design of exterior interfaces	Provide intuitive, simple interactions on the exterior of the vehicle that are easy to use from the first attempt	**Information & interactions exclusion** *Perceiving & understanding:* Inaccessible information modality *Interacting:* Unintuitive and unfamiliar – in emergencies, Inaccessible interaction modality – in emergencies	
Inclusive design of non-vehicle interfaces	Provide intuitive, simple interactions with personal devices/ items that are easy to use from the first attempt	**Information & interactions exclusion** *Perceiving & understanding:* Inaccessible information modality *Interacting:* Unintuitive and unfamiliar – in emergencies, Inaccessible interaction modality – in emergencies	
Exterior vehicle information	Ensure key information about SAV (e.g. access and availability) is obvious to passengers before boarding Allow location of a pre-booked SAV on the roadside by visually impaired people Allow prompt location of a pre-booked SAV on the roadside to reduce feeling unsafe by being on the roadside	**Information & interactions exclusion** *Perceiving & understanding:* Inaccessible information modality *Interacting:* Unintuitive and unfamiliar – in emergencies, Inaccessible interaction modality – in emergencies **Physical exclusion** *Navigating in/ through space:* Built environment **Psychological exclusion** *Fear:* Waiting for vehicle in public	Flag system – similar to London taxis Audio-based smartphone app; Bright exterior lighting; Audio beacons; Navilens – recognising vehicle and providing directions Bright exterior lighting

Opportunity	Consideration(s) What should it do to improve inclusion?	Exclusion What exclusion should it address?	Solutions/ existing strategies (workshop ideas) How might it do this?
Navigation interface	Build familiarity with area to aid future navigation Not reliant on having smartphone in hand to reduce fear of theft Ability to share location with service, friends, family to improve sense of security Allow independent navigation for visually impaired people Avoid obstructions Informing people about safety of the area Allow monitoring of passenger location Check that passenger has arrived safely at destination Allow for feedback to inform safety of future journeys	**Physical exclusion** *Navigating in/ through space:* Built environment *Moving in/ through space:* Built environment **Psychological exclusion** *Fear:* Theft, Walking in unsafe locations – at night, poorly lit, alone	SAV app to share location and provide end-to-end passenger safety App sharing location with friends, family, or service App – home safe feature pressed when arrived at home/ trigger responses if not App – simple rating system to inform future safety of service
Payment	Allow passengers to pay for the service with simple and understandable interactions	**Information & interactions exclusion** *Interacting:* Unintuitive and unfamiliar – in emergencies	Simple, phone-based ticketing; Payment using service-specific travel card

4.4.3 *Service and infrastructure: Inclusive SAV design opportunities*

TABLE 11 INCLUSIVE SAV DESIGN OPPORTUNITIES AND CONSIDERATIONS – SERVICE AND INFRASTRUCTURE

Opportunity	Consideration(s) What should it do to improve inclusion?	Exclusion What exclusion should it address?	Solutions/ existing strategies (workshop ideas) How might it do this?
Standardisation	Provide a consistent design for layout for SAVs to reduce need to learn multiple layouts for visually impaired people Provide a consistent design for information and interactions with SAVs to reduce need to learn multiple interfaces for groups with low digital literacy	**Physical exclusion** *Navigating in/ through space:* Interior **Information & interactions exclusion** *Availability of information:* Lack of interior navigation information – for visually impaired people **Psychological exclusion** *Confidence & control:* Unfamiliar services	
Education and familiarisation	Provide public, tactile means of familiarising visually impaired people with vehicle layouts before use Provide training, and information on how to use SAVs to groups with low digital literacy Provide general public information to build confidence in SAVs	**Physical exclusion** *Navigating in/ through space:* Interior **Information & interactions exclusion** *Availability of information:* Lack of interior navigation information – for visually impaired people *Interacting:* Unintuitive and unfamiliar **Psychological exclusion** *Confidence & control:* Unfamiliar services	Tactile model; Mock-up; Assistance Simulator
Payment methods and pricing	Allow passengers to pay for the service in ways that they have access to and can use	**Service exclusion** *Payment* **Information and interactions exclusion** *Interacting:* Unintuitive and unfamiliar	
Level of passenger choice and control	Allow passengers to make choices about sharing a vehicle to improve sense of safety Build familiarity with regular journeys and allow for control of routing according to passengers' knowledge and preferences	**Psychological exclusion** *Fear:* Sharing SAV with strangers *Confidence & control,* Unfamiliar services	

Opportunity	Consideration(s) What should it do to improve inclusion?	Exclusion What exclusion should it address?	Solutions/ existing strategies (workshop ideas) How might it do this?
Routing, timing and operation	Create familiarity with regular pick-up locations Stopping in accessible locations Stopping in safe locations to reduce fear Reducing distance to travel to SAV to reduce physical difficulties for disabled people and fear Monitoring journey to SAV Short waiting time and on-time services to reduce time feeling unsafe when waiting On-time SAV service to reduce missed connections in areas with poor service Provision of fixed locations to aid location of SAV for spontaneous access without complex interactions Demand -responsive swarming to ensure availability at fixed locations	**Physical exclusion** *Moving in/ through space:* Built environment *Navigating in/ through space:* Built environment **Psychological exclusion** *Fear:* Walking in unsafe locations – at night, poorly lit, alone, Waiting for vehicle in public **Service exclusion** *Availability:* Reduced flexibility, Vehicles not available when needed **Information and interactions exclusion** *Interacting:* Unintuitive and unfamiliar	
Service provision at waiting facilities	Ensuring waiting facilities are well maintained Provision of assistance for visually impaired people to navigate large SAV hubs Waiting facilities staff easy to communicate with for hearing impaired people	**Service exclusion** *Maintenance:* Vandalism *Staff:* Unavailable, Poor communication **Physical exclusion** *Moving in/ through space:* Waiting facilities/ hubs *Navigating in/ through space:* Waiting facilities/ hubs **Information & interactions exclusion** *Availability of information:* Lack of waiting facilities/ hub navigation information – for visually impaired people	
Routing, timing and operation	Ensure SAV stops close to the kerb to reduce distance to step Vehicle waiting until passengers are seated before moving Comfortable and smooth driving style Ensures drop off point is accessible and safe	**Physical exclusion** *Moving in/ through space:* Vehicle exterior – difficult to step/ wheel into vehicle, Vehicle interior, Built environment – obstructions *Navigating in/ through space:* Built environment **Service exclusion** *Vehicle operation:* Unstable when moving, Prioritising speed over inclusion *Staff:* Unavailable, Poor communication **Psychological exclusion** *Fear:* Walking in unsafe locations – at night, poorly lit, alone, Waiting for vehicle in public	

Opportunity	Consideration(s) What should it do to improve inclusion?	Exclusion What exclusion should it address?	Solutions/ existing strategies (workshop ideas) How might it do this?
Maintenance	Ensure interior is clean and hygienic Ensure interior is well maintained	**Service exclusion** *Maintenance:* Vandalism, Hygiene	
Passenger limits	Only allowing seated passengers to travel to reduce crowding Reducing access to service for passengers reported as dangerous or antisocial	**Interpersonal exclusion** *Dangerous/ illegal/ uncomfortable behaviours:* Crowding – inside the vehicle **Psychological exclusion** *Fear:* Sharing SAV with strangers	Denying access to dangerous passengers based on reports
Monitoring and surveillance	Service monitoring passengers to deter and respond to negative behaviours	**Interpersonal exclusion** *Dangerous/ illegal/ uncomfortable behaviours* **Psychological exclusion** *Fear:* Sharing SAV with strangers	CCTV; Female staff member
Education and familiarisation	Service educates public to be more aware of disability including use of assistance dogs, assistive devices, and priority spaces	**Interpersonal exclusion** *Awareness & inclusive/ excluding behaviours*	Public education
Routing, timing and operation	Provides enough time for disabled people to move and navigate from their seat to the door after vehicle is stopped	**Service exclusion** *Vehicle operation:* Unstable when moving, Prioritising speed over inclusion	
Waiting facilities	Provide seating and rest places	**Physical exclusion** *Resting*	

5 RESPOND: INCLUSIVE SAV INFORMATION & INTERACTIONS

5.1 INTRODUCTION

5.1.1 FRAMING THE INCLUSIVE SAV DESIGN RESPONSE

The following two chapters detail design concepts developed to respond to the opportunities identified in the previous chapter. Design responses were created in two main areas: information & interactions, and vehicle design.

Given the breadth of exclusion identified and the nascence of SAV design (especially inclusive SAV design), this project's design response sought to reflect this breadth by developing a range of design concepts. This broad scope was beneficial for two reasons.

1. **To stimulate further research** by sharing novel inclusive SAV design concepts for exploration and evaluation by research and design communities, thereby increasing the potential impact of informing inclusive SAV development.
2. **To demonstrate the potential for a universal SAV service** that addresses the needs of multiple excluded groups and provides equal access to all vehicles. This is essential for reducing service exclusion caused by limiting people's access to a subset of vehicles within a fleet. As experienced with Uber's wheelchair accessible vehicle (WAV) service (Hassanpour et al., 2021).

To ensure the conciseness of this thesis while retaining valuable detail of the designs created during this project, a supplementary document, *Designing Autonomy for All,* contains imagery and more in-depth discussions of the design responses summarised in these chapters. References to this document are made throughout chapters 5 and 6.

5.1.2 SCOPE OF INCLUSIVE SAV INFORMATION AND INTERACTIONS RESPONSES

Chapter 4 detailed the opportunities for the inclusive design of the information that SAV passengers receive and the digital interactions they perform. This chapter provides examples of how Action Research and inclusive design ideation have been used to address these opportunities by:

- *Ensuring the accessibility and usability of interfaces by diverse groups*, for example, by providing audio and visual outputs to account for visual and hearing impairments.
- *Providing information and interaction features that address the needs of excluded groups,* such as providing passenger reporting functionality to address women's security concerns.

Inclusive design requirements for web- and app-based services have already been extensively explored through research and are outlined in industry-standard accessibility guidelines. Therefore, detailed investigations of digital interface accessibility were considered out of scope for this project. Instead, the focus has been on exploring the following:

- The provision of inclusive SAV-specific interfaces that might be used throughout a journey in addition to or instead of personal devices.
- Specific functions of information and interfaces that could address issues of exclusion.

Some information and interactions barriers identified in the workshops and literature review are not solely experienced due to belonging to an excluded group, although they might affect excluded groups more acutely. These general requirements, such as providing accurate and timely information, are likely already priorities for SAV developers. To maximise the novelty of information and interaction design concepts, priority is given to addressing issues with more direct links to excluding factors.

5.2 MULTIMODAL INTERACTIONS FOR SAV SERVICE ACCESS

The most significant SAV interactions for passengers are those that enable access to the service. The flexibility of SAV services and varied operating models increase interaction complexity compared to traditional transport services, where fixed routes, scheduling, staffing, and cash-based ticketing provide predictable services, multiple planning and payment options, and assistance. While flexible models enable inclusivity through door-to-door routing and fewer modal changes, they require more mobile and personalised access methods without fixed infrastructure and staff.

Smartphone use is often considered essential for accessing SAV services. Proposals for inclusive SAV services typically focus on smartphone app design(Martelaro et al., 2022; Schuß et al., 2022). The benefits of smartphones as an open platform for innovation enable the development of specialised apps that support inclusive transport use and daily tasks. Workshop participants discussed examples, including the following:

- WalkSafe (Chaperhome Ltd, 2024): Improving women's safety when walking in public.
- Navilens (NUEVOS SISTEMAS TECNOLÓGICOS, S.L. (NEOSISTEC), n.d.): Allowing visually impaired people to access information as audio by scanning QR-style codes with their phone
- Be My Eyes *(Accessibly Inc., n.d.)*: Allowing visually impaired people to video call volunteer assistants who can help them with various visual tasks.

Despite these benefits, the barriers to smartphone and touchscreen use discussed by many workshop participants indicate that app-based solutions are not always the best option.

While app interface improvements can enhance inclusivity, the ground-up design of SAV services allows for alternative, easier, and less technology-dependent interactions. These may provide additional benefits, including:

- Access for financially excluded passengers, such as unbanked passengers without access to digital payment methods and those unable to afford smartphones.

- Alternative access if smartphones are lost, stolen, fail, or have low battery – a common concern among women due to security implications.
- Access for people in areas with poor network coverage, such as rural areas.

As smartphones offer personalised, multifunctional, and portable interactions, matching their functionality with a single alternative is challenging. Figure 20 demonstrates the different interfaces that might be available to passengers during an SAV journey. Public interface availability is limited by its provision in a service and the passenger's location. Computers and home voice assistants may be limited to a passenger's home. Vehicle-located interfaces only provide information during the journey. While feature phones (basic non-smartphones) and simple devices designed for SAV services enable on-the-go use, their functionality remains limited compared to more sophisticated digital interfaces.

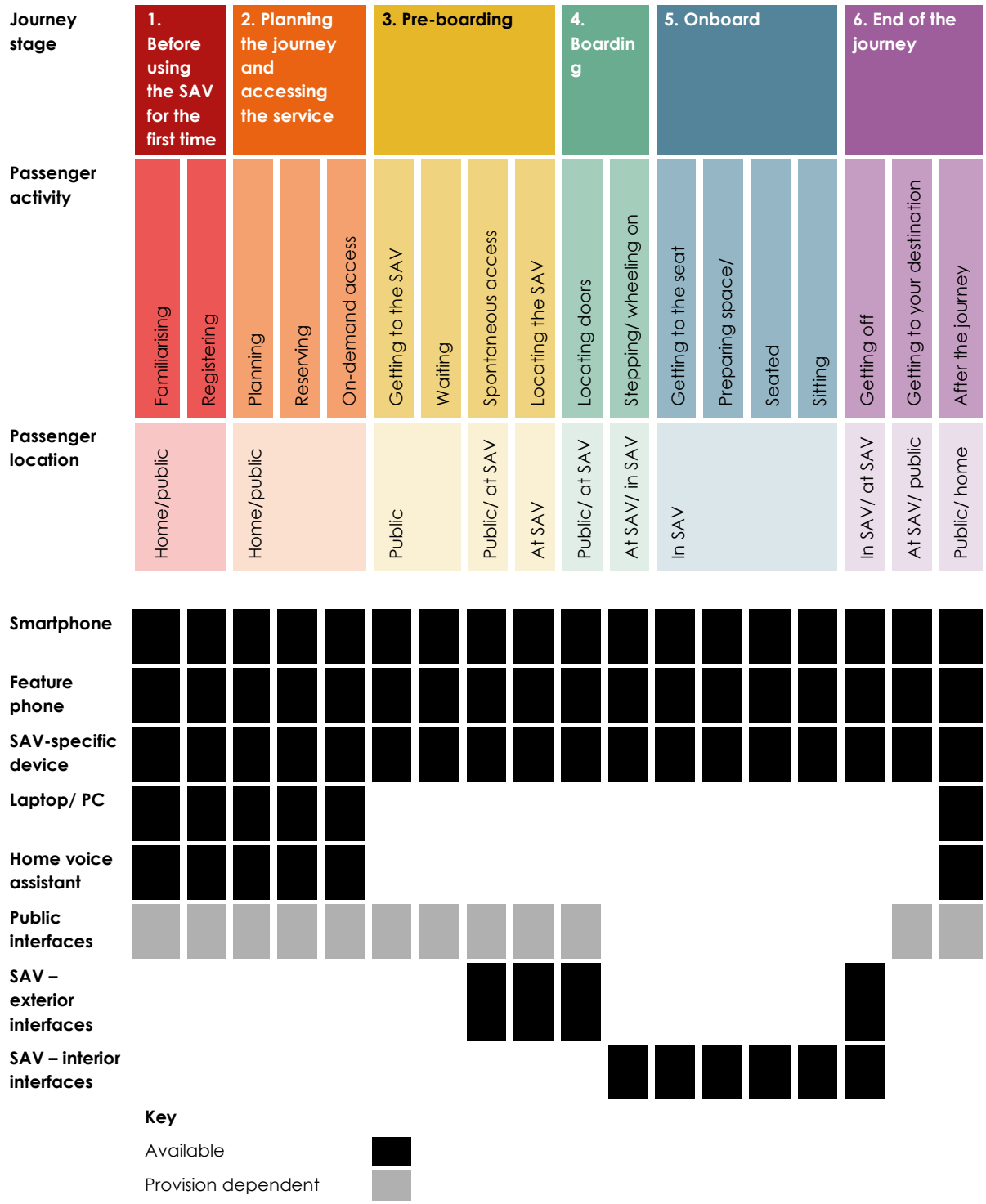

FIGURE 20 INTERFACE AVAILABILITY DURING AN SAV JOURNEY

While the utility of smartphones makes their incorporation into SAV services inevitable, this section describes how alternative interaction modes might be used during SAV journeys to provide access for groups excluded from smartphone use.

Many concepts incorporate combinations of personal devices and location-specific interfaces. The following personal devices were considered:

- Smart travel card: An RFID card, similar to existing contactless travel cards, linked to passenger accounts and able to communicate passenger information to the vehicle and service.
- SAV-specific device: Offering the same features as a smart travel card alongside additional functionality, such as connectivity, simple inputs, and audio/visual information communication.

Location-specific interfaces include the following:

- Public call point: An infrastructure-located interface for summoning SAVs and communicating basic journey information.
- Public booking terminal: An infrastructure-located interface similar to ticket machines, allowing complex interactions, such as destination choices and seat reservations.
- Public SAV interior interface: Interior displays and audio systems providing information for all passengers.
- Personal/ at-seat SAV interior interface: At-seat audio/visual/tactile interfaces for personal information.
- SAV exterior interface: SAV-based external information displays, audio interfaces and touch interfaces.

In response to requests for human-based interactions the provision of staff and phone/SMS/email services were also considered.

5.2.1 *Simplifying interactions and communication with the SAV service: smart travel card*

Workshop participants discussed a travel card as a simple means to communicate information to the SAV service without complex interactions and to access the service without a smartphone. A travel card could simplify interactions through the following:

- Automating adaptation and preferences with a tap to configure adaptable SAV elements.

- Providing shortcuts when using other interfaces, such as regular locations like home and work when selecting a destination onboard or at a public interface.

A smart travel card can enable interactions at various journey points:

- Vehicle exterior: to confirm identity and open the doors.
- Passenger seat: to provide regular destination options, set comfort features and interface modality, and trigger journey-specific information through at-seat interfaces.
- Public interfaces: to allow selection from common destinations and link to a payment account for reserving SAVs.

Travel cards themselves are limited with no connectivity, few interaction options, and no means of displaying information. Travel card functionality could be improved through technologies allowing the display of key journey information, such as integrated E-paper/e-ink displays (Ali Rabbani et al., 2023) or ticket machines which print journey information through rewritable thermal printing. Useful information that might be displayed includes pick-up and drop-off times, start and end locations, maps of transport hubs, and a unique SAV identification code.

5.2.2 On-demand SAV access in public: Public call points

For those without smartphones seeking to access an SAV in public, interfaces in the public realm could enable these interactions, as suggested by an older workshop participant:

> *'Could there be a place where, if you want it, you punch it in? So, for example, in London there would be points where people need [SAVs]…, supermarkets… So, there could be one of these pick up points.' – OP2(P6)*

Some existing work on SAV user experience mentions public interfaces for booking vehicles (Force, 2022), but research suggests that physical infrastructure could be replaced with virtual equivalents, such as augmented reality virtual stops (Hub et al., 2023, 2020; Kim et al., 2019), leaving few locations for such interfaces.

To enable flexible pick-up points without complex technology or extensive infrastructure, simple public call point interfaces can be retrofitted to street furniture,

such as lampposts and benches, to summon SAVs. Such a system could offer a ubiquitous means of SAV service access for all passengers.

Designing Autonomy for All (pp. 8-9) (accompanying this thesis) discusses how these simple on-street interfaces (Figure 21) might be designed inclusively while addressing trade-offs between simplicity of use, granularity of information inputs (e.g. ability to input destination to access synchronously shared SAVs), and suitability for public installation (e.g. resistance to vandalism). Using a travel card with these interfaces is also presented as a means of allowing selection from pre-registered destinations and paying for/validating the journey.

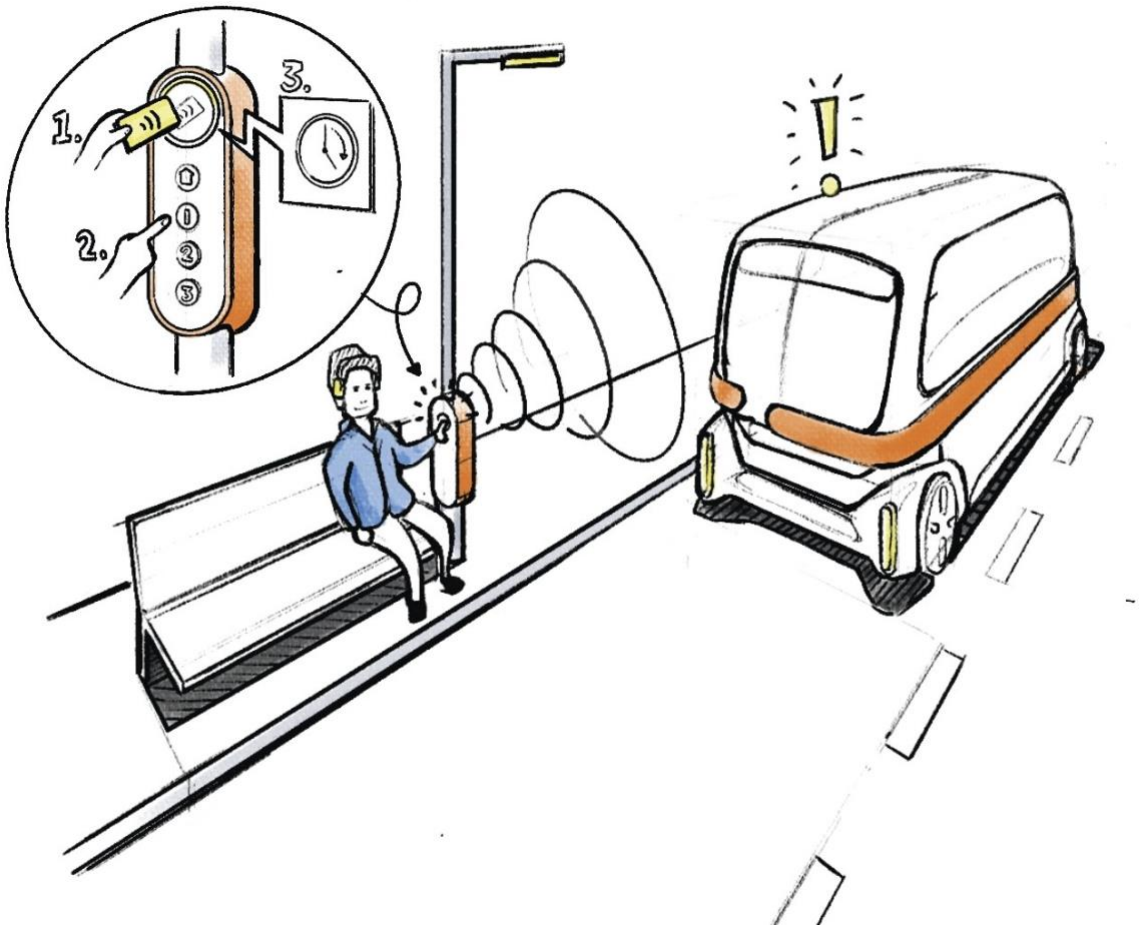

FIGURE 21 ILLUSTRATION OF USING A PUBLIC CALL POINT TO HAIL AN SAV (FROM ACCOMPANYING PRACTICE DOCUMENT, *DESIGNING AUTONOMY FOR ALL)*

5.2.3 *SPONTANEOUS SAV ACCESS: GESTURE-BASED HAILING*

For some users of SAV services, spontaneous access to the service may be more inclusive than pre-booking journeys, reducing the need for passenger accounts and digital booking while providing a familiar, taxi-like experience.

Older workshop participants suggested that SAVs could be accessed through gesture-based hailing of passing vehicles (also discussed as a potential option in some literature(Force, 2022; Mastouri et al., 2023; Smith and Vardhan, 2017).

Designing Autonomy for All (pp. 10-11) demonstrates how gesture-based hailing might be enabled through SAV-mounted external human-machine interfaces (eHMIs) to communicate availability and destination information, and the use of SAV cameras to recognise hailing passengers, and travel cards to validate the passenger and allow them to communicate a specific destination (e.g. a pre-registered home address) (Figure 22).

While simplicity and low-tech means of accessing SAVs might be addressed by public call points in urban areas, this infrastructure may be less viable in less populated areas. A fleet of roaming SAVs accessed through gesture-based hailing may ensure access in these areas.

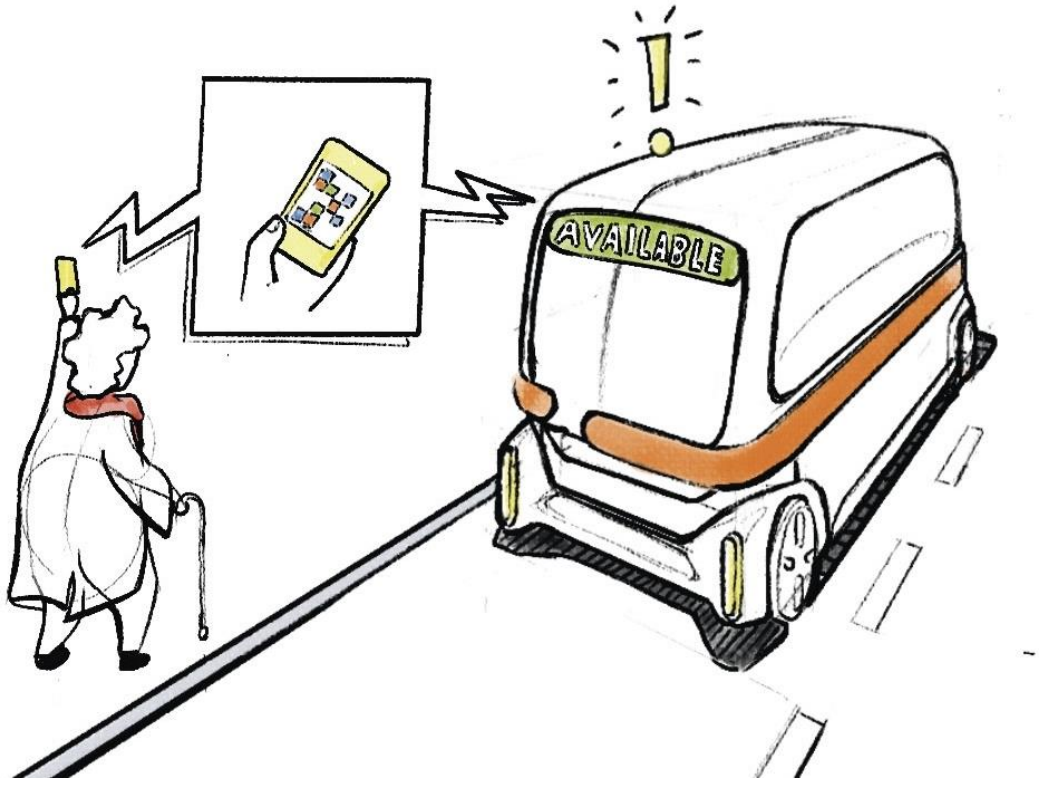

FIGURE 22 ILLUSTRATION OF SPONTANEOUS ROADSIDE HAILING OF AN SAV USING A TRAVEL CARD FOR VALIDATION (FROM ACCOMPANYING PRACTICE DOCUMENT, *DESIGNING AUTONOMY FOR ALL)*

5.2.4 SAV-SPECIFIC DEVICE

Workshop participants suggested that a dedicated device could simplify SAV service access by offering connectivity for information and location services, output through display/speaker/vibration, and controls for destination selection and on-demand access.

This concept was discussed by visually impaired participants as an alternative to smartphones for multiple interactions, including:

- Calling the vehicle to their location with a single button.
- Vibrating when they are near to the vehicle.
- Triggering a sound to aid in the location of the vehicle.

Designing Autonomy for All (pp. 12-13) shows a concept for a key fob-sized device to provide simple interaction with audio, visual, and vibrotactile modes.

5.2.5 Conclusion: Multimodal interactions for SAV service access

This section has summarised alternative means of accessing the SAV service for passengers without smartphone access due to:

- Poor accessibility for disabled people.
- Low confidence with digital interfaces, particularly common among older people.
- Low connectivity, more likely to occur in rural areas.
- High costs and reliance on digital payment accounts, challenging for financially excluded people.

Although these solutions are designed to address the above exclusions, they offer wider benefits in ensuring a failsafe access mode in the event of smartphone unavailability.

Decisions regarding interactions for accessing an SAV service ultimately depend on their operating models and service locations. Until access to personal digital devices is fully inclusive, SAV services should consider alternatives to maximise inclusion. The concepts discussed provide a foundation for developing novel low-tech access modes.

5.3 Secure SAV journeys: App design

During focused workshops exploring SAV security with women, several design opportunities were identified relating to accessing information and feeling in control of the entire SAV journey. Participants suggested several smartphone app-based solutions to address their security concerns. Between the two sets of women's focused workshops, an app interface design was created, combining multiple features inspired by these opportunities. This design prompted further discussion and iteration in the final women's workshops. This section discusses the app features designed and suggests potential improvements and SAV interface features that might improve feelings of security.

As the participants in the women's workshops had no significant difficulties with smartphone use, an app was chosen to demonstrate design responses. However, intersectionality in exclusion might mean that some individuals who experience security-related exclusion also face barriers to smartphone use. Further research should explore how these features can be provided through alternative means.

5.3.1 SECURE SAV BOOKING AND RESERVATION

To ensure their security onboard, women wished to know about the passengers with whom they were sharing the vehicle. While participants discussed how public passenger profiles could inform these choices, two significant issues were identified:

- Privacy concerns regarding the collection and sharing of these data with SAV service users.
- Anticipated complexity of making choices based on personal information for all passengers in a given vehicle.

Designing Autonomy for All (p. 16) shows how an app interface (Figure 23) could provide a simple indication of how secure the passenger might feel when sharing a vehicle (through traffic light colour codes), considering calibrated preferences related to the quantity, age, and gender of fellow passengers, and other security influences, including the time of day. For passengers with more acute security concerns, the app provides detailed but anonymised information about other passengers.

To simplify the input of security preferences, W2P1 suggested using a guided questionnaire:

> *'If you have […] a questionnaire […] where you can fill out your preferences… When you call this vehicle, the app can […] decide for you.' – W2P1*

While this questionnaire could allow the selection of multiple options (e.g. ideal number of sharing passengers), such isolated choices fail to capture how workshop participants described fear – as an intuitive response to multiple factors. The app design in *Designing Autonomy for All* (p. 17) shows a concept for an intuitive scenario-based security preference tool (Figure 24) that allows users to indicate their comfort level in various SAV scenarios to inform future journey recommendations.

Participants also discussed how their position relative to other passengers and interior dividers might affect their sense of security. The app design in *Designing Autonomy for All* (p. 18) offers seating choices, showing other passengers' positions, seat reservations, and selection of adaptable dividers (Figure 25). While seat position selection was seen as beneficial, participants evaluating designs in the final two focused workshops considered specific choices about seat division unnecessary, preferring to make these decisions when onboard.

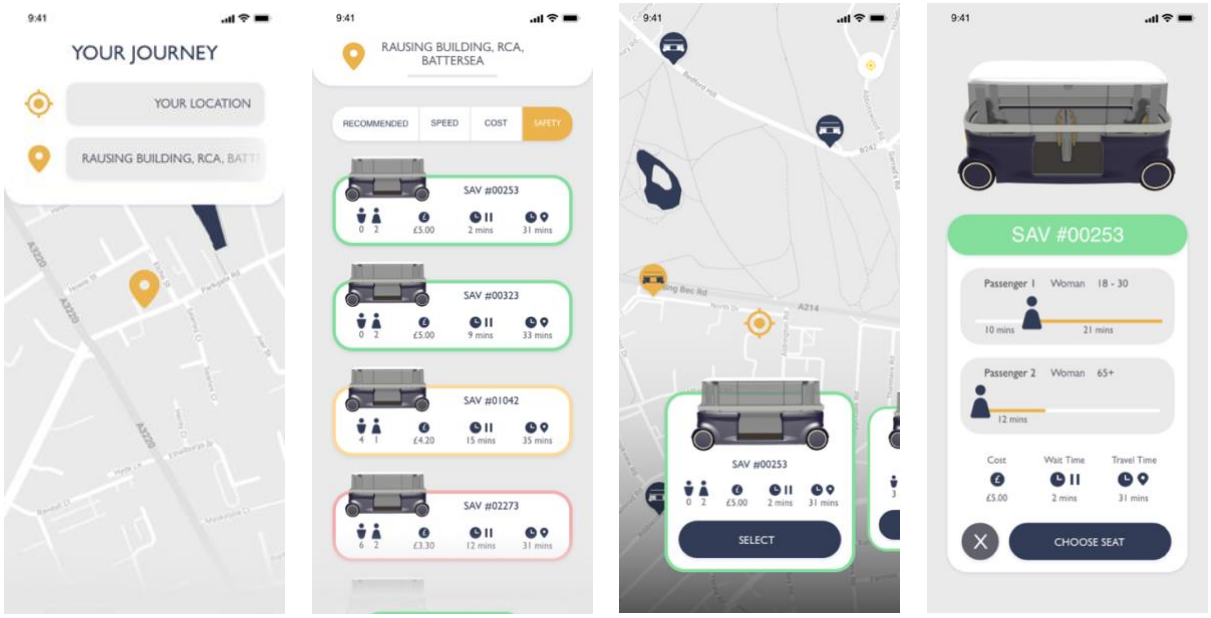

FIGURE 23 SECURE VEHICLE SELECTION THROUGH SAV APP

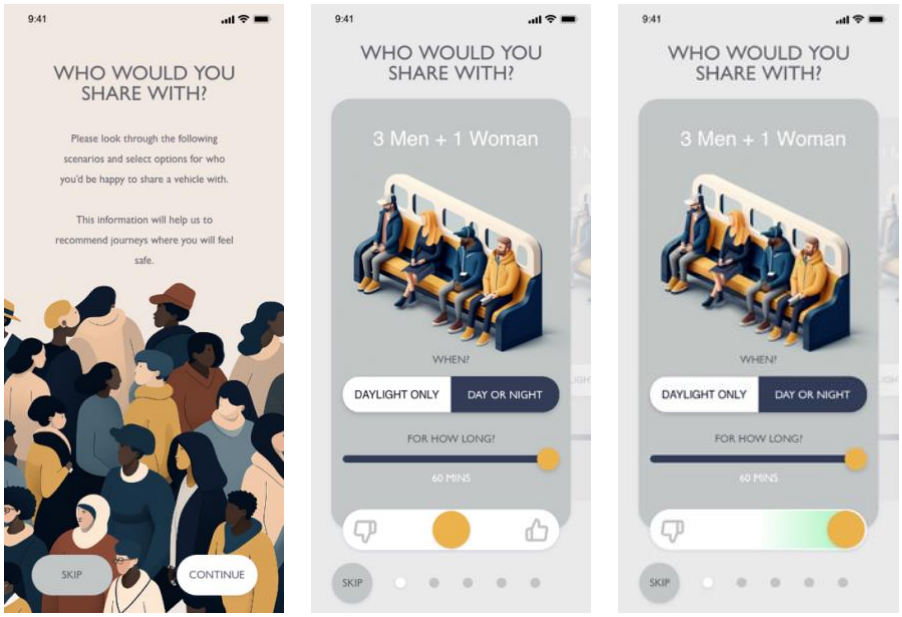

FIGURE 24 SECURITY CALIBRATION QUESTIONNAIRE IN SAV APP

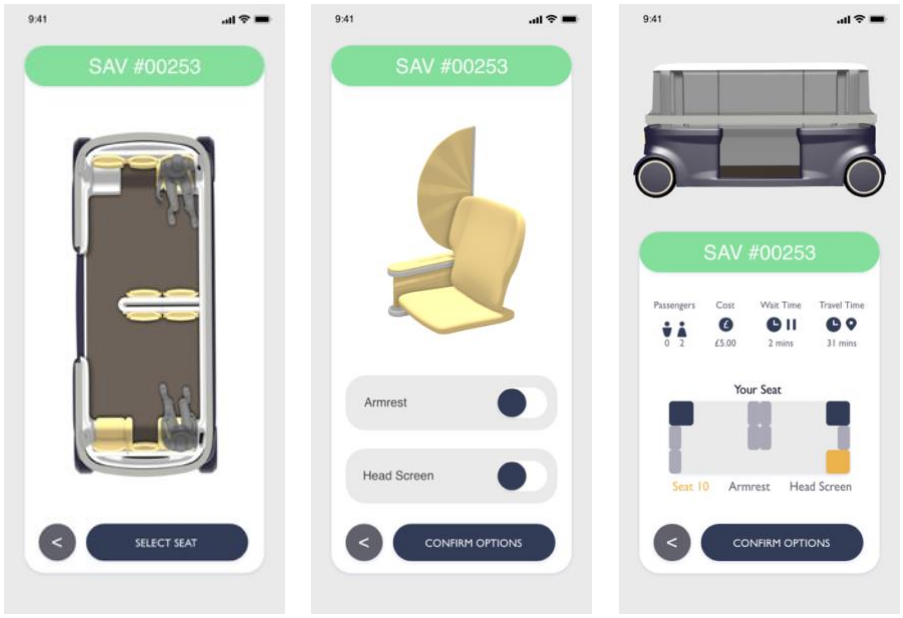

FIGURE 25 SEAT CHOICE IN SAV APP

5.3.2 *SECURE SAV BOOKING AND RESERVATION: LIMITATIONS AND FURTHER DEVELOPMENT*

While personal information about passengers was identified as beneficial in informing secure sharing choices, issues of data privacy may limit the extent to

which SAV services are able to gather such personal information and share it with other passengers, potentially giving rise to new security concerns.

Given the choice, some passengers may opt out of data sharing due to these concerns, creating a group of unknown passengers. Unknown passengers would remove the potential for passengers to screen who they might be sharing a vehicle with. An SAV recommendation system that suggests journeys based on individual security preferences and passenger information that the service stores may allow a less intrusive compromise, sharing only the seating position and number of passengers, allowing informed choices of secure seating positions.

If passengers refuse to share information with the SAV service completely, unknown passengers could be factored into security recommendations as potential risks. However, large numbers of passengers who choose to remain anonymous could limit the numbers of recommended secure journey options, excluding groups who are concerned about their safety by increasing wait times, and reducing the potential cost savings offered by sharing. Alternatively, unknown passengers could *themselves* be ruled out of shared journeys with fewer passengers (to maintain feelings of safety in numbers). However, this could lead to the exclusion of this group by limiting their access to certain journeys.

The need to share personal information also conflicts with previous suggestions for less digital interaction, as an SAV service with non-digital access methods would not be able to easily gather information about all passengers.

5.3.3 Secure navigation: To and from SAV

Women discussed their fear when waiting for and travelling to vehicles, suggesting that door-to-door SAV services should account for their security during these times.

The SAV app design in *Designing Autonomy for All* (pp. 19-20) includes a navigation feature to guide passengers to (Figure 26) and from (Figure 28) the SAV with a "safe mode" for quick access to security features.

On returning home, the app provides means to ensure passenger safety through a confirmation interaction (Figure 29) and a "follow me" feature for use on solo journeys (Figure 27), where the SAV provides lighting and monitoring until the passenger is safely inside. A similar home safe concept was suggested by Schuß et al. (2022) and is a current feature of safe navigation apps such as WalkSafe

(Chaperhome Ltd, 2024). For passengers wishing to keep their home addresses anonymous from other passengers, a feature to choose a drop-off point was also incorporated.

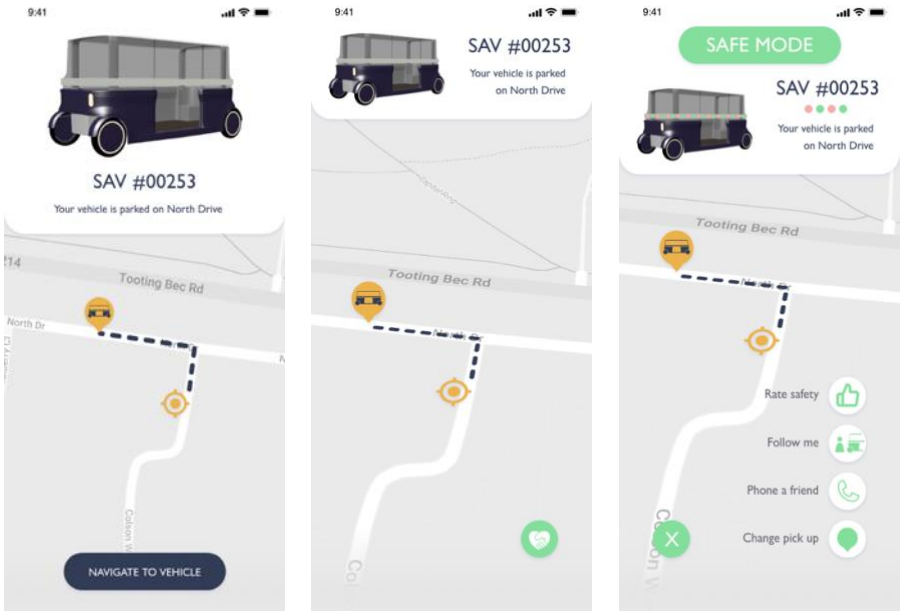

FIGURE 26 SECURE NAVIGATION TO VEHICLE IN SAV APP

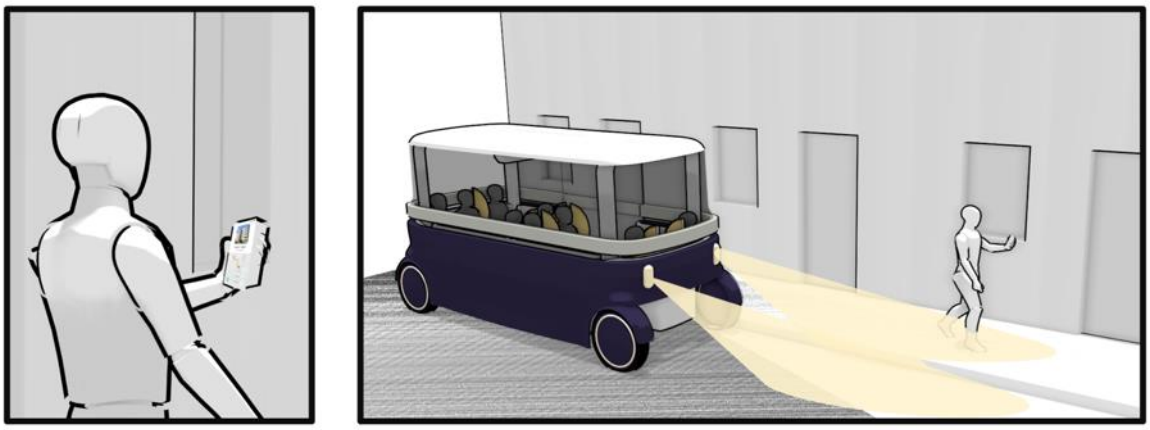

FIGURE 27 "FOLLOW ME" FUNCTION ENSURING PASSENGER ARRIVES SAFELY AT THEIR DOOR

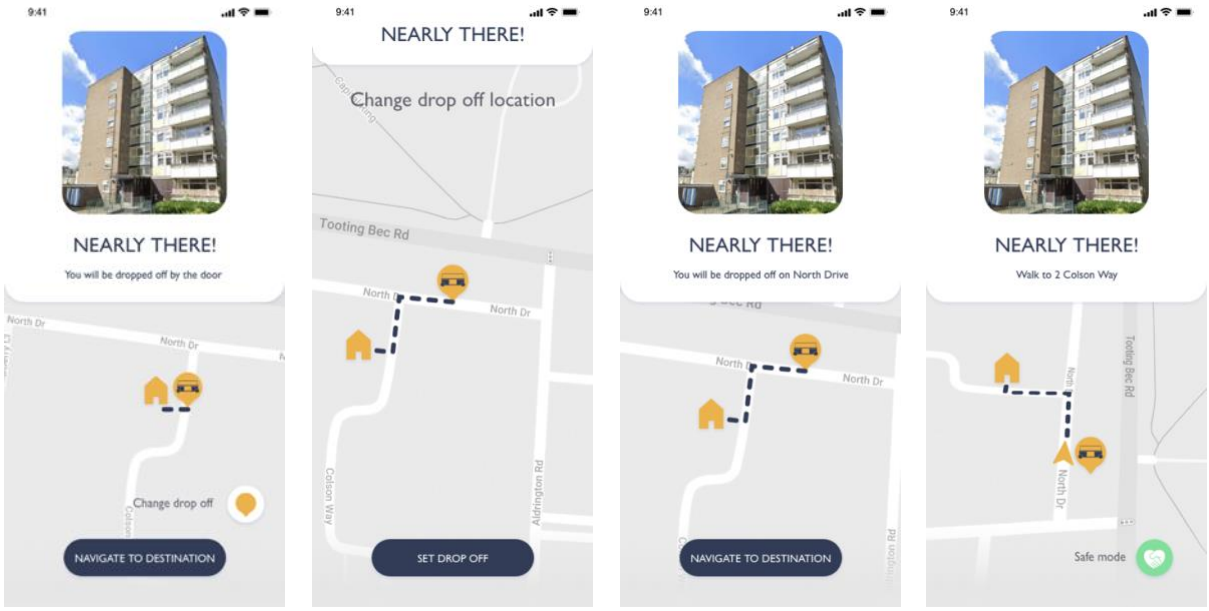

FIGURE 28 CHANGING DROP OFF LOCATION FOR SECURITY AND PRIVACY IN SAV APP

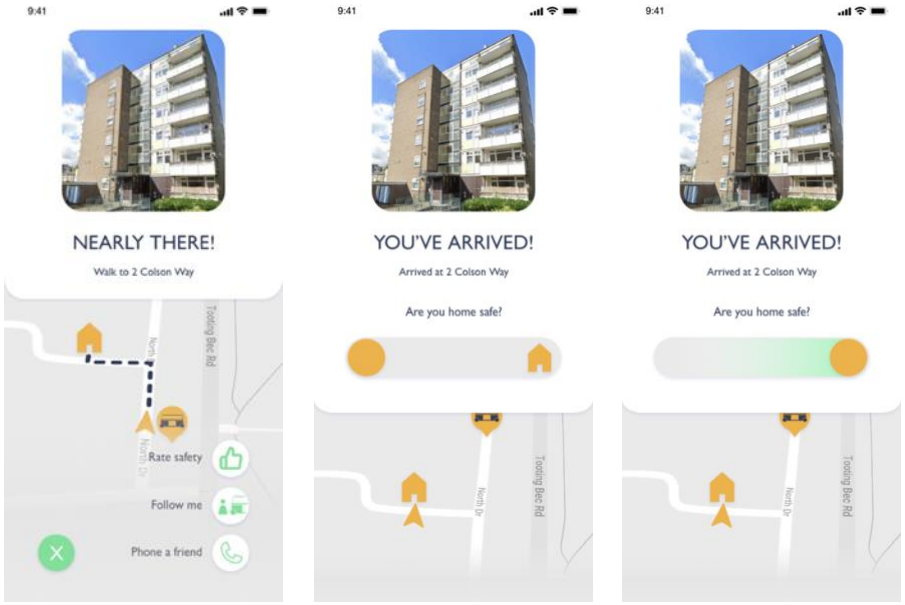

FIGURE 29 "HOME SAFE" FEATURE IN SAV APP

5.4 SAV EXTERIOR INTERFACES AND INTERACTIONS

Vehicle exterior human-machine interfaces (eHMIs) have been explored in the context of communication between SAVs and other road users, including disabled people. Although communication with non-passengers is outside the scope of this study, several eHMI functions have been identified as beneficial for excluded

passenger groups, including communicating vehicle availability and destinations for gesture-based hailing, as discussed above.

5.4.1 POSITIONING EHMIS

For the physical design of the SAV exterior, ensuring eHMI placement and size allows easy visibility is the most pertinent consideration. Roundtree et al. (2020) recommend that eHMIs for communicating SAVs' intent to other road users should be positioned by the vehicle's front bumper and wheels. However, when discussing eHMIs for identifying pre-booked vehicles, participants wanted the positioning to be at the top to ensure visibility above other vehicles. Figure 30 shows a mock-up from exploratory workshops based on P2's suggestion for a side-mounted display near the top to indicate his pre-booked SAV. In the concept inclusive SAV design presented in *Designing Autonomy for All*, eHMIs are positioned high on the front, rear, and door-side to ensure visibility.

FIGURE 30 WORKSHOP FACILITATOR POSITIONING FOAMBOARD EHMI MOCK-UP ACCORDING TO P2'S SUGGESTIONS

FIGURE 31 VISUALISATION OF INCLUSIVE SAV WITH SIDE EHMIS

5.4.2 *LOCATING AND IDENTIFYING SAV*

Locating a vehicle on the roadside is challenging in an SAV service, where identical vehicles are ubiquitous, particularly when identifying a specific pre-booked vehicle. This need was prominent in workshop discussions with visually impaired people, who require alternatives to visual identification, and women, who need prompt vehicle location to reduce waiting time in unsafe areas. As all passengers must locate and identify vehicles, inclusive SAVs should incorporate multiple exterior modes of identification to accommodate groups with different needs, such as hearing and visually impaired people. A combination of exterior audio, visual, and personal device-based interactions should be incorporated into inclusive SAV services to:

- Allow location of a pre-booked SAV on the roadside by visually impaired people.
- Allow prompt location of a pre-booked SAV on the roadside to reduce feelings of insecurity when waiting at the roadside.

Designing Autonomy for All (pp. 28-30) discusses design concepts for visual, audio, and vibrotactile means of indicating vehicle location and distinguishing pre-booked vehicles from others, utilising eHMIs, app interfaces, exterior audio information, and dedicated SAV-specific devices.

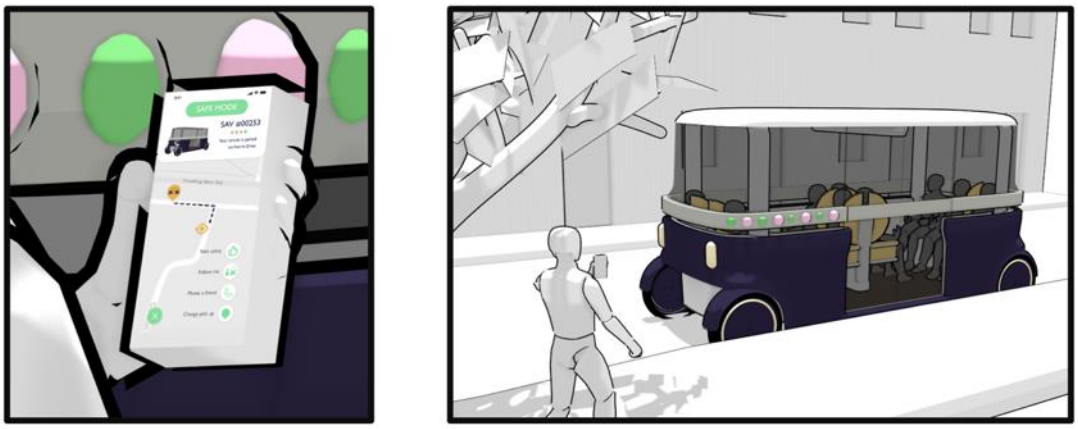

FIGURE 32 VEHICLE IDENTIFICATION BY COLOURED LIGHTING CONCEPT SUGGESTED IN WOMEN'S FOCUSED WORKSHOPS

FIGURE 33 VISUALISATION OF INCLUSIVE SAV DESIGN WITH FRONT EHMI SHOWING VEHICLE NUMBER AND COLOUR PATTERN

5.4.3 BOARDING: LOCATING AND INDICATING MOVING PARTS

As well as the need for guidance when locating vehicles on the streetside, visually impaired people may also need assistance when boarding SAVs. Workshop participants discussed the need to know the location and status of ramps, steps, and doors when boarding. To locate doors, interior audio was suggested, and audio and visual cues were proposed to indicate door and ramp movement. The concept SAV in *Designing Autonomy for All* (p. 31) incorporates clear visual features such as door-mounted eHMIs with bright, contrasting colours and bold symbols (e.g. to indicate door opening) alongside corresponding audio signals to aid visually impaired people when boarding.

5.5 ONBOARD INFORMATION AND INTERACTIONS

5.5.1 INTERIOR LAYOUT AND NAVIGATION INFORMATION

For visually impaired passengers, navigation inside SAVs presents a challenge. While passive physical features such as tactile flooring, surfaces, and colour contrast can assist (discussed in the following chapter), workshop participants suggested more active navigation information.

During workshops, refreshable tactile maps on vehicle exteriors were discussed to indicate seating availability and adaptable interior configurations, with a 3D printed mock-up presented to prompt discussions. However, participants discussed how visually impaired people can struggle with understanding tactile maps because of the difficulty in gauging the scale of the space. Having these interfaces outside the vehicle was also viewed negatively by some participants who disliked being outside longer than necessary. To provide live information about the positions of passengers and configurable components (e.g. folding seats), participants suggested that the vehicle could, instead, provide an audio description of the interior upon boarding.

> *'I'd wanna walk up the stairs and the vehicle would tell me, speaking "On the left you've got seats 1,2,3"' – V1P1*

As with other exclusion-specific interactions, tapping a smart travel card or journey validation could trigger these announcements for visually impaired people when boarding.

Interior layout information may also be communicated to visually impaired people before journeys through personal devices, including screen reader-compatible smartphone apps, text updates, or phone calls.

5.5.2 *Personal at-seat interfaces*

Onboard the vehicle, passengers' needs for information access and interactions must be met. Personal access to journey information is essential in SAV operating models in which passengers have different origins and destinations. However, several participants expressed concerns about retaining privacy of personal journey information (e.g. home address) and interactions (e.g. reporting of other passengers). While the privacy of such information and interactions could be achieved with a smartphone app, accessibility issues and some evidence of passenger preference for inbuilt interfaces (Oliveira et al., 2018) indicate the potential for SAVs with dedicated interior interfaces.

Many concepts for SAV interior interfaces use touchscreens as the main interaction method (Bhalearo et al., 2022; Eskandar et al., 2022; Park et al., 2023). Touchscreen interfaces present barriers for visually impaired people, particularly where screen-reader functionality is not provided, and can lead to interface complexity excluding those with disabilities affecting cognition and those with lower digital proficiency. Touchscreen interfaces can also require high accuracy when using controls, causing challenges for dexterity impaired people (as experienced by P4) and potential accuracy issues for all passengers due to vehicle motion (Salmon et al., 2011). Arfini et. al (2023) highlight the accessibility of input and output modes for SAV-based interfaces. Their table (Table 12) demonstrates how no single interface can be accessible to all disabled people.

Table 12 Different types of physical abilities and how they influence how users give and receive information through the interface (*the use of the interface could be limited according to the single agent's impartments) from *Design for Inclusivity in Driving Automation: Theoretical and Practical Challenges to Human-Machine Interactions and Interface Design (Arfini et al., 2023)*

Interface	Visual impaired	Hearing impaired	Speech impaired	Upper extremity impaired
Eye tracking		X	X	X
Gesture recognition	X	X	X	*
Voice recognition	X			X
Remote operator	X			X
Capacitive touchscreen		X	X	*

Physical button/ keyboard	*	X	X	*
Wired/ wireless connected mobile device	*	X	X	*
Display		X	X	X
Speaker	X		X	X
Braille reader	X	X	X	*
Touch-less haptic interface	X	X	X	*

As touchscreen-only interfaces cannot meet the needs of all groups, alternative means should enable the accessibility of interactions and information in audio, visual, and (where possible) tactile formats.

Designing Autonomy for All (pp. 32-35) discusses how an at-seat interface might combine tactile and physical controls usable by people with low strength and dexterity with customisable bimodal audio and visual outputs for the widest range of users. For wheelchair users unable to reach from their chair, the ability to control these interfaces by pairing personal devices and peripherals is also proposed.

Along with considerations for the personal interface's accessibility, participants discussed functions that might address needs related to their inclusion. While detailed design concepts for each function could not be created given the constraints of this project, a brief description of how at-seat interfaces might provide for these needs is provided in *Designing Autonomy for All* (p. 36)

5.5.3 PUBLIC INTERIOR INTERFACES

While most passenger journey information can be provided through personal interfaces, general information that is relevant to all passengers (e.g. route) may be provided via public interfaces. Multimodal information is essential for these interfaces, as visually impaired people face barriers in accessing public in-vehicle information due to their reliance on visual displays, and hearing impaired people cannot respond to audio alerts and notifications.

Disabled participants in research workshops discussed how public information and announcements help ensure that passengers engage in inclusive behaviours by not blocking spaces or occupying priority areas. While general announcements through onboard displays and speakers may address this, onboard cameras (needed for passenger security) and computer vision technology that enables the recognition of

people and items within the interior space could allow targeted announcements when obstructions are detected.

6 RESPOND: INCLUSIVE SAV VEHICLE DESIGN

6.1 INTRODUCTION

Perhaps the most urgent priority for improving inclusion in SAVs is the design of vehicle itself. A combination of automotive development lead times of several years (Bhise, 2017), imminent UK government legislation regarding automated vehicles (*Automated Vehicles Act*, 2024), and the expectation of the first non-trial automated transport services in the UK from 2027 (Zenzic, 2023) indicate that swift action is needed to ensure that SAVs are inclusive from the outset.

This chapter details the development of a single SAV design with multiple features designed in response to the inclusive SAV opportunities identified in Chapter 4. Applying multiple design concepts to one vehicle demonstrates how needs might be addressed in a real-world SAV design through inclusive engineering, exterior design, and interior design.

A more detailed discussion of the concepts designed to address these opportunities can be found in *Designing Autonomy for All.*

6.1.1 BASIC CONCEPT SAV PARAMETERS

Prior to developing inclusive vehicle design responses, parameters were fixed based on the common features of existing SAVs of a similar typology to those explored in this project. These early decisions mirror those made in the pre-program planning phase of vehicle development (Bhise, 2017) and are likely to form key criteria and constraints that must be adhered to by those involved in the design of future SAVs. The previously determined target occupancy of 8-12 seated passengers indicated that a shuttle-type SAV typology (Jones et al., 2023) would be most appropriate. Table 13 lists the dimensions and occupancies of similar vehicles. The concept SAV was designed with specifications similar to these vehicles, with target exterior dimensions of L=4800 mm, W=2100 mm, and H=2800 mm.

TABLE 13 SAV SHUTTLE DIMENSIONS BENCHMARKING

Vehicle	Dimensions + Occupancy (mm)	Source
Ohmio Lift	4700Lx2150Wx2740H 12 seated	(Marquordt, 2024)
Navya Autonom Shuttle	4750Lx2110Wx2650H 11 seated	(Navya, n.d.)

Holon Mover	4900Lx2350Wx2800H 10 seated	(beep, 2024)
Toyota e-Palette	5250Lx2070Wx2760H 8 seated (estimated from images). Quoted figure of 20 includes standing	(Toyota (GB) PLC, 2019)
WeRide Robobus	5500Lx2050Wx2650H 10 seated (depending on layout)	(Land Transport Guru, 2023)

6.2 INCLUSIVE SAV PLATFORM DESIGN

Before engaging in more detailed inclusive SAV design, it is essential to ensure that the platform upon which such designs are built is inclusive. Bhise's (2017) outline of a typical automotive product development process notes that high-level early decisions regarding vehicle concepts are often made in dialogue between designers and engineers to establish a feasible basis for further design. Bhise also describes how vehicle packaging engineers ensure that occupants, systems, and luggage can be suitably accommodated throughout the development process.

In this project, occupancy and luggage are considered within the vehicle interior layout design and are described subsequently. However, the packaging of key systems and structures that bodywork and interiors are built upon – sometimes called a "skateboard" or platform – has implications for SAV inclusivity, particularly regarding disabled passengers' boarding and movement. Therefore, developing a suitable platform design was a key component of the early design work. The key considerations for inclusive platform design are as follows:

- Reducing vehicle step-in height to make entry easier for disabled people
- Reducing ramp steepness/ allowing for level boarding to ensure efficient and independent entry for wheelchair users
- Reducing protrusions into the interior space to allow unobstructed movement and navigation

6.2.1 *DEVELOPMENT OF INCLUSIVE SAV PLATFORM DESIGN*

The development of the inclusive SAV platform aimed to minimise vehicle height at boarding, reducing ramp steepness and step-in height, which are key factors in providing inclusive boarding for disabled people. While inclusion was the priority, design practice also sought to balance other priorities for SAV packaging, including the efficient use of the vehicle footprint to maximise passenger capacity.

Determining the minimum floor height for a conventional SAV platform

Through discussions with packaging experts and benchmarking existing SAVs, the minimum floor height was determined to be ~270 mm, allowing a ground clearance of 130 mm and vehicle sill depth of 140 mm (as demonstrated in Holon's Mover (HOLON GmbH, n.d.)).

Understanding trade-offs between wheel size, floor height, and seat placement

Although the 270 mm floor height was feasible, a trade-off emerged between allowing lower floor heights and incorporating seating above the SAV wheelhouses (a common method of increasing passenger occupancy in a given vehicle footprint) as the higher position of seating above the wheelhouses requires a higher floor to provide a comfortable sitting height. This interaction between vehicle floor height, footprint/ occupancy, and wheelhouse size (dictated by wheel diameter) presented three potential outcomes:

Positioning seating between the axles: Resulting in reduced interior occupancy for the predetermined vehicle length.

Increasing floor height to allow seating above wheelhouses: Resulting in a high floor height for vehicles with larger wheels.

Reducing wheel size: This was determined to be the least impactful option, as larger wheels are often an aesthetic decision rather than a functional one.

Developing a concept kneeling suspension system

A wheel diameter of 650 mm was selected (per packaging expert recommendations); however, seating above the wheelhouses still required a relatively high floor compared to the target height of 270mm. To reduce boarding height, a kneeling air suspension system was conceptualised, which would allow the vehicle to lower without sacrificing interior space to the larger wheelhouses often required for such systems. By restricting vehicle kneeling operation to use in parked positions with straight wheels, this system limits additional wheelhouse height (needed to accommodate the wheel in its kneeled position) to the outside of the vehicle footprint, allowing space for lower seating in between.

Ensuring interior standing height

The overall interior height of the SAV was determined to ensure that passengers can walk through at standing height, thereby reducing challenges for mobility-impaired people.

Developing a parametric SAV platform design tool

A parametric design tool was developed to assist SAV designers by demonstrating the impact of wheel size, ground clearance, sill depth, kneeling suspension travel, and other parameters on step-in height and ramp length for inclusive SAVs.

A complete discussion of the inclusive SAV platform design process and details of the designs and tools developed can be found in *Designing Autonomy for All* (pp. 40-53).

6.2.2 *Proposed inclusive SAV platform design*

Figure 34 shows the dimensions of the final platform design (modelled in Shapr3D for dimensioned drawings (Shapr3D Zrt., 2024)) and demonstrates the kneeling suspension system concept, with a lowering height of 220 mm, allowing 20 mm under the vehicle when lowered. Figure 35 shows the ramp lengths required to achieve 1:12 gradients to the kerb height (125 mm) and ground.

The platform design addresses the initial inclusive design opportunities as follows:

Reducing vehicle step-in height to make entry easier for disabled people: With a narrow sill depth of 140 mm and a kneeling suspension system that lowers the vehicle near the road surface, the step-in height from a 125 mm kerb is 35 mm and from road-level is 160 mm.

Reducing ramp steepness/allowing for level boarding to ensure efficient and independent entry for wheelchair users: The low step-in height enables a 1:12 ramp to road-level that is short enough to be packaged within the vehicle width, beneath the vehicle floor.

Reducing protrusions into the interior space to allow unobstructed movement and navigation: The wheel diameter and wheelhouse design allow seating above the wheels and maximise the clear floor space for this vehicle length. Common SAV system packaging conventions are likely to be applied without encroaching on the interior floor space. The interior design of this floor space is detailed in the following section.

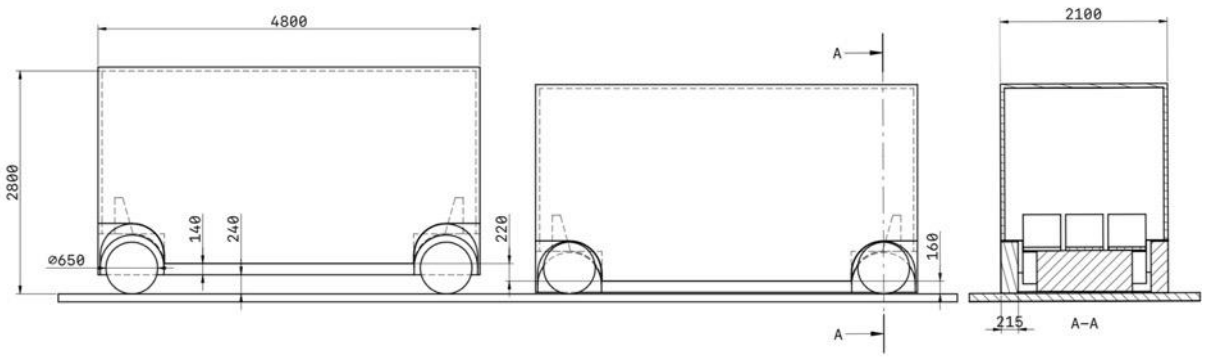

FIGURE 34 BASIC VEHICLE PACKAGE BASED ON BENCHMARKED OVERALL DIMENSIONS INCORPORATING PROPOSED KNEELING SUSPENSION SYSTEM.

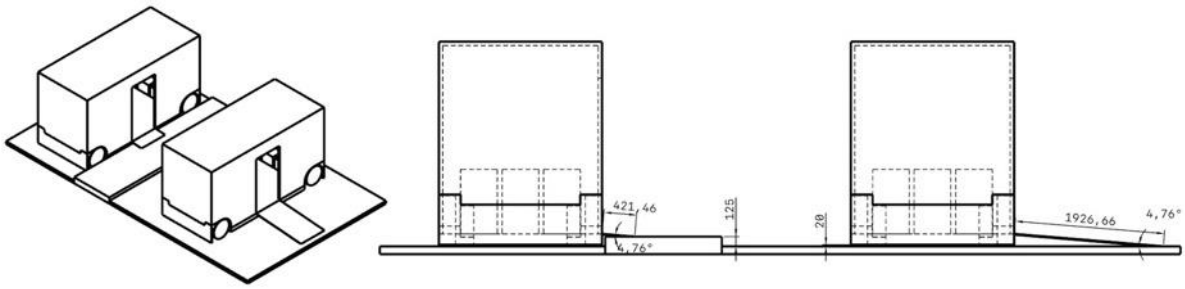

FIGURE 35 COMPARISON BETWEEN SAV RAMP LENGTHS TO KERB AND TO GROUND

6.3 INCLUSIVE SAV INTERIOR

Given that many points of exclusion occur within the interior space, its layout and features are key priorities in designing inclusive SAVs. Having determined an interior floor space of 3.25x1.9m according to the platform design above, this section describes how this space can be designed to address inclusivity considerations while meeting general preferences and constraints.

SAVs allow greater flexibility in interior design than traditional vehicles because of the open floor space afforded by an electric powertrain and varied seating arrangements without the need for a driver's seat. Many shuttle-type SAV designs incorporate U-shaped seating around a nearside entry point. These designs often include folding seats to create space for wheelchair users. A selection of SAV layouts is shown in Figure 36. Sideways-facing seating allows greater interior space utilisation for standing passengers but can increase the risk of motion sickness (Salter et al., 2019). Shuttle-type SAVs rarely use rows of seating, with WeRide's Robobus being a notable exception (Land Transport Guru, 2023). Perhaps because of their current use in trials and proposed use in public transport contexts, the interiors of shuttle-type SAVs tend to be utilitarian. Some additional functionality is added through tables in WeRide's Robobus(Land Transport Guru, 2023)and Holon's Mover(beep, 2024), and inclusion is partially considered with grab handles and rails in many designs.

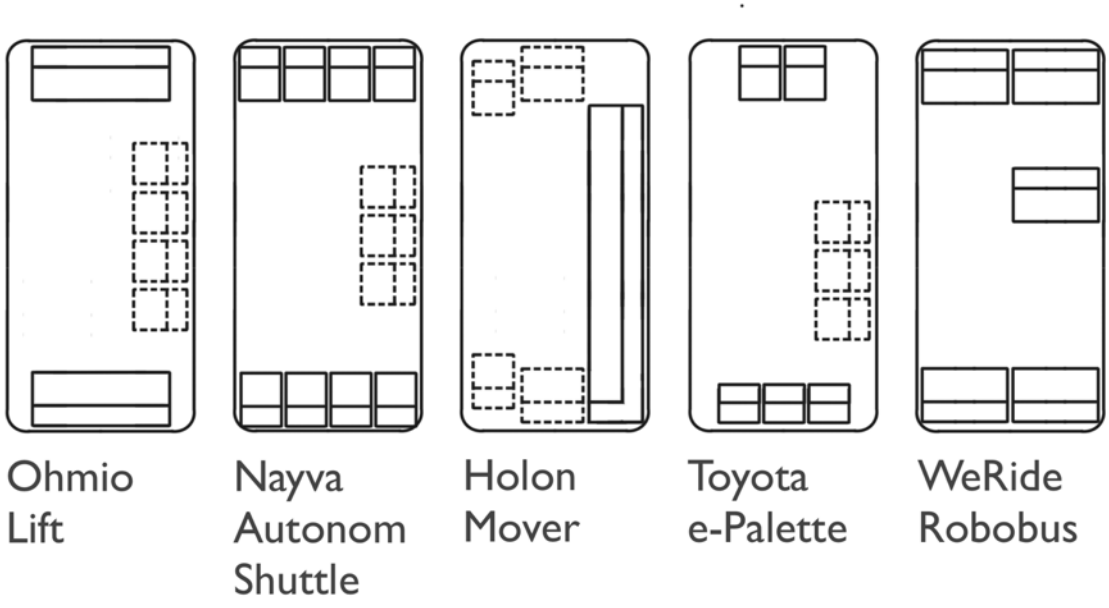

FIGURE 36 INTERIOR LAYOUTS OF EXISTING SAV DESIGNS

SAV concept designs by automotive manufacturers and consultancies tend to offer more developed interiors with features including storage for umbrellas and bikes, as in PriestmanGoode's New Car for London (PriestmanGoode, 2024), luggage racks, as in Renault's EZ-GO (Groupe Renault, 2018), and passenger privacy, lighting, and interfaces, as in Seymourpowell's Quarter Car (Seymourpowell, 2024). These concepts are typically based on taxi-like vehicle platforms that would not serve all passengers' needs (particularly wheelchair users), and such design attention rarely extends to larger vehicles, such as those explored in this project. Given the compelling passenger experience these concepts communicate, smaller vehicles with less potential for inclusion are at risk of becoming the norm, as evidenced by recent announcements of two-seat autonomous taxis from Rimac and Tesla (Hawkins, 2024; Tesla, 2024). There is an opportunity in the interior design of shuttle-type SAVs to meet the needs of excluded passengers and create a space that is equally considered to those found in these concepts. The SAV interior design responses explored in the following section seek to ensure that basic elements, such as layout and seating, allow for inclusion, while considering how additional features might improve the experience for excluded groups and create a more compelling inclusive SAV interior design.

6.3.1 *WHEELCHAIR SPACE*

As much of an SAV's interior space is needed for wheelchair occupancy and manoeuvring, it is useful to consider the wheelchair space location and design before making other interior decisions. The process for determining a suitable SAV wheelchair space is detailed in *Designing Autonomy for All* (pp. 58-67) with the key decisions summarised below.

Wheelchair space dimensions

A wheelchair space of 1010 mm × 1710 mm was selected to accommodate all wheelchair users from Bharathy and D'Souza's (2018) sample.

Wheelchair restraint system

Incorporating UDIG (Hobson and Van Roosmalen, 2007), a universal, automatically operable restraint system to eliminate driver-operated restraints and enable independent service use by wheelchair users.

Wheelchair space orientation and position

A forward-facing wheelchair space on the vehicle's offside, adjacent to the door, was determined to be the most suitable for ease of manoeuvring (based on a focused workshop co-designing an interior layout with a manual wheelchair user), while allowing other passengers to easily access seats.

Adaptable seating designs

To provide a wheelchair space without reducing passenger occupancy, two folding seating designs were developed. Reversible seating at the front maximises the manoeuvring space and provides rear-facing seating for wheelchair users' companions, forward-facing seating for other passengers and a low-profile folded position to extend the length of the wheelchair space if necessary. Folding seating in the wheelchair space ensures maximum passenger capacity when no wheelchair user is onboard, but is designed to fold by default, blending into the interior and encouraging passengers to occupy other seats first.

6.3.2 *SEATING LAYOUTS FOR SOCIALISING AND COMMUNICATION*

Although ensuring a suitable wheelchair space position and size should be the starting point for an inclusive SAV interior design, other inclusive design opportunities are also pertinent and must be addressed in the interior layout.

While rear-facing seating is not preferred by many passengers, providing seats that face each other is essential for British Sign Language (BSL) and lip-reading communication between hearing-impaired people and their companions (as discussed by P2). Some participants discussed wanting to face other passengers to socialise. The two reversible seats developed for the wheelchair space provide an adaptable front and middle seating section for passengers to choose their facing direction and travel orientations.

6.3.3 *LAYOUT AND DIVISION OF INTERIOR SPACE TO MEET SECURITY NEEDS*

During workshops with women, discussions explored the SAV's interior space including the potential for division and layouts which promote security. Previous studies have suggested that dividing the interior space between passengers can improve their sense of security when using an SAV (Asha et al., 2024); however, such research is limited to discussions of standard automotive layouts rather than exploring how division might be incorporated into the overall interior design.

Concept SAV designs have addressed division and privacy with Layer's Joyn and SeymourPowell's Quarter Car concepts utilising movable dividers between seats. While these concepts present compelling solutions for privacy and security when sharing an SAV, they demonstrate the potential pitfalls of focusing only on one area of inclusion, with their emphasis on interior space division reducing the potential for wider inclusion, notably through the absence of a wheelchair space.

To ensure that security and privacy needs are addressed alongside other exclusion-related needs, insights from workshops with women have been applied to the vehicle layout in ways that allow inclusive innovations to remain functional and reduce unnecessary obstacles that could impact interior navigability for visually impaired people.

The following section discusses interior space design based on preferences suggested by women in focused workshops, including two workshops where layouts and features were evaluated and iterated by participants using Gravity Sketch VR (Gravity Sketch, 2024).

In the focused workshops, women tested a basic SAV layout using VR and suggested ways to improve safety by providing separation between passengers, including tables between facing seats, armrests and head-height dividers between adjacent seats, and large, semi-transparent screens separating the vehicle into sections. These ideas were tested onboard the SAV mock-up and sketched in the VR vehicle during the session by the researcher and participants. Figure 37 shows a selection of these ideas along with the initial interior layout presented to the

participants.

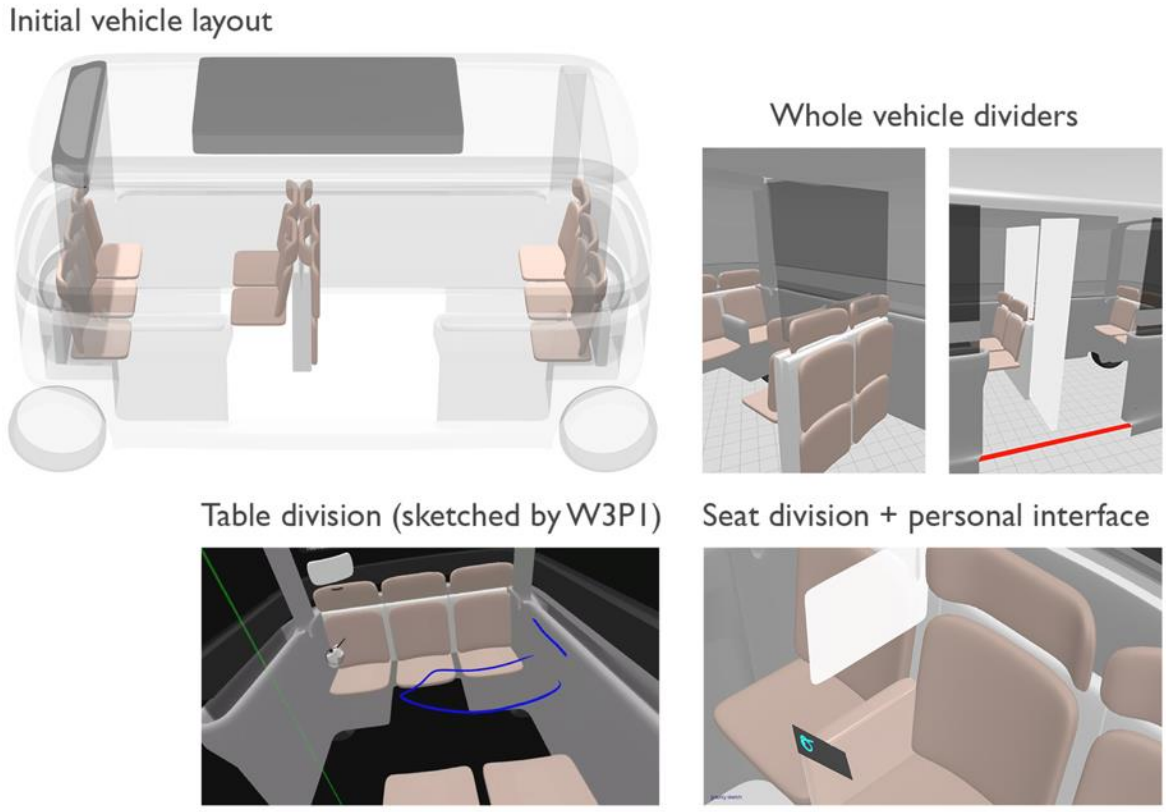

FIGURE 37 IMAGES FROM WOMEN'S FOCUSED WORKSHOPS SHOWING PARTICIPANTS' IDEAS AND SKETCHES INSIDE THE VIRTUAL REALITY SAV

In response to insights from the focused workshops, a more developed, adaptable vehicle interior design was created using Gravity Sketch. This interior was designed to offer multiple options for at-seat and whole-vehicle divisions, depending on the scenario in which it is used. As women had previously discussed the impact that vehicle occupancy has on their perception of safety, the subsequent focused workshops presented the interior in three scenarios representing low, medium, and high occupancy, with manikins included to help participants visualise the use of space and the presence of other passengers. Each scenario presented the vehicle in a different configuration (Figure 38):

- Scenario 1, with one fellow passenger, incorporated a dividing screen completely separating the vehicle into two halves, each accessible through its own door.
- Scenario 2, with five other passengers, had a more open layout with folded unoccupied seating, a head-height divider, and an armrest.

- Scenario 3, a full vehicle with nine other passengers, demonstrated the use of the dividers and headrests between all seats.

FIGURE 38 VR SAV LAYOUTS FOR 3 SCENARIOS IN WOMEN'S SECOND FOCUSED WORKSHOP

Detailed discussions of designs addressing security needs are included in *Designing Autonomy for All* (pp. 70-73) with further details of the following key areas:

Seating layout

Forward-facing seating was maximised to reduce discomfort from eye contact with passengers (seven forward-facing seats and three rear-facing seats). Seating rows also provide distinct interior sections for enhanced privacy.

Whole vehicle division

A semi-transparent screen and overhead luggage racks separate the interior space while maintaining the visibility needed for situational awareness to improve passenger security.

At-seat division

Individual seats (i.e. not bench seats), rigid and textile dividers between seats, and armrests are incorporated to improve security by providing privacy and separation from adjacent passengers.

6.3.4 *INTERIOR GUIDANCE AND SUPPORT*

Interior space navigation presents challenges for visually and mobility impaired people. The SAV seating layout described above may already enable easier navigation with four rows accessible from a clear aisle at the vehicle's nearside. In this layout, two nearside front and rear seats are also directly accessible without the need to move interior components or navigate around fellow passengers. These seats may serve as priority seating.

While the interior layout might improve ease of navigation, visually and mobility impaired workshop participants discussed how additional physical features could offer further improvements. The features incorporated into the inclusive SAV design include:

Guiderails and grab handles
Horizontal guide rails allow visually impaired people to follow them through the interior to their seat, and vertical grab handles provide support for mobility impaired people moving through the vehicle.

Tactile surfaces
Guiderails incorporate a directional chevron-shaped texture to indicate the vehicle door direction from the passenger seats and a different lozenge-shaped texture to indicate when they are close to the door.

Tactile flooring
Raised lines on the floor can be followed by visually impaired people using a cane to navigate, indicating proximity to seats, and the boundaries of walkways and wheelchair spaces.

High contrast interior colouring
Contrasting colours for different interior areas and features make it easier for visually impaired people to understand the vehicle layout, with contrasting wall, floor, and seat colours and bright highlights for key touchpoints, including guide rails.

Further details of these designs can be found in *Designing Autonomy for All* (pp. 76 & 77).

6.3.5 *INTERIOR STORAGE/ LUGGAGE SPACE*

Participants across the workshops discussed needs relating to luggage storage in SAVs. Incorporating dedicated storage presents challenges for the effective use of vehicle space, particularly when storage competes with passenger occupancy.

Without dedicated luggage space, wheelchair spaces and aisles are at risk of obstruction.

Designing Autonomy for All (pp. 78 & 79) details the design of luggage spaces which are usable by disabled people and reduce obstruction, including:

Overhead luggage storage

Providing space for passengers without strength or mobility impairments to store luggage without obstructing the floor space.

Folding seating luggage storage

Offering low-level storage for mobility impaired people and storage next to seats for visually impaired people who wish to keep possessions secure through physical contact.

Floor-located luggage storage

The space beneath the folding seating serves as storage for seated passengers' belongings. A marked space under the reversible seating indicates its use for luggage when the seats are unoccupied, ensuring available floor space for large items while keeping the wheelchair space unobstructed.

6.4 INCLUSIVE SAV EXTERIOR

The exterior of an SAV presents fewer opportunities for inclusion, given that excluded passengers' interactions with the exterior of the SAV are limited to a short time when boarding. The informational elements of the vehicle exterior have already been discussed in the previous chapter, and the location of doors and the use of ramps have been discussed above.

One remaining element of the vehicle exterior that can improve inclusion is the design of physical guidance and support that can allow visually impaired people to navigate from the outside of the vehicle to its doors and provide support to mobility impaired people when stepping into the vehicle. As with the solutions discussed for improving navigation and support inside the vehicle, the inclusive SAV concept presented in *Designing Autonomy for All* (pp. 74-75, 82-83) details an exterior guide rail that wraps around the outside of the vehicle. Visually impaired passengers who arrive at the SAV can locate this guide rail at any point on the vehicle and feel a directional texture (chevron-shaped arrows) to determine the direction of the door

before following the rail towards the door and into the vehicle, where it connects with the interior guide rail.

7 CONCLUSION

7.1 INCLUSIVE DESIGN FOR TRANSPORT FRAMEWORK: REVISITED AND REVISED

In Chapter 2, an inclusive design for transport framework was presented which defined and summarised the following:

- The groups which are affected by transport exclusion.
- The levels at which people experience exclusion within a transport service.
- The types of exclusion that people may experience.

This framework provided a strong starting point for the research and design activities described in this thesis, ensuring a broad exploration of needs across different excluded groups, as discussed in Chapter 4, and leading to a universal approach to the design practice in Chapters 5 and 6 which demonstrated how multiple needs might be addressed in SAV design.

While the framework's utility in initially planning and scoping this research is clear, ongoing reflections through subsequent research and design activities has led to developments which provide a more complete picture of how exclusion occurs and how it might be addressed. Several revisions to this framework are described below.

7.1.1 LEVELS OF EXCLUSION

The levels of exclusion in the initial framework aimed to expand inclusive design beyond usability, considering transport availability and experiential factors for excluded groups. Four main observations have informed a reconsidered approach to these levels.

Experience, usability, and availability are not easily delineated

Research workshops have revealed that points of exclusion are often more complex than suggested in the literature. Individual barriers cannot be neatly categorised into the three levels, with personal and environmental contexts causing the same exclusion to present across multiple levels. Disabled participants noted how the variable nature of some conditions can cause barriers to shift from minor frustrations on a good day to major obstacles on a bad one. Similarly, usability barriers that might be overcome by using an alternative mode of transport can become availability barriers in areas where these alternatives are lacking.

Severity of exclusion is independent of the three levels

While the three levels were intended to show varying degrees of exclusion and promote design beyond usability, the ordering does not account for cases where barriers that might best be described as experiential can cause significant exclusion. This is evident when considering the security needs of women using SAVs. Although fear caused by poor security is experiential in nature, this barrier severely impacts women's journeys and should not be considered less severe.

Inclusion drives experience

When discussing experience-related 'nice to have' features in workshops, participants were reluctant to spend time on such topics. Discussions prompting more frivolous ideation were often steered back to pragmatic matters by participants prioritising the more severe barriers they might face. Such discussions demonstrated that for many excluded groups their experience is often primarily driven by their level of inclusion. Engaging these groups in playful design explorations might be more effective once designers demonstrate that their essential needs will be addressed.

Experience preferences and priorities are varied and often independent of exclusion

Although members of excluded groups prioritise inclusion, their preferences for pleasant features and aesthetics should still be considered in inclusive transport design. Throughout this research, discussions of desired experiential aspects of a journey have demonstrated that individuals' preferences are varied and often independent of exclusion, reflecting more general diversity in taste and priorities.

For designers, inclusive experiential design may largely be addressed through a more general approach to making such decisions according to the preferences of the general population, while ensuring that these designs are equitably accessible and enjoyable for excluded groups.

While this approach removes the (somewhat patronising) assumption that excluded groups' experiential preferences should be distinct from those of the general population, such design decisions must still consider their needs to avoid conflicts with inclusion priorities. For example, colour choices must maintain the contrast needed by visually impaired people.

Although making assumptions about the homogeneity of the experiential preferences of excluded groups can be unhelpful, there may be certain characteristics of such groups that impact the ways they experience the world and the ways designers can create pleasant experiences for them. As more severe issues of exclusion are addressed, co-design with excluded groups may reveal such areas, for example, providing soundscapes for visually impaired people or designing sensory experiences for neurodivergent passengers.

Levels of exclusion: revised

To better describe transport exclusion levels, the revised framework utilises a spectrum of severity rather than defined categories of exclusion. This spectrum considers an individual's journey, allowing for severity to be assessed based on contextual factors and intersectionality. Levels of this spectrum are described by statements indicating how passengers might experience particular journeys.

Level 3 – Complete exclusion

'I cannot/will not make the journey due to exclusion'

Level 2 – Moderate – severe exclusion

'I will make the journey but only with assistance' (for those for whom assistance wouldn't typically be required for other daily tasks)

'I will make the journey but with additional cost or time than other passengers'

'I will make the journey, but it feels physically, mentally, or emotionally uncomfortable'

Level 1 – Mild exclusion/ Inequity

'I will make the journey, but I will not be able to access the same additional features and services as other passengers'

'I will make the journey, but it is not as enjoyable for me as it is for other passengers'

Level 0 – Inclusion

'I will make the journey and enjoy it.'

As with the original levels, these exclusion levels prompt stakeholders to consider that providing basic journey access does not constitute inclusive transport. Until excluded

groups can travel with equal convenience, cost, and enjoyment, exclusion will persist. While Level 0 is the goal, the levels help prioritise barriers, with Level 3 requiring the most urgent interventions.

The revised levels are also mode- and service-type-agnostic to accommodate the different areas in which users of the framework might have influence.

For those overseeing entire transport networks, such as local governments, the levels can assess multimodal journeys and integrated networks. Here, Level 3 may be less frequent because of multiple mode options, but Level 2 considerations may be more pertinent, for example, the cost implications of a taxi/private hire vehicle being the only available mode.

For those evaluating exclusion in a single service, such as private transport operators, the levels can be used to investigate specific journey scenarios and identify how the service might cause exclusion. For narrower scopes, Level 3 exclusion may be more common, as alternative modes would not be considered. If the transport service is intended as part of an integrated multimodal network, Level 3 exclusion may not indicate complete exclusion from all potential journey means. However, for a single transport service aiming to provide for all transport needs and replace alternatives, as SAV services may seek to do, Level 3 exclusion might have more severe consequences, and ensuring the inclusion of the service becomes more critical. Additionally, where such services might replace existing ones, the severity of Level 3 exclusion increases if new services do not maintain at least the same level of inclusion.

For those considering exclusion in vehicle design, such as manufacturers, the levels may evaluate general vehicle use, with less focus on service contexts such as availability. Here, Level 3 exclusion would stem from features of the vehicle that may render it unusable for certain excluded groups.

Prioritising exclusion

Considering the severity of exclusion helps determine the priorities for inclusive transport development. Another key dimension is the occurrence of exclusion, which is the number of individual journeys likely to be impacted by a given barrier.

The occurrence of an excluding barrier is related to the number of people experiencing it and the proportion of their journeys that it impacts. When varying

severity levels exist for an exclusion due to personal contexts and external factors, these different severity levels will have different occurrence rates. Higher severity levels may typically have lower occurrences, with fewer people experiencing extreme exclusion and fewer journeys featuring multiple aggravating factors.

By understanding the most severe and common exclusions, stakeholders can identify areas to prioritise for inclusive development. While quantifying severity and occurrence would aid prioritisation, the complexity of exclusion makes it challenging to capture the occurrence across the range of severity. Simpler estimates may be made based on affected groups, their size and journey numbers, and general exclusion frequency (e.g. every journey, majority of journeys, minority of journeys). Although stakeholders may lack resources for quantitative prioritisation approaches, considering the relative severity and occurrence of exclusions using available information enables a more informed understanding of priorities in addressing exclusion.

7.1.2 TYPES OF TRANSPORT EXCLUSION

The transport exclusion types described in the original framework were validated throughout the project, with barriers generally relating to physical, information & interactions, psychological, interpersonal, or service exclusion. However, when engaging in co-design activities, these exclusion types, while valuable for describing experiences, proved to be less practical when considering solutions. For these more pragmatic purposes, it is necessary to examine the factors influencing exclusion to inform inclusive design and development.

While analysing barriers identified in research, determining an exclusion type from the framework proved difficult if the individual's experience of the barrier fit one category, but the cause of the barrier appeared to relate to another. This was particularly notable when the participants discussed the absence of features that were essential for their exclusion. For example, the absence of staff to deploy a ramp for wheelchair users boarding trains might appear as service exclusion caused by poor staffing levels. However, boarding a train is related to passengers' physical needs and while it could be addressed through staffing improvements, other solutions, such as an automatic ramp, may also prove effective. In this case, the need for staff would be irrelevant, but the physical need to board would remain.

To consider factors influencing exclusion alongside observable causes, the revised framework presents *areas influencing transport exclusion*. These areas are psychology, other people, information & interactions, physical, and service. Each area has a corresponding exclusion type from the original framework, demonstrating how each might directly result in exclusion within its corresponding exclusion type. However, each area may also be identified and linked as the cause of exclusion observed across any of the five types of exclusion. Similarly, interventions addressing a barrier observed as one type of exclusion might be identified across any of the five areas.

Using this structure, one can describe observed exclusion, trace influencing factors, and identify suitable areas for inclusive interventions. This approach shows how exclusions belonging to difficult-to-influence types, such as psychological and interpersonal exclusion, can be addressed through other areas. For example, exclusion, often presenting as psychological (e.g. fear), can be partially addressed through interior space layout, owing to how physical layout and passenger positioning influence security.

The revised approach to exclusion types and areas of influence better describes the complexity of exclusion while allowing practical prioritisation of inclusive design opportunities. By understanding how different areas influence exclusion, focus areas can be identified that align with individual or organisational capabilities. For example, an interior designer at an automotive OEM creating an inclusive SAV could identify points of exclusion linked to the physical area which are more likely to be addressed through design interventions.

7.1.3 THE REVISED INCLUSIVE DESIGN FOR TRANSPORT FRAMEWORK

The final revised framework incorporates areas influencing transport exclusion, showing how different stakeholders, including designers, might influence inclusion across these areas and how inclusion might be prioritised according to its severity and occurrence.

Using the revised framework

Throughout this PhD project, a key challenge has been deciding how to focus research and design work as the project moved from broad needs exploration to targeted design practice. This challenge was heightened by the limitations of a

single designer/researcher in fully exploring exclusion or addressing all potential inclusive solutions in the design process.

In real-world projects, decisions should be made based on the impact of exclusion and the organisation's ability to address it. To aid decision-making, the revised framework is structured in five stages according to questions that may help select impactful exclusions likely to be successfully addressed by the individual/organisation seeking to improve the inclusivity of transport. These stages are illustrated in Figure 39.

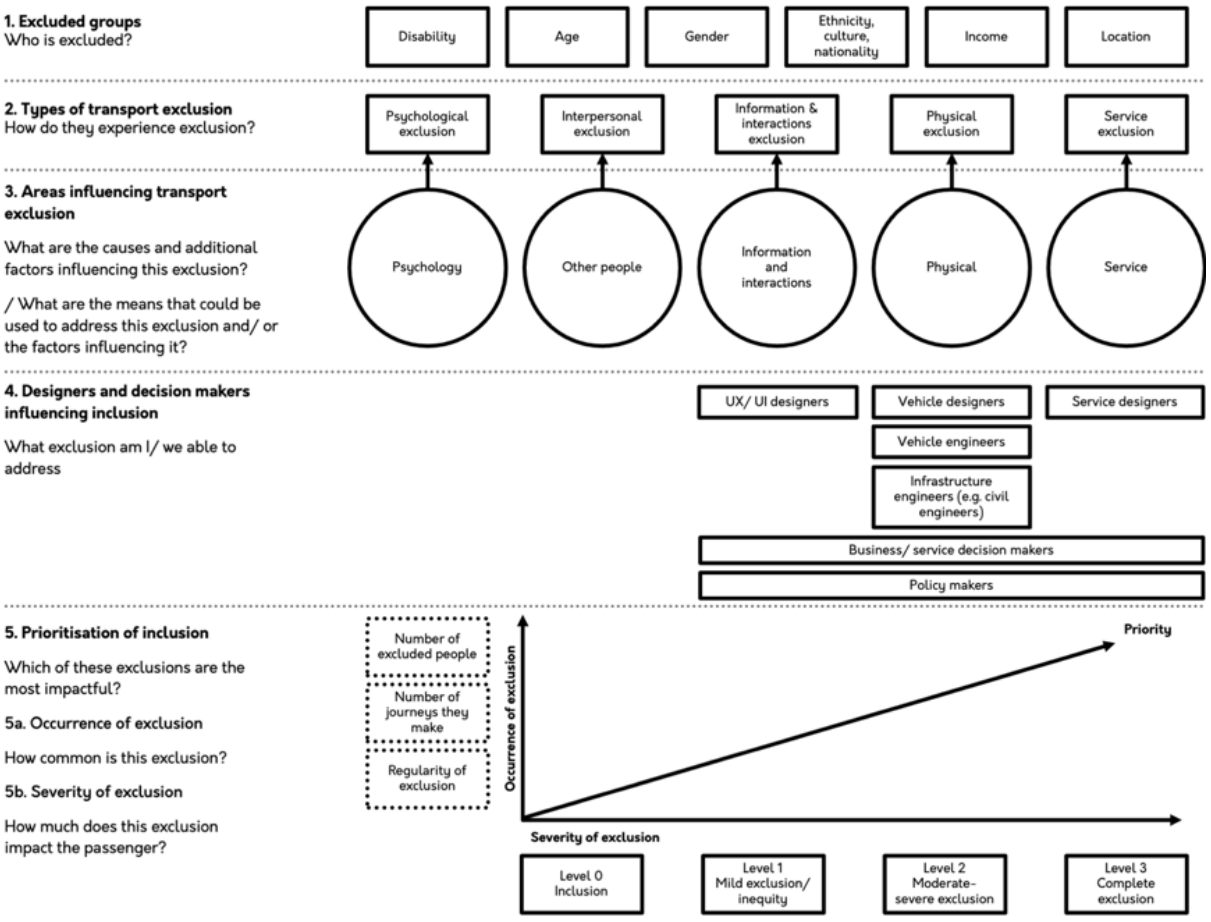

FIGURE 39 THE REVISED INCLUSIVE DESIGN FOR TRANSPORT FRAMEWORK

To use the framework, stakeholders can progress through each stage as follows (a hypothetical example is illustrated in Figure 40):

Excluded groups: *Who is excluded?* Research is conducted to understand which groups face exclusion from the six types of excluded groups. While exploring all

exclusions is ideal, decisions will likely be made to limit the selection of groups at this point.

Types of transport exclusion: *How do they experience transport exclusion?* Research identifies specific needs and barriers experienced by each excluded group. The five types of exclusion inform this research, ensure complete consideration of all exclusion, and categorise identified barriers.

Areas influencing transport exclusion: *What causes this exclusion and what could address it?* Influences, causes, and potential solutions are identified for each need/barrier and categorised by area of influence.

Designers and decision-makers influencing inclusion: *What exclusion can I/we address?* Based on stakeholder expertise and capabilities, the identified exclusions can be narrowed to relevant areas of influence. If stakeholders can only impact one area, Stage 3 research could focus on identifying influences relevant to that area.

Prioritisation of inclusion: *Which exclusions are most impactful?* When addressable exclusions are too numerous, stakeholders prioritise focus areas based on the occurrence and severity of exclusion. The sophistication of this process might range from formal scoring using statistics and survey data, to more subjective discussions about occurrence and impact. Figure 40 shows one way to map and prioritise opportunities by plotting them according to their level of occurrence and severity.

Limitations of the revised framework

The revised framework provides a detailed overview of exclusion with a more practical use case in scoping inclusive transport projects for maximum impact. However, its use does not extend to the specifics of the design process itself because of the variety of design and innovation approaches that might be applied to address different challenges.

While methods may differ, the ongoing involvement of excluded groups in research, ideation, evaluation, and iteration should remain a key component throughout any development. The methods used in this project demonstrate how human-centred co-design processes can be used for vehicle design and journey-wide service, information, and interaction design.

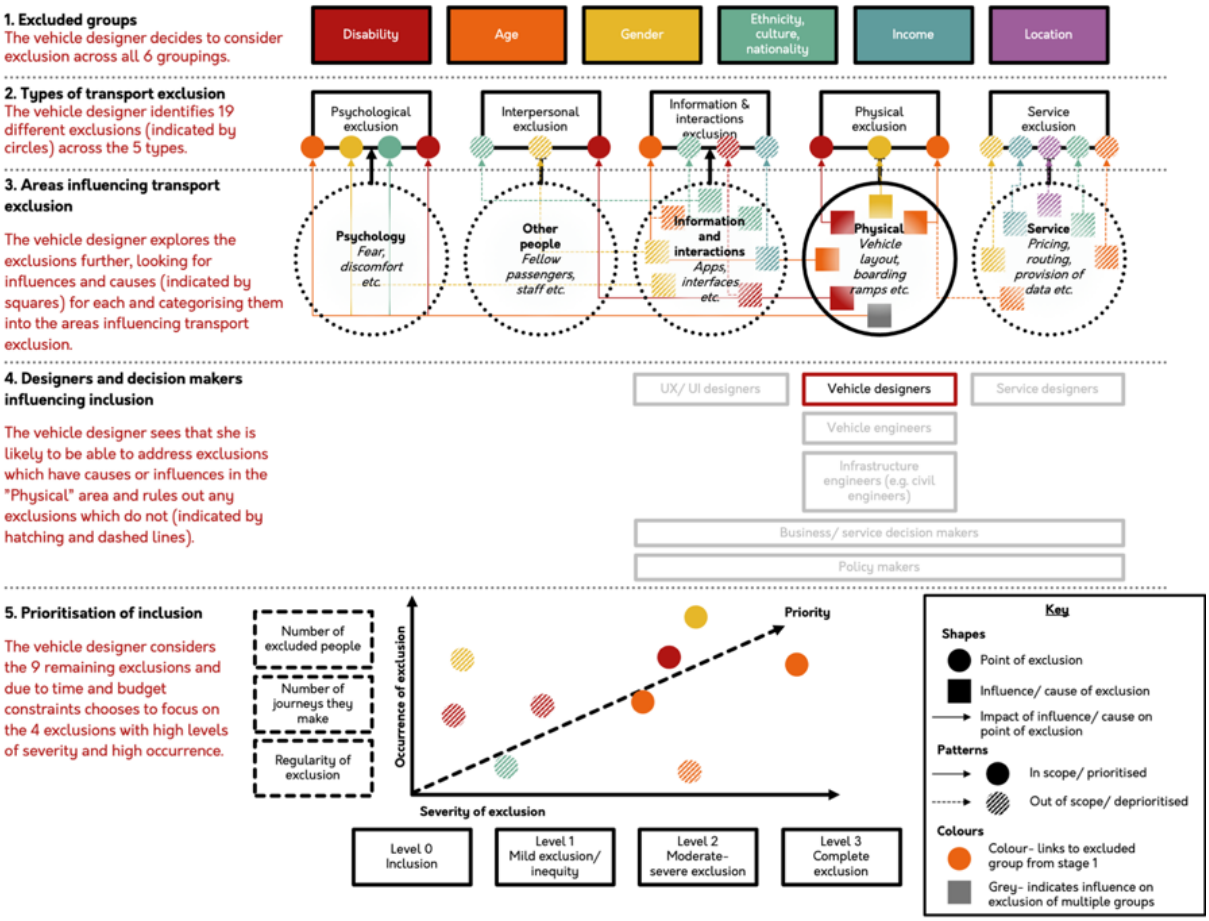

FIGURE 40 A HYPOTHETICAL EXAMPLE OF A VEHICLE DESIGNER'S USE OF THE INCLUSIVE DESIGN FOR TRANSPORT FRAMEWORK FOR PROJECT SCOPING

7.2 INFLUENCING INCLUSIVE DESIGN IN THE AUTOMOTIVE AND TRANSPORT SECTOR

This project explored transport exclusion, identified SAV-related barriers, and developed design concepts to address these barriers. The disruptive potential of SAV services creates an urgent need for further inclusive design development prior to their widespread introduction. While academic research continues, much responsibility for improving inclusion lies with stakeholders outside academia. Researchers must consider effective dissemination and ways to remove barriers to inclusion in commercial contexts. The following discussion examines the results of research with automotive and transport industry professionals including an industry questionnaire (N=34) and a focus group with an automotive OEM's design team (N=9) (detailed in Chapter 3) to understand the state of inclusive practice in the automotive and transport sectors and how inclusive design research findings, such as those presented in this thesis, might be best shared with the industry.

7.2.1 CURRENT ATTITUDES AND ACTIVITY RELATED TO INCLUSION

The questionnaire examined industry professionals' views on inclusion and current inclusive design activities. Likert-style questions assessed the respondents' views on the needs of excluded groups, areas requiring inclusion, and vehicle types requiring inclusive design input.

Regarding the consideration of excluded groups in the development process, respondents prioritised those with physical requirements and larger populations (Table 14). Groups less likely to face physical or information & interactions-related exclusion were of lower priority. While the desire to meet excluded groups' needs is encouraging, actual consideration of needs was lower (Table 15), especially for disability-related needs.

When examining areas of vehicle development that should engage in inclusive practice, respondents considered functionality-focused disciplines to be more important for inclusion than aesthetic-driven ones (Table 16).

For transport modes, public and service-based modes were seen to require more urgent inclusion than private, personal, or work-related vehicles (Table 17). This may reflect the universal nature of transport services and the view that private vehicles can be designed for narrower target groups and only bought by those for whom they are suitable.

These results show industry professionals' willingness to address the physical needs of excluded groups through practical interventions. The perceived difference in inclusivity obligations between those designing public and private vehicles suggests a barrier to inclusive design in private vehicles. As the design and manufacture of SAVs may be closer to that of cars than other traditional public transport vehicles, car manufacturers may ultimately be responsible for developing these vehicles. Therefore, it may be necessary to ensure that those working at these manufacturers are suitably prepared to give greater consideration to inclusion when designing SAVs.

TABLE 14 RESULTS FOR Q4 'THE NEEDS OF THE FOLLOWING GROUPS SHOULD BE SPECIFICALLY ADDRESSED IN THE DESIGN AND DEVELOPMENT OF VEHICLES'

The needs of the following groups should be specifically addressed in the design and development of vehicles	Avg. score (Strongly disagree – strongly agree, 1-5 Likert-style scale)
Older people	4.3

Children	4.1
Disabled people	4.4
Women	4.0
Ethnic minorities	3.5
People in low income households	3.5
People living in rural communities	3.7

TABLE 15 RESULTS FOR Q7 'IN MY DEPARTMENT, THE NEEDS OF THE FOLLOWING GROUPS ARE SPECIFICALLY ADDRESSED'

In my department, the needs of the following groups are specifically addressed	Avg. score (Strongly disagree – strongly agree, 1-5 Likert-style scale)
Older people	3.4
Children	3.2
Disabled people	3.0
Women	3.3
Ethnic minorities	2.9
People in low income households	2.7
People living in rural communities	2.9

TABLE 16 RESULTS FOR Q5 'THE NEEDS OF EXCLUDED PEOPLE GROUPS SHOULD BE ADDRESSED IN THE FOLLOWING AREAS OF VEHICLE DEVELOPMENT'

The needs of excluded people groups should be addressed in the following areas of vehicle development	Avg. score (Strongly disagree – strongly agree, 1-5 Likert-style scale)
Product planning & research	4.3
Vehicle packaging & engineering	4.1
Vehicle styling	3.5
Interior design	4.1
HMI design	4.2
CMF design	3.6

TABLE 17 RESULTS FOR Q6 'THE NEEDS OF EXCLUDED PEOPLE GROUPS SHOULD BE ADDRESSED IN THE DESIGN OF THE FOLLOWING VEHICLE TYPES'

The needs of excluded people groups should be addressed in the design of the following vehicle types	Avg. score (Strongly disagree – strongly agree, 1-5 Likert-style scale)
Privately owned cars	3.8
Shared/ hire cars (e.g. Zipcar service)	4.2
Goods vehicles	3.6
Buses and minibuses	4.5
Trains, trams, underground	4.6
Taxis	4.3
Bicycles	3.7

7.2.2 BARRIERS TO INCLUSIVE DESIGN IN THE AUTOMOTIVE AND TRANSPORT SECTOR

To understand the barriers to applying inclusive design in the automotive and transport industries, survey respondents were asked, 'What do you think are the main barriers to creating more inclusive vehicles?'. Several barriers were also discussed by the participants in the industry focus group. These barriers fell into six main themes.

Cost and business case

Financial limitations were cited as barriers to the development of inclusive vehicles. Survey respondents mentioned that 'higher vehicle development and product cost[s]' might limit the incorporation of specific features for excluded groups. Many discussed how market forces and business decisions might reduce inclusive design focus as 'product creation follows demand from users, if users do not demand and pay for a feature it is not viable.' Similarly, the focus group participants discussed how the automotive industry's model of selling vehicles to individuals justifies meeting the needs of the majority but excludes those with specific needs, as the cost of designing for these groups may not sufficiently increase sales.

Industry and organisational culture and structure

Respondents discussed how automotive industry culture can create barriers. One suggested some in the industry have a view that 'doing extra for these 'minority' groups does not make sense.' The structure of organisations can mean that unless 'decision-makers at the top' prioritise inclusion, employees will be limited in addressing exclusion. The slow-moving nature of the industry was seen as a barrier, with one designer likening it to a 'Leviathan' that struggles to adapt to changing societal priorities.

Legislation and policy

A lack of regulation was another key barrier to implementation. One respondent mentioned that 'legislation is not driving sales and marketing', suggesting that stricter regulations might force manufacturers to consider inclusion. It was noted that public transport systems can be 'more considerate' because of stricter regulations than private vehicles. However, designers argued that such regulatory approaches can result in arbitrary 'box-ticking' instead of fostering more creative and impactful inclusive innovation.

Knowledge and empathy gaps

While respondents indicated that they engaged in user testing and participatory research, some suggested that engagement with excluded groups remains a significant gap affecting their ability to address needs effectively. The designers in

the focus group expressed concerns about understanding and designing for diverse needs. Suggestions included meeting users 'face-to-face,' and fostering empathy through 'direct experience of the challenges they need to help resolve.'

Creativity and design conflicts

Designing for diverse user needs while maintaining vehicle style and functionality was also suggested as a barrier. One respondent noted that vehicles are 'designed to accommodate the widest population demographic', often at the expense of minority groups. The challenge of addressing 'diverse and specific needs' without compromising mainstream appeal further complicates this issue. Some respondents advocated for a more innovative approach to inclusion in design, seeing constraints as 'exciting challenges to address creatively' rather than as obstacles. One respondent discussed how a 'mindset of designing for extreme users, not average users' could benefit everyone.

While addressing these barriers would require systemic and legislative changes, several could be addressed through resourcing and education that enable designers to incorporate inclusive design into routine practice. By equipping designers to incorporate inclusive design more intuitively, the vehicles they design may accommodate more groups without requiring additional costs or time for dedicated inclusive design work.

7.2.3 *DESIGNERS' PREFERENCES AND IDEAS FOR INCLUSIVE DESIGN RESOURCES AND TOOLS*

The dissemination of information to 'knowledge users' is considered key to inclusive design, with previous research seeking to assess inclusive design tools based on designers' preferences (Dong et al., 2013). To explore how inclusive transport design information might be shared, survey questions determined existing resources used for informing inclusive design (Table 18) and preferred formats for dedicated inclusive design resources (Table 19).

The favoured methods for accessing information were concise written sources (web and anthropometric data) or specific market/customer research. Longer formats, including academic papers and books, were used the least, indicating that for academic inclusive design research to be impactful, consideration must be given to its dissemination to designers.

Preferences for inclusive design resource formats were evenly split across the examples given. One surprising outcome was the low preference for conceptual design solutions. However, as the question limited respondents to three selections and two similar design solution options were given, this could indicate a preference for more proven existing vehicle solutions over potential ones while ultimately indicating the value of complete designs to communicate inclusive design findings.

TABLE 18 RESULTS FOR Q8 'WHEN CONSIDERING THE NEEDS OF EXCLUDED PEOPLE GROUPS, WHERE DO YOU NORMALLY FIND INFORMATION ABOUT THEIR NEEDS?'

When considering the needs of excluded people groups, where do you normally find information about their needs? (Select all that apply)	Number of respondents
Anthropometric data	19
User research (user testing, focus groups, questionnaires etc.)	23
Market research (reports on trends etc.)	22
Academic sources (research papers, academic conferences etc.)	12
Books	7
Online resources (websites, videos, blogs etc.)	25
Experts/ consultants	15

TABLE 19 RESULTS FOR Q10 'WHICH OF THE FOLLOWING RESOURCES WOULD BE MOST USEFUL TO YOU IN LEARNING ABOUT THE NEEDS OF EXCLUDED PEOPLE GROUPS?'

Which of the following resources would be most useful to you in learning about the needs of excluded people groups? (Select 3)	Number of respondents
User profiles/ personas demonstrating the needs of excluded people groups with images and storyboards	16
Videos of members of excluded people groups explaining/ demonstrating the exclusion they face	17
Opportunities to meet and talk with members of excluded groups	19
Case studies of key general issues of exclusion in transport	13
Examples of existing inclusive vehicle design solutions	17
Examples of potential inclusive vehicle design solutions (sketches, renders, images of prototypes etc.)	4

To understand how best to disseminate inclusive design information in the automotive and transport industries, a write-in question was included in the questionnaire: 'Please add any additional ideas you have for useful resources for learning about the needs of excluded people groups'. The discussions in the designers' focus group also explored preferences for resource formats and learning about exclusion.

Empathy and immersion tools

Developing empathy was seen as key to enabling designers to address exclusion more intuitively through design practice. A survey respondent discussed developing empathy through props that replicate impairments, including glasses simulating

visual impairments. Others suggested 'Digital twins of personas that could either be used in CAD or experienced in VR', and enacting excluded people's journeys, such as 'Take a train ride in a wheelchair'.

Concise and visual information

Visual resources were commonly suggested for encouraging inclusive design among designers who may not have time for in-depth research and learn better through visual means. Infographics and a 'top 10' list of issues were suggested as potential formats.

Working with excluded groups

People in both the focus group and survey responses noted the value of engaging with excluded groups to better empathise with their needs. Designers acknowledged that limited personal experiences of exclusion might restrict their ability to address it, but that interviews with those affected would build empathy and identify barriers. A respondent suggested that more disabled engineers in the industry may foster greater empathy while bringing in expertise from their lived experiences.

Examples and best practices

Participants acknowledged that inclusivity is often better addressed in other industries and suggested that resources detailing inclusive design practices across disciplines might help apply similar strategies. Examples of existing inclusive design features in transport were also considered beneficial.

7.3 CONTRIBUTION TO KNOWLEDGE

Through the research and design conducted during this project, a range of practical, methodological, and theoretical contributions to knowledge have been made. As the ultimate aim of this project was to provide a practical basis for the future development of inclusive SAVs and associated services, it is helpful to consider original contributions according to their usefulness to stakeholders who may be able to influence and conduct further work in this space in a variety of contexts.

7.3.1 AUTOMOTIVE AND TRANSPORT INDUSTRY PROFESSIONALS

As a design-focused project, several contributions have been made pertaining to the role of the automotive and transport industries in developing more inclusive mobility.

Multivariate inclusive design of an SAV concept

Inclusion in transport often appears as an afterthought, with the needs of excluded groups catered for through retrofitted adaptations, or a few specialised vehicles within a fleet. The approach of holistically addressing the needs of multiple excluded groups through a single vehicle design demonstrates how designers in industry contexts might address exclusion more intentionally from the outset, negotiating various trade-offs, compromises, and priorities to arrive at a more inclusive SAV design. In contrast to typical academic approaches to SAV inclusivity which focus on the design of specific components to meet the needs of specific groups, this multivariate, multi-group approach more closely demonstrates how inclusive design might be pragmatically incorporated into a vehicle design process, alongside a multitude of competing priorities. In addition to ensuring that typical vehicle design decisions address exclusion, the inclusive SAV design also demonstrates a number of novel individual design features, including folding seat designs to enable greater adaptability of SAV interiors, continuous exterior-interior guide rails to aid visually impaired people navigating in the vehicle, and a concept kneeling suspension system which may allow for lower step-in heights while retaining the efficiency of SAV occupant packaging.

Inclusive SAV information and interaction concepts

Similarly, examples of novel inclusive information and interaction designs demonstrate how simple, familiar, and multimodal interfaces might improve the inclusivity of key interactions required to use an SAV service, demonstrating how design can ensure that SAV access is provided to a wider portion of society. The identification of barriers related to the availability and usability of digital interfaces has also led to the creation of several non-digital and low-tech concepts for SAV interaction that might ensure that groups experiencing such barriers are not left behind by an increasingly digital-reliant mobility landscape. These low-tech methods of interaction are often neglected by academia and industry risking the exclusion of various groups as digital-dependent transport services replace the familiarity and intuitiveness of traditional modes of transport. Key examples of concepts developed include simple travelcard-based means of accessing the service, physical controls for onboard interfaces, and simple public interfaces for calling SAVs.

Barriers and enablers to inclusive design in the automotive and transport industry

This thesis has identified commercial, policy-related, and personal (employee-related) barriers to the implementation of inclusive design in industry contexts highlighting the need for inclusive design research to be communicated to the industry in ways that coincide with existing processes and minimise the time and resources needed for it to be implemented. This thesis has also presented insights into how research might best be communicated with industry professionals through interventions including design tools, concise and engaging summaries of needs and examples of best practices, and potentially even through the facilitation of in-person workshops for designers to engage with members of excluded groups.

Parametric SAV platform design tool

One way of equipping designers to explore inclusivity in an industry context is through the provision of digital tools which highlight how their decisions impact the inclusivity of their designs. An example of one such tool is the parametric tool developed during this project to intuitively demonstrate the impact of design decisions (e.g. wheel size and proportion) on the inclusivity of the SAV platform designs. As this tool uses open-source, freely available, and designer-friendly software, it (or similarly designed tools) might be easily implemented into design workflows to aid inclusive design decision-making at the early stages of a project.

7.3.2 TRANSPORT POLICY AND SERVICE DECISION MAKERS

As the inclusivity of SAV services is likely to be highly dependent on decisions made in the areas of policy and service, several contributions may prove beneficial to those involved in such decision-making.

Inclusive SAV fleets, regulation and standardisation

Discussions throughout this thesis highlight the necessity for SAV services to ensure the inclusivity of all vehicles within the fleet, avoiding time delays and poor availability resulting from special-purpose vehicles. Without widespread adoption within SAV fleets, the impact of inclusive SAV designs, such as those presented in this thesis, will be severely limited, and exclusion will continue. The designs presented in this thesis may be useful to policymakers in providing a starting point for the development of regulations and guidance for the level of inclusion that must be achieved by SAVs to operate in transport services. Such standardisation would additionally benefit excluded groups who rely on familiarity.

Demonstrating low-tech and equitable service access and payments

Because SAVs may operate as a public transport service, policymakers may be positioned to influence decisions related to the accessibility of information, interfaces, and payments essential to their use. Designs and recommendations for low-tech alternatives to complex digital interactions and financial transactions that are accessible to unbanked passengers might assist decision-makers in providing more equitable access by demonstrating that futuristic mobility services do not have to be solely reliant on digital interactions.

7.3.3 DESIGN RESEARCHERS

Theoretical and methodological contributions based on approaches taken during this project may benefit design researchers in academic and industry contexts by supporting the planning and scoping of inclusive transport design projects and providing novel methods for more immersive co-design activities.

Inclusive design for transport framework

The inclusive transport design framework developed during this project makes a theoretical contribution to the field of inclusive transport design research by providing an overview of the true breadth of transport exclusion and capturing the often-overlooked necessity for inclusive design to embrace the compromises and trade-offs associated with meeting the needs of multiple groups through prioritisation. Highlighting the breadth of exclusion in this framework encourages a multivariate approach to inclusive mobility design which is essential for the development of vehicles and transport services to be used by the public, where ubiquity and universality are critical.

Using mixed-reality for real-time co-design ideation with non-expert participants

The method of mixed reality co-design developed for use in focused workshops appears to be one of the first examples of such tools being used for live co-design research activities. Examples of prior use of VR tools in participatory design research activities are limited to the testing and evaluation of designs rather than live iteration and co-creation. The value of such a method in enabling rapid and convincing iteration may be invaluable to other design researchers, particularly those exploring future technologies where previous experiences or example products are unable to provide a clear point of reference for non-expert co-design participants.

7.3.4 INCLUSIVE SAV STAKEHOLDERS

One final contribution that underpins many of the above and is useful for members of all three of the above disciplines is in providing an overview of SAV-related barriers and inclusive design considerations. The approach of detailing an end-to-end SAV journey identifies interface- and vehicle-related needs for designers to address, as well as service- and infrastructure-related needs that might inform policy decisions. All the identified barriers and their associated journey stages should form the basis for further academic contributions. For these purposes, stakeholders may use the summary of needs and tables of considerations from Chapter 4, or the more detailed tables in Appendix 1.

7.4 FUTURE RESEARCH

An inclusive design approach that seeks to understand and respond to the needs of a wide spectrum of excluded groups inevitably raises more questions than can be answered within the limitations of a PhD project. The nascence of SAV design and the contribution of this PhD in presenting a variety of design concepts make future research and development of inclusive SAVs paramount to ensuring the impact of this body of work. Such work should seek to address the areas of SAV exclusion and design that this project has been unable to explore, and further explore the methods, findings, and design concepts that have been discussed.

7.4.1 INCLUSIVE SAV DESIGN FOR ALTERNATIVE TYPOLOGIES AND SERVICE OPERATING MODELS

As this research has focused on one particular SAV typology and a limited selection of potential service and operating models, future work should consider how the inclusion needs and design concepts presented in this thesis might translate into different SAV propositions and typologies including smaller 2-4 seater SAVs, larger bus-like SAVs, and more traditional car/ taxi-like SAVs.

These inclusion needs and the proposed designs may be considered in these alternative contexts in three ways.

1. The identified need is not applicable to or is automatically resolved by the proposed SAV/service (e.g. single-seater asynchronously shared SAVs that do not require consideration of sharing-related security).
2. The identified need is applicable, but the design concept requires modification because of typology/service differences.

3. The identified need is applicable, and the design concept can be applied directly or with minor adjustments.

Service-level decisions significantly influence the efficacy and application of design concepts, such as providing public interfaces for non-smartphone users and collecting passenger data for secure journey-sharing recommendations. In the same way that designing inclusive vehicles and interfaces presents trade-offs, decisions on how the service is structured and operated create similar predicaments. As SAVs allow for various service models, further research should examine how these decisions impact service inclusivity. Many decisions depend on policy, as transport services are regulated nationally and locally, with inclusivity often achieved through such regulations. Table 20 summarises a selection of potential policy/service-level decisions and their impact on inclusion, based on service-related considerations identified and discussed throughout chapters 4-6 of this thesis.

TABLE 20 SAV POLICY AND SERVICE DECISIONS AND THEIR POTENTIAL IMPACTS ON INCLUSION

Policy/ service decision	Potential options	Potential inclusivity impact
Service/ vehicle standardisation	Unregulated/ standardised	Standardised vehicle layouts making navigation easier for visually impaired people.
Service type/ business model	Privately operated/ public transport	Public transport allowing for subsidised travel for excluded groups e.g. through freedom pass.
Service access model	Reservation/ on-demand/ spontaneous	Pre-reserved allowing more tailored provision of inclusivity features and door-to-door journeys. Spontaneous reducing complexity of pre-booking.
Service scope/ provisions	Vehicle-only/ providing staffing, phone-support infrastructure etc.	Provision of services and features beyond vehicle allowing broader inclusion e.g. level-boarding from raised kerbs, smart-phone free public booking terminals, staff assistance etc.
Cost and pricing	Multiple potential pricing structures	Pricing reductions according to number of sharers resulting in conflicts between feeling secure when sharing a vehicle and saving money.
Payment modes	Account-based/ contactless-only/ multimodal	Limiting payment methods to digital means reducing access to unbanked passengers, or those without digital device access.
Fleet	Different vehicles in fleet (limited number of accessible vehicles)/ Universal single vehicle	Limiting accessibility features, e.g. wheelchair access, to small number of vehicles could create unequal service with longer wait times and less access to sharing benefits for those that need them.
Vehicle typology	Multiple options for size, capacity etc.	Smaller vehicles unable to accommodate a wheelchair space, multiple factors influencing boarding e.g. step-in height.
Operating environment	Dedicated areas <> all roads	More restricted operating environments reducing potential for door-to-door journeys and associated inclusivity benefits e.g. reduced walking distance.

Operating area	Urban/ suburban/ rural etc.	Focus on urban areas reducing realisation of SAV benefits for location-excluded groups who may benefit more from the flexibility of an SAV service.
Service routing/ vehicle distribution	Multiple ways of distributing vehicles according to demand and need	Strict demand responsive models could concentrate SAVs in urban centres reducing access for groups with non-typical travel patterns e.g. those who are not commuting into the centre of a city.
Transport network integration	Competing with other modes/ complementing existing services	Competition with other transport modes causing unnecessary SAV use by those who can use other transport modes, more complementary SAV services could fill the gaps in existing networks for those that need them e.g. prioritising wheelchair users for journeys with no accessible alternative. SAVs supporting multimodal journeys for those who are able to make them, could free up capacity for those that cannot.
Sharing model	Synchronous/ asynchronous/ both	Asynchronous sharing reducing security concerns but perhaps leading to smaller vehicles with poor accessibility (see vehicle typology) Providing both options creates less potential for sharing, favouring wealthier passengers, with financially excluded people less able to benefit from sharing discount/ waiting longer.
Passenger monitoring	Open service/ account-based/ both	Open access to service reducing barriers related to payment/ digital access but reducing ability to monitor passenger behaviour and guarantee security of service.

7.4.2 INCLUSIVE SAV DESIGN FOR OTHER EXCLUDED GROUPS

The research focused on disabled people groups, older people, and women, addressing their needs explicitly in design concepts while considering known needs of other groups where appropriate. Although much exclusion remains to be addressed before SAV services can be fully inclusive, the selected groups demonstrate how SAV design can address multiple groups' needs simultaneously. The groups were chosen based on their anticipated impact on key vehicle and service design decisions, likely providing a foundation for further inclusive design work without requiring fundamental changes. For example, the wheelchair space positioning, seating layout, interior division, and interior guidance creates a space that is usable by most passengers.

Future work should explore SAVs' implications for those with needs better addressed through service and policy decisions, including those experiencing exclusion related to ethnicity, race, culture, income, and location. Further attention should also be paid to meeting needs of disabled people with less-physical impairments, including cognitive impairments, learning disabilities, and neurodiversity. While simpler interaction designs discussed in Chapter 5 might address some needs, participatory research with these groups would help test and tailor designs to their specific requirements.

7.4.3 *Inclusive SAV engineering*

Although the vehicle designs presented in Chapter 6 were discussed and evaluated through conversations with automotive packaging experts, not all elements of the designs can be assumed to be completely feasible without further engineering development. Future work should seek to validate the packaging concepts presented in Chapter 6, particularly the viability of using kneeling suspension systems to significantly reduce the SAV step-in height. Further SAV packaging and engineering innovations in reducing sill depth and step-in height will be beneficial in creating more inclusive SAVs.

Owing to the complexity of the engineering challenge, the design of an independently operable wheelchair restraint system was not explored in this project. However, as an essential component for providing wheelchair access in the absence of a driver, future work should consider how this can be best achieved.

7.4.4 *Evaluating and applying concept inclusive SAV designs*

The concepts presented in this project represent early steps towards a more inclusive SAV design. As these designs were primarily intended to stimulate further development and research on SAV inclusion, their impact and implementation depend on subsequent work to:

- Explore the feasibility of designs with regard to engineering, user interface design, and service design.
- Explore the usability and inclusivity of designs through further testing with excluded groups.

7.4.5 *Developing mixed-reality co-design methods*

The mixed-reality co-design methods used throughout the *focused workshops* proved to be beneficial in iterating design solutions with participants, particularly in being able to test ideas that could not have been rapidly tested with physical mock-ups (e.g. adjusting the transparency of divider materials). The potential of this new method to enable rapid design iteration in co-design contexts warrants further exploration, and future research should seek to evaluate its efficacy compared to other co-design methods.

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APPENDICES

Appendix 1 TABLES DETAILING THE NEEDS OF EXCLUDED GROUPS THROUGHOUT AN SAV JOURNEY

Appendix 1.1 SUMMARY OF NEEDS AND BARRIERS IN AN SAV JOURNEY

TABLE 21 SUMMARY OF NEEDS AND BARRIERS IN AN SAV JOURNEY

Stage	1 Before using the SAV for the first time		2 Planning the journey and accessing the service					3 Pre-boarding				
Activity	Familiarising with the SAV/ service	Registering for the SAV service	Planning the journey and reserving the SAV	Accessing the SAV service – on-demand	Accessing the SAV service – spontaneously	Making choices about the journey	Paying for the journey	Getting to the vehicle	Using waiting facilities	Accessing journey information	Waiting for the vehicle – timing and reliability	Locating an SAV
Tasks/ needs	Getting used to SAVs Familiarising oneself with the interior layout Learning how to interact with the SAV	Registering personal information – knowing about other passengers Registering needs with SAV service Registering to access preferential pricing and services Validating registered information Ensuring security of personal data	Feeling in control and utilising existing knowledge Planning comprehensively Being able to use planning and reservation services	On-demand access using mobile phone On-demand access using public interfaces On-demand access using low-tech means/ dedicated devices	Spontaneous access at roadside Spontaneous access of passing SAV Communicating journey information when accessing spontaneously	Making choices about sharing Making choices about interior space	Paying for the journey	Navigating to the vehicle Moving in the built environment Behaviour of other pedestrians and road users Feeling safe when walking to the vehicle	Waiting facilities providing for passengers' needs Accessing assistance Moving in waiting facilities Feeling safe at waiting facilities	Knowing about vehicle arrival Being reminded of journey details Receiving journey updates and responding to journey changes Knowing about the vehicle interior	Reliable, on-time services	Locating an SAV for spontaneous access Locating a pre-booked SAV Distinguishing your SAV from others
Psychological	Low confidence – using unfamiliar services	Fear – sharing SAV with strangers Fear – sharing personal information	Lack of agency Mental load of extensive planning			Fear – sharing SAV with strangers		Fear/ anxiety – dangerous driving Fear – in public spaces – alone, at night etc. Fear – theft	Fear – at waiting facilities – alone, at night etc.	Fear – waiting in public spaces – long wait times Mental load of extensive planning + remembering details	Fear – waiting in public spaces – long wait times	Fear – waiting in public spaces Fear – sharing personal information
Interpersonal					Crowding to access vehicle	Passengers occupying priority seating/ wheelchair spaces		Poor disability awareness – Impatient drivers			Crowding – caused by poor timings	
Information and interactions	Lack of interior navigation information Difficulties learning to use interfaces	Multiple – addressed by registration of needs	Accessibility: dexterity issues, visual-only Usability: unintuitive, unfamiliar, complex	Accessibility: dexterity issues, visual-only Usability: unintuitive, unfamiliar, complex Reliability: battery issues, poor connection Language barriers	Accessibility: dexterity issues, visual-only Usability: unintuitive, unfamiliar, complex		Usability: unintuitive, unfamiliar, complex		Lack of accessible transport node navigation information	Lack of interior navigation information Accessibility: dexterity issues, visual-only Usability: unintuitive, unfamiliar, complex Reliability: battery issues, poor connection		Accessibility: visual-only/ audio-only Usability: unintuitive, unfamiliar, complex
Physical	Difficulty navigating interior layout	Multiple – addressed by registration of needs	Multiple – need to be planned for			No priority seating/ wheelchair spaces		Difficulties navigating and moving in the built environment	**Waiting location-**No seating/ rest places Difficulties navigating and moving	Difficulties navigating in the vehicle		Difficulties navigating to the vehicle
Service		Higher transport costs Inaccessible transport networks Both addressed by registration for priority SAV service	Difficulty responding to unexpected changes due to complex needs		Driving behaviour-vehicle not stopping Vandalism of exterior interfaces	Poor availability of inclusive vehicles Higher transport costs – if not sharing	Reliance on few payment modes that are inaccessible/ unavailable Higher transport costs – waiting charges		**Waiting facilities –** Poorly maintained Unreliable **Staff –** unavailable assistance, communication difficulties	Difficulty responding to unexpected changes due to complex needs	Poor availability	Poor availability – where needed

Stage	4 Boarding the SAV			5 Onboard the SAV						6 End of the journey		
Activity	Getting to the doors	Opening the doors and validating the journey	Stepping/ wheeling onboard	Getting to (and from) the seat	Ensuring suitable seating	Accessing information and interacting with the SAV	Enjoying the journey	Sharing the journey	Preparing to end the journey	Leaving the vehicle	Getting from vehicle to destination	Security after leaving the vehicle
Tasks/ needs	Locating the SAV doors (visually impaired people)	Validating access to the vehicle Controlling the door opening	Physical support when boarding Locating steps and ramps when boarding Short distance to step onboard Wheelchair access	Moving in the vehicle Navigating in the vehicle	Wheelchair occupancy Placing luggage Sitting with others Comfort Adjusting and arranging seating Priority disabled space	Inclusive on-journey interfaces Provision of necessary information and interactions for excluded groups	Good interior condition Comfort On-journey activities	Reducing crowding Managing dangerous, illegal, and antisocial passenger behaviours Calibrating social interaction with other passengers Awareness and attitudes of other passengers	Notification of journey end Ensuring suitable drop-off location	Getting from your seat to the door Operating ramp/ lift Returning adapted interior to default	Onward navigation	Feeling safe when getting from vehicle to destination
Psychological		Fear – sharing SAV with strangers	Stigma – delaying other passengers		Fear – feeling unsafe due to poor wheelchair restraints Fear – theft	Fear – sharing personal information Fear – privacy of interactions	Discomfort – unhygienic, unclean, vandalised interior	Fear – sharing SAV with strangers Anxiety – unwanted social interaction	Fear – in public spaces – alone, at night etc. Fear – sharing personal information e.g. address	Stigma – delaying other passengers		Fear – in public spaces – alone, at night etc.
Interpersonal				Passengers obstructing interior space	Passengers occupying priority seating/ wheelchair spaces – sitting, luggage Social interaction – difficult communications caused by seating layout		Passengers with poor personal hygiene	Crowding – obstructing interior space Dangerous, illegal and antisocial passenger behaviours Social interaction – unwanted/ wanted but not possible Poor disability awareness Passengers occupying priority seating/ wheelchair spaces				
Information and interactions	Lack of clear information for locating doors	Multiple – addressed by sharing needs with vehicle Lack of clear information for locating door controls	Lack of clear information for locating boarding features – e.g. steps Unreachable exterior door controls (WU)	Lack of interior navigation information		Not able to use in emergencies Accessibility: dexterity issues, visual-only, audio-only, not tactile, not reachable, not locatable Usability: unintuitive, unfamiliar, complex Reliability: battery issues, poor connection Understandability: Language barriers			Accessibility: visual-only journey end information			
Physical	Difficulties locating vehicle doors	Multiple – addressed by sharing needs with vehicle Difficulties locating door controls Difficulties with strength & dexterity to open doors	Difficulties stepping onboard – stability, distance, height Difficulties wheeling onboard – steep ramps, obstructed pavement, from road level Difficulties locating boarding features	Difficulties navigating and moving in the vehicle – exacerbated by vehicle movement and interior changes.	No priority seating/ wheelchair spaces – unavailable, not reservable Unusable wheelchair restraints Difficulties placing luggage in storage No space for assistance dogs Difficulties with strength & dexterity to configure interior					Difficulties navigating and moving in the vehicle	Difficulties navigating and moving in the built environment	
Service				Driving behaviour – starting to drive before seated		Driving behaviour – starting to drive before seated			Difficulties navigating and moving in the built environment	Driving behaviour – not stopping for long enough to leave vehicle		

Appendix 1.2 BEFORE USING THE SAV SERVICE FOR THE FIRST TIME

Registering for the SAV service

TABLE 22 NEEDS OF EXCLUDED GROUPS – REGISTERING FOR SAV SERVICE

Journey stage	1. Before using the SAV for the first time
Journey activity	**Registering for the SAV service**

Task/ general need	Specific need	Related barrier	Suggested negatives/ trade-offs	Ideas/ solutions	Excluded group(s)
Registering personal information – knowing about other passengers	Knowing about age and gender of other passengers	*Psychological exclusion* – fear – sharing SAV with strangers	Retaining privacy of personal data Exclusion of groups seen as less safe (e.g. men)	Public passenger profile	Women
	Knowing rating of other passengers	*Psychological exclusion* – fear – sharing SAV with strangers	Being rated Passenger prejudices informing rating	Public passenger profile Negative ratings validated through CCTV	Women
Registering needs with SAV service	Calibrating secure sharing preferences for automatic recommendation of journeys	*Psychological exclusion* – fear – sharing SAV with strangers		Simple scenario-based questionnaire	Women
	Registering accessibility needs and preferences to ensure inclusion	*Physical exclusion* *Information and interactions exclusion* – inaccessible interfaces		Card/ pass linked to account with saved accessibility needs App	Disabled people
Registering to access preferential pricing and services	Accessing preferential pricing to counter existing exclusion in other transport modes	*Service exclusion* – higher transport costs		Service reducing cost based on passenger needs and lack of suitable alternatives	Women Disabled people
	Continuation of concessionary public transport schemes	*Service exclusion* – higher transport costs – loss of concessions			Older people Disabled people
	Accessing priority services	*Service exclusion* – partially accessible network *Psychological exclusion* – fear - sharing SAV with strangers		Service prioritising journeys based on passenger needs and lack of suitable alternatives	Women Disabled people

Journey stage	1. Before using the SAV for the first time				
Journey activity	**Registering for the SAV service**				

Task/ general need	Specific need	Related barrier	Suggested negatives/ trade-offs	Ideas/ solutions	Excluded group(s)
Validation of registered information	Validation of public personal information to ensure trustworthy informed decisions about safety	*Psychological exclusion* – fear – sharing SAV with strangers	Lack of privacy Difficult to enforce	Official identification documents Passenger reporting CCTV	Women
	Validation of access to preferential pricing and services	*Service exclusion* – higher transport costs – loss of concessions		Official documentation related to disability e.g. personal independence payment	Disabled people
Ensuring security of personal data	Individuals able to balance access to service features against the level of information they wish to share	*Psychological exclusion* – fear – sharing personal information	Not sharing some data may reduce access to certain features		Multiple groups

Familiarising with the SAV/ service

TABLE 23 NEEDS OF EXCLUDED GROUPS – FAMILIARISING WITH THE SAV/ SERVICE

Journey stage	1. Before using SAV for the first time			
Journey activity	**Familiarising with the SAV/ service**			
Task/ general need	**Specific need**	**Related barrier**	**Ideas/ solutions**	**Excluded group(s)**
Getting used to SAVs	Building trust in the functionality of SAV services	*Psychological exclusion* – low confidence-using unfamiliar services	Seeing SAVs in operation Education about SAVs	Women visually impaired people Older people Hearing impaired people
	Building confidence to the point of using an SAV	*Psychological exclusion* – low confidence-using unfamiliar services	Test drives Standardised vehicle design Similarity to existing transport Operating on fixed routes	Women visually impaired people Older people Hearing impaired people
Familiarising oneself with the interior layout	Knowing the layout of the vehicle interior to aid navigation for visually impaired people	*Physical exclusion* – interior layout – difficult to navigate for visually impaired people *Information and interactions exclusion* – information about vehicle – lack of interior navigation information for visually impaired people	Public, tactile SAV models Public, full-scale SAV mock-ups Intuitive navigation through tactile interior features Standardised vehicle design	visually impaired people
Learning how to interact with the SAV	Knowledge on how to use the SAV in emergency scenarios	*Information and interactions exclusion – poor* learnability, intuitiveness, familiarity	Simulators	Older people

Appendix 1.3 PLANNING THE JOURNEY AND ACCESSING THE SERVICE

Planning the journey and reserving the SAV

TABLE 24 NEEDS OF EXCLUDED GROUPS – PLANNING THE JOURNEY AND RESERVING THE SAV

Journey stage	2. Planning the journey and accessing the service
Journey activity	**Planning the journey and reserving the SAV**

Task/ general need	Specific need	Related barrier	Suggested negatives/ trade-offs	Ideas/ solutions	Excluded group(s)
Feeling in control and utilising existing knowledge	Ability to learn regular journey routes	*Psychological exclusion* – lack of agency		Service using the same route every time	Older people visually impaired people
	Ability to adjust vehicle routing according to prior knowledge	*Psychological exclusion* – lack of agency			Older people
Planning comprehensively	Simple planning to ensure accessibility of journey – including assistance and accessibility features	*Psychological exclusion* – mental load – extensive planning *Service exclusion* – unexpected changes – difficulty responding to changes due to complex needs *Physical exclusion*		Selecting accessibility features during booking	Disabled people
Being able to use planning and reservation services	Reduced complexity of Planning the journey and accessing the service services	*Information and interactions exclusion* – complexity of interactions			Cognitively impaired people (Risser et al., 2012) Autistic people (Deka et al., 2016)
	Reduced reliance on digital services	*Information and interactions exclusion* – inaccessibility-dexterity issues with fine interactions, visual-only information, poor learnability, intuitiveness, familiarity – low digital literacy complexity-need to use multiple apps	More complex interactions may rely on digital services		Dexterity impaired people (P4) visually impaired people Older people

Journey stage	2. Planning the journey and accessing the service				
Journey activity	**Planning the journey and reserving the SAV**				

Task/ general need	Specific need	Related barrier	Suggested negatives/ trade-offs	Ideas/ solutions	Excluded group(s)
	Availability of person-to-person planning services	*Information and interactions exclusion* – poor learnability, intuitiveness, familiarity Inaccessibility complexity		Friend or family assistance Transport staff Telephone service	Older people visually impaired people
	Conversational, voice-based booking services	*Information and interactions exclusion* – poor learnability, intuitiveness, familiarity	Can be difficult to know what commands to use Inaccessible to hearing impaired people	Home voice assistant	Older people

Accessing the SAV service – On-demand

TABLE 25 NEEDS OF EXCLUDED GROUPS – ACCESSING THE SAV SERVICE – ON-DEMAND

Journey stage	2. Planning the journey and accessing the service
Journey activity	**Accessing the SAV service – on-demand**

Task/ general need	Specific need	Related barrier	Suggested negatives/ trade-offs	Ideas/ solutions	Excluded group(s)
On-demand access using mobile phone	Easy to use smartphone app if necessary for on-demand SAV calling	*Information and interactions exclusion* – inaccessibility-dexterity issues with fine interactions, visual-only information, poor learnability, intuitiveness, familiarity – low digital literacy complexity-need to use multiple apps	Unreliability of smartphone battery, functionality, and connectivity		Dexterity impaired people (P4) visually impaired people Older people
	Simpler phone-based means of on-demand SAV calling	*Information and interactions exclusion* – inaccessibility – visual-only information, screen reader incompatibility poor learnability, intuitiveness, familiarity – low digital literacy		Email SMS Phone call – with a real person, not automated	Hearing impaired people visually impaired people Older people
On-demand access using public interfaces	In-person assistance when calling a vehicle	*Information and interactions exclusion* – poor learnability, intuitiveness, familiarity – low digital literacy	Unreliability of staff	Ticket office Public booking terminals in other businesses allowing access to staff assistance	Older people
	Calling SAV using publicly available booking facilities	*Information and interactions exclusion* – unreliability – smartphones battery, connectivity etc.	Potential for vandalism Unreliability of existing ticket machines	On-street Inside businesses Simple call points Interfaces allowing more complex inputs	Older people

Journey stage	2. Planning the journey and accessing the service				
Journey activity	**Accessing the SAV service – on-demand**				

Task/ general need	Specific need	Related barrier	Suggested negatives/ trade-offs	Ideas/ solutions	Excluded group(s)
	Accessible public booking interfaces – audio, large text, multiple language options	*Information and interactions exclusion* – inaccessibility – visual-only information Not understandable – language barriers			visually impaired people Non-native language speakers (Schachter and Liu, 2005)
	Simple means of inputting journey information at public interface	*Information and interactions exclusion* – Complexity		Card/ pass to automatically input journey preferences	visually impaired people
On-demand access using low-tech means/ dedicated devices	Using dedicated device to call vehicle to location	*Information and interactions exclusion* – Complexity	Potential for device to get lost	Key fob or similar with location tracking and a button to call SAV	visually impaired people

Accessing the SAV service – Spontaneously

TABLE 26 NEEDS OF EXCLUDED GROUPS – ACCESSING THE SAV SERVICE – SPONTANEOUSLY

Journey stage	2. Planning the journey and accessing the service				
Journey activity	**Accessing the SAV service – spontaneously**				
Task/ general need	**Specific need**	**Related barrier**	**Suggested negatives/ trade-offs**	**Ideas/ solutions**	**Excluded group(s)**
Spontaneous access at roadside	Simple access to SAV at roadside location	*Information and interactions exclusion* – poor learnability, intuitiveness, familiarity		Simply Boarding the SAV as you would a bus or taxi	visually impaired people
Spontaneous access of passing SAV	Familiar, gesture-based means of hailing a passing SAV	*Information and interactions exclusion* – poor learnability, intuitiveness, familiarity	Misuse SAV misunderstanding gestures	Card/ pass held out to validate gesture	Older people
	Knowing suitability of passing vehicle – availability, accessibility, destination	*Information and interactions exclusion* – inaccessibility not understandable poor learnability, intuitiveness, familiarity		Flag system to indicate availability	Multiple groups
	Knowing presence of a passing SAV and ensuring it stops – visually impaired people	*Service exclusion* – drivers/ staff – fail to stop for visually impaired people			visually impaired people
Communicating journey information when accessing spontaneously	Inputting journey information from safety and comfort of your seat	*Service exclusion* – vandalism and maintenance – vandalised exterior interfaces *Interpersonal exclusion* – crowding – potential uncomfortable crowding to access vehicle with exterior interface			Neurodivergent people (P3) visually impaired people
	Simple means of inputting journey information at the vehicle	*Information and interactions exclusion* – complexity		Card/ pass to automatically input journey preferences	visually impaired people Older people

Making choices about the journey

TABLE 27 NEEDS OF EXCLUDED GROUPS – MAKING CHOICES ABOUT THE JOURNEY

Journey stage	2. Planning the journey and accessing the service				
Journey activity	**Making choices about the journey**				
Task/ general need	**Specific need**	**Related barrier**	**Suggested negatives/ trade-offs**	**Ideas/ solutions**	**Excluded group(s)**
Making choices about sharing	Choosing who to share with based on passenger information – age, gender, and rating	*Psychological exclusion* – fear – sharing SAV with strangers	Retaining privacy of personal data Exclusion of groups seen as less safe (e.g. men) Being rated Passenger prejudices informing rating	App showing age, gender, and rating of potential sharers	Women
	Simple sharing choices	*Psychological exclusion* – fear – sharing SAV with strangers		App selects safe journey based on calibration of individual safety preferences	Women
	Ensuring safe sharing choices don't result in time/ cost penalties	*Psychological exclusion* – fear – sharing SAV with strangers *Service exclusion* – poor availability – of suitable vehicles Higher transport costs – reduced access to sharing discounts			Women
Making choices about interior space	Reserving an accessible seat/ wheelchair space	*Interpersonal exclusion*-excluding behaviours-occupying priority seating and wheelchair spaces *Physical exclusion* – priority seating – none wheelchair space – none			Wheelchair users Autistic people (Deka et al., 2016) Multiple groups
	Selecting a comfortable seat – forward facing			Preference for sitting in the direction of travel	Multiple groups
	Ensuring availability of luggage space				Multiple groups

Paying for the journey

TABLE 28 NEEDS OF EXCLUDED GROUPS – PAYING FOR THE JOURNEY

Journey stage	2. Planning the journey and accessing the service
Journey activity	**Paying for the journey**

Task/ general need	Specific need	Related barrier	Ideas/ solutions	Excluded group(s)
Paying for the journey	Alternative payment modes – not reliant on digital/ card-based payment	Service exclusion – Payment – digital and card-based payments not available for all		Financially excluded people – unbanked (Brakewood and Kocur, 2013)
	Simple and convenient payment modes	Information and interactions exclusion – complexity	Simple, phone-based ticketing Service-specific card/ pass payment	Cognitively impaired people (Risser et al., 2012) Multiple groups
	Not charging by time	Service exclusion – Higher transport costs – by the minute charges disadvantage disabled people who take longer to board etc.		Disabled people

Appendix 1.4 PRE-BOARDING

Getting to the vehicle

TABLE 29 NEEDS OF EXCLUDED GROUPS – GETTING TO THE VEHICLE

Journey stage	**3. Pre-boarding**			
Journey activity	**Getting to the vehicle**			
Task/ general need	**Specific need**	**Related barrier**	**Ideas/ solutions**	**Excluded group(s)**
Navigating to the vehicle	Familiarity with route to vehicle	*Physical exclusion* – built environment – difficult to navigate for visually impaired people	Using cane to help with navigation	visually impaired people
	Assistance when navigating unfamiliar route to vehicle	*Physical exclusion* – built environment – difficult to navigate for visually impaired people	Other people to guide	visually impaired people
Moving in the built environment	Unobstructed pavements and good visibility	*Physical exclusion* – built environment – difficult to move through for disabled people		Mobility impaired people (Park and Chowdhury, 2018) visually impaired people (Fürst and Vogelauer, 2012) Hearing impaired people (Fürst and Vogelauer, 2012) Cognitively impaired people (Risser et al., 2012)
Behaviour of other pedestrians and road users	Safety from dangerous and unpredictable drivers	*Psychological exclusion* – fear /anxiety – dangerous driving		Cognitively impaired people (Risser et al., 2012)
	Better driver awareness of disability – particularly less obvious disabilities	*Interpersonal exclusion* – Poor disability awareness – impatience when driving		Mobility impaired people visually impaired people
Feeling safe when walking to the vehicle	Ensuring a safe pick-up point	*Psychological exclusion* – fear – alone, at night, or in poorly lit areas		Women
	Someone else knowing your location	*Psychological exclusion* – fear – alone, at night, or in poorly lit areas	SAV app to share location and provide end-to-end passenger safety	Women
	Monitoring and deterring criminal behaviours	*Psychological exclusion* – fear – alone, at night, or in poorly lit areas Fear – theft	Keeping phone out of site to reduce risk of theft CCTV	Women visually impaired people

Using waiting facilities

TABLE 30 NEEDS OF EXCLUDED GROUPS – USING WAITING FACILITIES

Journey stage	**3. Pre-boarding**		
Journey activity	**Using waiting facilities**		
Task/ general need	**Specific need**	**Related barrier**	**Excluded group(s)**
Waiting facilities providing for passengers' needs	Shelter from bad weather in convenient locations		Multiple groups
	Comfortable and well-placed seating	*Physical exclusion* – no rest places	Mobility impaired people Older people
	Easy to access and locate toilet facilities	*Physical exclusion* – transport facilities – difficult to navigate for visually impaired people *Information and interactions* – information about transport facilities – lack of navigation information for visually impaired people	Older people visually impaired people
	Phone charging facilities	*Information and interactions exclusion* – unreliability – smartphone battery	Multiple groups
	Reliable and well maintained facilities	*Service exclusion* – vandalism and maintenance – poorly maintained facilities Unreliable facilities	Multiple groups
Accessing assistance	Provision of assistance to guide visually impaired people to vehicle	*Physical exclusion* – transport facilities – difficult to navigate for visually impaired people *Information and interactions* – information about transport facilities – lack of navigation information for visually impaired people *Service exclusion* – drivers/ staff – assistance unavailable	visually Impaired people
	Easy to communicate with staff	*Service exclusion* – drivers/ staff – communication difficulties for hearing impaired people	Hearing impaired people
Moving in waiting facilities	Easy navigation of transport hub	*Information and interactions* – information about transport facilities – unclear wayfinding information including signage and tactile paving	Cognitively impaired people (Risser et al., 2012) visually impaired people
	Unobstructed movement in transport hubs	*Physical exclusion* – transport facilities – difficult to move through. Steep ramps, no lifts	Mobility impaired people Wheelchair users
	Short waiting time	*Psychological exclusion* – fear – when alone at waiting facilities	Women

Journey stage	3. Pre-boarding
Journey activity	Using waiting facilities

Task/ general need	Specific need	Related barrier	Excluded group(s)
Feeling safe at waiting facilities	Ensuring safety while waiting	*Psychological exclusion* – fear – when alone at waiting facilities	Women

Accessing journey information

TABLE 31 NEEDS OF EXCLUDED GROUPS – ACCESSING JOURNEY INFORMATION

Journey stage	**3. Pre-boarding**
Journey activity	**Accessing journey information**

Task/ general need	Specific need	Related barrier	Ideas/ solutions	Excluded group(s)
Knowing about vehicle arrival	Accurate vehicle ETA		Smartphone app Arrival display board Infrastructure-based audio arrivals information activated by button	Multiple groups
	Notification of vehicle arrival		Smartphone app	Multiple groups
	Knowing precise vehicle location		Smartphone app	Multiple groups
	Vehicle arrival information improving feelings of safety by minimising time waiting on the roadside	*Psychological exclusion* – fear – waiting for vehicle in public	Smartphone app	Women
Being reminded of journey details	Complete journey information available on-demand in an accessible format	*Information and interactions* – complexity Inaccessibility – screen reader incompatibility, visual only information Unreliability – smartphones battery, connectivity etc.	Offline information – stored in notes/ emails on phone, can be read by screen reader. Can be inaudible in busy locations Smartphone app Physical maps, tickets, notes (braille and handwritten)	Older people visually impaired people Multiple groups
Receiving journey updates and responding to journey changes	Knowing about delays, changes, and service status	*Psychological exclusion* – mental load – extensive planning *Service exclusion* – unexpected changes – difficulty responding to changes due to complex needs		Multiple groups
	Knowing about alternative routes	*Psychological exclusion* – mental load – extensive planning *Service exclusion* – unexpected changes – difficulty responding to changes due to complex needs	Handwritten notes	Multiple groups

Journey stage	**3. Pre-boarding**
Journey activity	**Accessing journey information**

Task/ general need	Specific need	Related barrier	Ideas/ solutions	Excluded group(s)
Knowing about the vehicle interior	Knowing interior layout and occupancy to prepare for interior navigation	*Physical exclusion* – interior layout – difficult to navigate for visually impaired people *Information and interactions exclusion* – information about vehicle – lack of interior navigation information for visually impaired people		visually impaired people

Waiting for the vehicle – timing and availability

TABLE 32 NEEDS OF EXCLUDED GROUPS – WAITING FOR THE VEHICLE – TIMING AND AVAILABILITY

Journey stage	**3. Pre-boarding**		
Journey activity	**Waiting for the vehicle – timing and reliability**		
Task/ general need	**Specific need**	**Related barrier**	**Excluded group(s)**
Reliable, on-time services	On-time services reducing crowding	Interpersonal exclusion – crowding – potential uncomfortable crowding if vehicle's not on time	Women
	On-time services reducing wait times	Psychological exclusion – fear – waiting for vehicle in public	Women
	On-time services reducing missed connections	Service exclusion – poor availability – reducing flexibility	Location excluded people (P9)

Locating an SAV

TABLE 33 NEEDS OF EXCLUDED GROUPS – LOCATING AN SAV

Journey stage	**3. Pre-boarding**
Journey activity	**Locating an SAV**

Task/ general need	**Specific need**	**Related barrier**	**Ideas/ solutions**	**Excluded group(s)**
Locating an SAV for spontaneous access	Knowing fixed locations where SAVs can be found	*Information and interactions exclusion – poor* learnability, intuitiveness, familiarity	Bus stops Fixed routes Taxi ranks	Older people visually impaired people
	SAVs positioning themselves according to likelihood of passengers being there	*Service exclusion* – poor availability – vehicles not available where needed	SAVs swarming to stations etc.	Older people
Locating a pre-booked SAV	Locating the SAV with visual impairment	*Physical exclusion* – built environment – difficult to navigate for visually impaired people *Information and Interactions exclusion* – Inaccessibility – visual-only information	Audio-based smartphone app Bright exterior lighting Audio beacons Navilens – recognising vehicle and providing directions	visually impaired people
	Locating the SAV promptly to reduce feeling unsafe at roadside	*Psychological exclusion* – fear – waiting for vehicle in public	Bright exterior lighting	Women
Distinguishing your SAV from others	Knowing the SAV is for you with visual information and retaining anonymity	*Information and interactions – Inaccessibility* – audio-only information *Psychological exclusion* – fear – waiting for vehicle in public, sharing personal information	External display with your name or alias Exterior lighting pattern, matching pattern in app	Hearing impaired people Women
	Knowing the SAV is for you with audio information	*Information and Interactions exclusion* – Inaccessibility – visual-only information	Unique audio signature emitted by vehicle	visually impaired people

Appendix 1.5 BOARDING THE SAV

Getting to the doors

TABLE 34 NEEDS OF EXCLUDED GROUPS – GETTING TO THE DOORS

Journey stage	**4. Boarding the SAV**			
Journey activity	**Getting to the doors**			
Task/ general need	**Specific need**	**Related barrier**	**Ideas/ solutions**	**Excluded group(s)**
Locating the SAV doors for visually impaired people	Highly visible door location for visually impaired people with some vision	Physical exclusion – vehicle exterior – difficult to navigate to vehicle doors for visually impaired people Information and interactions exclusion – information about vehicle – lack of door location information for visually impaired people	Contrast colours Dynamic lighting	visually impaired people
	Audible way of locating the doors for visually impaired people	Physical exclusion – vehicle exterior – difficult to navigate to vehicle doors for visually impaired people Information and interactions exclusion – information about vehicle – lack of door location information for visually impaired people	Audio beacon located by doors	visually impaired people
	Tactile way of locating the doors for visually impaired people	Physical exclusion – vehicle exterior – difficult to navigate to vehicle doors for visually impaired people Information and interactions exclusion – information about vehicle – lack of door location information for visually impaired people	Continuous guide rail Tactile surfaces Handles	visually impaired people
	Assistance when locating the doors	Physical exclusion – vehicle exterior – difficult to navigate to vehicle doors for visually impaired people Information and interactions exclusion – information about vehicle – lack of door location information for visually impaired people	Guide dog Staff Other passengers	

Opening the doors and validating the journey

TABLE 35 NEEDS OF EXCLUDED GROUPS – OPENING THE DOORS AND VALIDATING THE JOURNEY

Journey stage	**4. Boarding the SAV**			
Journey activity	**Opening the doors and validating the journey**			
Task/ general need	**Specific need**	**Related barrier**	**Ideas/ solutions**	**Excluded group(s)**
Validating access to the vehicle	Stopping people following you into vehicle or using your pre-booked vehicle	*Psychological exclusion* – Fear – sharing SAV with strangers	Unique code Smartphone app Travel card linked to user account	Older people Women visually Impaired people
	Communicating journey needs when validating access to trigger vehicle adaptation	*Physical exclusion* *Information and interactions exclusion*	Travel card linked to user account	Multiple excluded groups
Controlling the door opening	Locatable and easy to use means of opening doors	*Physical exclusion* – vehicle exterior – difficult to locate to vehicle door controls for visually impaired people *Information and interactions exclusion* – information about vehicle – lack of door control location information for visually impaired people *Physical exclusion* – physical actions – difficulties with dexterity and strength when opening doors	Journey validation triggering automatic door opening Easy to locate and use physical buttons to open door	visually impaired people Disabled people

Stepping/ wheeling onboard

TABLE 36 NEEDS OF EXCLUDED GROUPS – STEPPING/ WHEELING ONBOARD

Journey stage	**4. Boarding the SAV**
Journey activity	**Stepping/ wheeling onboard**

Task/ general need	Specific need	Related barrier	Ideas/ solutions	Excluded group(s)
Physical support when boarding	Physical support features to hold when boarding	Physical exclusion – vehicle exterior – difficult to move onboard. Unstable when moving	Handles Guiderail	visually impaired people Disabled people
Locating steps and ramps when boarding	Boarding features locatable with visually impaired person's cane	Physical exclusion – vehicle exterior – difficult to locate vehicle boarding features for visually impaired people Information and interactions exclusion – information about vehicle – lack of boarding location information for visually impaired people		visually Impaired people
	Boarding features highly visible for visually impaired people with some vision	Physical exclusion – vehicle exterior – difficult to locate vehicle boarding features for visually impaired people Information and interactions exclusion – information about vehicle – lack of boarding location information for visually impaired people	Bright lighting	visually Impaired people
Short distance to step onboard	Low step-in height	Physical exclusion – vehicle exterior – difficult to step onboard	Kneeling suspension system	Mobility impaired people visually impaired people
	Vehicle stopped close to kerb	Physical exclusion – vehicle exterior – difficult to step onboard	SAV pulls close to kerb	Mobility impaired people visually impaired people
Wheelchair access	Level boarding from kerb height	Physical exclusion – vehicle exterior – difficult to wheel onboard	Kneeling suspension system	Wheelchair users
	Unobstructed boarding location	Physical exclusion – built environment-obstructed pavements reducing access to vehicle		Wheelchair users
	Efficient and destigmatising wheelchair boarding process	Psychological exclusion – stigma – delaying other passengers		Wheelchair users
	Usable in multiple locations e.g. to road-level when no direct access to pavement	Physical exclusion – vehicle exterior – no wheelchair boarding from road level	Lift Automatic ramp	Wheelchair users

Journey stage	4. Boarding the SAV			
Journey activity	Stepping/ wheeling onboard			

Task/ general need	Specific need	Related barrier	Ideas/ solutions	Excluded group(s)
	Easy way of triggering ramp/ lift access	Information and interactions exclusion – vehicle exterior – reaching ramp controls from wheelchair	Travel card linked to user account – tap card and it knows to deploy ramp	Wheelchair users

Appendix 1.6 ONBOARD THE SAV

Getting to (and from) the seat

TABLE 37 NEEDS OF EXCLUDED GROUPS – GETTING TO (AND FROM) THE SEAT

]	5. Onboard the SAV
Journey activity	**Getting to (and from) the seat**

Task/ general need	Specific need	Related barrier	Ideas/ solutions	Excluded group(s)
Moving in the vehicle	Flat and clear floor space	*Physical exclusion* – interior layout – difficult to move through for disabled people		Wheelchair users Mobility impaired people
	Reducing obstructions from other passengers	*Interpersonal exclusion*-excluding behaviours-obstructing interior space	Audio announcements	Wheelchair users Mobility impaired people
	Physical support when moving	*Physical exclusion* – interior layout – difficult to move through for disabled people, unstable when moving.	Handles	Wheelchair users Mobility impaired people
	Vehicle waiting until seated before moving	*Service exclusion* – vehicle operation – prioritising speed and excluding groups that take longer for certain tasks	Sitting close to door	Wheelchair users Mobility impaired people
Navigating in the vehicle	Flat and clear floor space	*Physical exclusion* – interior layout – difficult to navigate for visually impaired people		visually impaired people
	Knowing basic vehicle layout	*Physical exclusion* – interior layout – difficult to navigate for visually impaired people *Information and interactions exclusion* – information about vehicle – lack of interior navigation information for visually impaired people	Standardised SAV designs	visually impaired people
	Knowing changing vehicle layout – occupancy and adaptation	*Physical exclusion* – interior layout – difficult to navigate changing interior for visually impaired people *Information and interactions exclusion* – information about vehicle – lack of changing interior navigation information for visually impaired people	Interior audio description	visually impaired people
	Intuitive tactile navigation	*Physical exclusion* – interior layout – difficult to navigate for visually impaired people	Tactile surfaces Tactile flooring	visually impaired people

	Information and interactions exclusion – information about vehicle – lack of interior navigation information for visually impaired people	Handles Continuous guide rail	
Highly visible interior features for visually impaired people with some vision	*Physical exclusion* – interior layout – difficult to navigate for visually impaired people *Information and interactions exclusion* – information about vehicle – lack of interior navigation information for visually impaired people	Bright coloured seats – contrasting top and bottom colours to make it easy to know if folded	visually impaired people

Ensuring suitable seating

TABLE 38 NEEDS OF EXCLUDED GROUPS – ENSURING SUITABLE SEATING

Journey stage	5. Onboard the SAV
Journey activity	**Ensuring suitable seating**

Task/ general need	Specific need	Related barrier	Ideas/ solutions	Excluded group(s)
Wheelchair occupancy	Reserved wheelchair space	*Physical exclusion* – wheelchair space – not reservable		Wheelchair users
	Space for multiple wheelchair users	*Physical exclusion* – wheelchair space – unavailable		Wheelchair users
	Ensuring wheelchair space is unoccupied	*Interpersonal exclusion* – Excluding behaviours – occupying wheelchair space	Audio announcements Folding seating – unobvious, folded by default, and lockable	Wheelchair users
	Reducing difficulty of and dependence on others when applying wheelchair restraints	*Physical exclusion* – wheelchair space – unusable restraints *Psychological exclusion* – Feeling unsafe – poor wheelchair restraints		Wheelchair users
Placing luggage	Ensuring luggage space available to reduce obstructions	*Interpersonal exclusion* – Excluding behaviours – luggage occupying wheelchair space		
	Keeping luggage safe close to seat, in line of sight, or in contact	*Psychological exclusion* – Fear – theft		visually impaired people Women
	Luggage storage reachable and not requiring much strength to lift or position	*Physical exclusion* – luggage storage – inaccessible	Ramp access for wheeled luggage	Disabled people
Sitting with others	Seating near wheelchair space to allow conversation	*Interpersonal exclusion – social* – Not being able to enjoy socialising		Wheelchair users
	Facing seating to allow for lip reading and BSL interpretation	*Interpersonal exclusion* – communication – Not being able to communicate with others		Hearing impaired people
	Space for assistance dogs	*Physical exclusion* – Space for items and companions – No space for assistance dogs		visually impaired people Hearing impaired people
Comfort	Access to forward facing seating			Multiple groups
	Access to different seating types		Perch seating	Multiple groups

Journey stage	5. Onboard the SAV
Journey activity	**Ensuring suitable seating**

Task/ general need	Specific need	Related barrier	Ideas/ solutions	Excluded group(s)
	Sufficient leg room			Multiple groups
Adjusting and arranging seating	Minimal strength and dexterity required to adjust seating	*Physical exclusion* – physical actions – difficulties with dexterity and strength when adapting interior	Folding seating – button operated, self-folding	Disabled people
Priority disabled space	Provision of priority access to seats with accessibility features	*Interpersonal* – Other people occupying disabled spaces *Physical exclusion* – physical actions – difficulties with dexterity and strength when adapting interior		Disabled people

Accessing information and interacting with the SAV

TABLE 39 NEEDS OF EXCLUDED GROUPS – ACCESSING INFORMATION AND INTERACTING WITH THE SAV

Journey stage	5. Onboard the SAV
Journey activity	**Accessing information and interacting with the SAV**

Task/ general need	Specific need	Related barrier	Suggested negatives/ trade-offs	Ideas/ solutions	Excluded group(s)
Inclusive on-journey interfaces	Simple and locatable buttons and switches	*Information and interactions exclusion* – inaccessibility – difficult to locate interface controls		Large, tactile buttons Contrasting colours and highlights	visually impaired people
	Personal at-seat interface – providing an alternative to smartphone	*Information and interactions exclusion* – inaccessibility – dexterity issues with fine interactions, visual-only information *poor* learnability, intuitiveness, familiarity – low digital literacy			visually impaired people Older people Dexterity impaired people
	Personal at-seat interface – simple, tactile controls instead of touchscreens	*Information and interactions exclusion* – inaccessibility – non-tactile controls inaccessible to visually impaired people		Simple, physical tactile controls	visually impaired people
	Personal at-seat interface – voice control	*Information and interactions exclusion-poor* learnability, intuitiveness, familiarity inaccessibility -visual-only information	Automated voice interfaces – unreliable	Voice interface	visually impaired people Older people
	Personal at-seat interface – controls reachable from wheelchair	*Information and interactions exclusion* – Inaccessibility – not reachable			Wheelchair users
	Personal at-seat interface – audio format	*Information and interactions exclusion – poor* learnability, intuitiveness, familiarity inaccessibility – visual-only information		Headphone socket for privacy	visually impaired people
	Personal at-seat interface – easy to understand visual format	*Information and interactions exclusion* – not understandable			Multiple groups
	Personal at-seat interface – privacy	*Psychological exclusion* – fear – sharing personal information			Multiple groups

Journey stage	5. Onboard the SAV
Journey activity	**Accessing information and interacting with the SAV**

Task/ general need	Specific need	Related barrier	Suggested negatives/ trade-offs	Ideas/ solutions	Excluded group(s)
	Information for all passengers – simple, large, graphical route maps and location information	*Information and interactions exclusion* – complexity		Visual display – simple, large, graphical route maps and location information	Multiple groups
	Information for all passengers – audio routing and location information	*Information and interactions exclusion* – inaccessibility – visual-only information		Button to trigger audio announcement for visually impaired people	visually impaired people
	Information for all passengers – audible alerts and notifications	*Information and interactions exclusion* – inaccessibility – visual-only information		Audio announcements	visually impaired people
	Information for all passengers – non audio alternatives for alerts and notifications	*Information and interactions exclusion* – inaccessibility – audio-only announcements		Visual alerts and notifications	Hearing impaired people
	Automation of interactions based on stored needs and preferences	*Information and interactions exclusion* – complexity *Physical exclusion*		Travel card – tapped when seated to apply preferences	Multiple groups
Provision of necessary information and interactions for excluded groups	Initiating the journey once seated to avoid moving when the vehicle is driving	*Service exclusion* – vehicle operation – prioritising speed and excluding groups that take longer for certain tasks		Button to initiate journey	visually impaired people Wheelchair users Mobility impaired people
	Initiating the journey by paying at seat				Multiple groups
	Accessing journey information – vehicle ETA				Multiple groups
	Accessing journey information – routing				Multiple groups
	Accessing journey information – alerts and updates e.g. delays				Multiple groups

Journey stage	5. Onboard the SAV				
Journey activity	**Accessing information and interacting with the SAV**				

Task/ general need	Specific need	Related barrier	Suggested negatives/ trade-offs	Ideas/ solutions	Excluded group(s)
	Accessing journey information – current location for visually impaired people unable to look outside	*Information and interactions exclusion* – inaccessibility – visual-only information			visually impaired people
	Responding to emergencies – intuitive controls if vehicle needs to be moved in emergency	*Information and interactions exclusion – poor* learnability, intuitiveness, familiarity in safety-critical scenarios			Older people
	Responding to emergencies – simple to activate emergency phone	*Information and interactions exclusion – poor* learnability, intuitiveness, familiarity in safety-critical scenarios Inaccessibility in safety-critical scenarios			Multiple groups
	Responding to emergencies – clear, accessible information about arrival of replacement vehicle	*Information and interactions exclusion – poor* learnability, intuitiveness, familiarity in safety-critical scenarios			Multiple groups
	Responding to emergencies – easy to locate emergency exits for visually impaired people	*Physical exclusion* – interior layout – difficult to navigate for visually impaired people in emergencies *Information and interactions exclusion* – information about vehicle – lack of interior navigation information for visually impaired people I emergencies			visually impaired people

Enjoying the journey

TABLE 40 NEEDS OF EXCLUDED GROUPS – ENJOYING THE JOURNEY

Journey stage	5. Onboard the SAV
Journey activity	Enjoying the journey

Task/ general need	Specific need	Related barrier	Ideas/ solutions	Excluded group(s)
Good interior condition	Hygiene when sharing vehicle	*Interpersonal* – Hygiene of other passengers *Psychological* – discomfort-unhygienic interior	Crowdsourced reports on interior condition	Multiple groups
	Clean vehicle interior	*Psychological*-discomfort-unclean interior	Crowdsourced reports on interior condition	Multiple groups
	Non-vandalised interior	*Psychological* – discomfort – vandalised interiors	Crowdsourced reports on interior condition	Multiple groups
Comfort	Accessible and usable controls of climate control features			Multiple groups
	Comfortable and smooth driving style			Multiple groups
	Pleasant and configurable lighting		Lighting features Configurable window blinds	Multiple groups
On-journey activities	Facilitating personal device use and reading		Folding table Charging sockets	Multiple groups
	Ensuring passenger health		Health monitoring	Older people
	Keeping family updated on whereabouts		Location sharing	Older people
	Luxury/ surprise and delight features		Drinks cabinet Complementary food Refrigerated shopping section Free newspapers	Older people

Sharing the journey

TABLE 41 NEEDS OF EXCLUDED GROUPS – SHARING THE JOURNEY

Journey stage	5. Onboard the SAV
Journey activity	**Sharing the journey**

Task/ general need	Specific need	Related barrier	Ideas/ solutions	Excluded group(s)
Reducing crowding	Reducing crowding for easy movement and navigation	*Interpersonal exclusion* – crowding – movement and navigation difficult	SAVs only transporting seated passengers	visually impaired people Cognitively impaired people (Risser et al., 2012)
	Reducing crowding to reduce potential for sexual assault	*Interpersonal exclusion* – dangerous, illegal and antisocial passenger behaviours – sexual assault in crowds	SAVs only transporting seated passengers	Women
Managing dangerous, illegal, and antisocial passenger behaviours	Monitoring of the vehicle and passengers to deter and respond to negative behaviours	*Interpersonal exclusion* – dangerous, illegal, and antisocial passenger behaviours *Psychological exclusion* – fear – sharing SAV with strangers	CCTV Female staff member	Women
	Division of interior space to separate passengers	*Interpersonal exclusion* – dangerous, illegal and antisocial passenger behaviours *Psychological exclusion* – fear – sharing SAV with strangers	Floor-to-ceiling division – walls, curtains, semi-transparent dividers Division between seats – armrests, moveable dividers, headrests	Women
	Providing emergency responses to dangerous passenger behaviour	*Interpersonal exclusion* – dangerous, illegal and antisocial passenger behaviours *Psychological exclusion* – fear – sharing SAV with strangers	Panic button – hidden location Vehicle responds to panic button by driving to safe location/ locking	Women Older people
	Passenger reporting of others' negative behaviours	*Interpersonal exclusion* – dangerous, illegal and antisocial passenger behaviours *Psychological exclusion* – fear – sharing SAV with strangers	CCTV monitoring – to verify accounts Denying access to dangerous passengers based on reports	Women
Calibrating social interaction with other passengers	Seating layout providing for privacy	*Interpersonal exclusion* – social interaction – unwanted *Psychological exclusion* – anxiety – unwanted social interaction	Adaptability of seating layout	Multiple groups
	Seating layout providing for social interaction	*Interpersonal exclusion* – social interaction – lack of social interaction	Adaptability of seating layout	Multiple groups

Awareness and attitudes of other passengers	Public patience and awareness of disabilities – Particularly related to assistance dogs and assistive devices	*Interpersonal exclusion* – poor awareness – disability	Public education	Cognitively impaired people (Risser et al., 2012) Hearing impaired people visually impaired people
	Reducing need to advocate for use of priority spaces and features	*Interpersonal exclusion* – poor awareness – disability, obstructing and occupying disabled spaces	Signage Audio announcements	Mobility impaired people visually impaired people Disabled people

Preparing to end the journey

TABLE 42 NEEDS OF EXCLUDED GROUPS – PREPARING TO END THE JOURNEY

Journey stage	Onboard the SAV			
Journey activity	**Preparing to end the journey**			
Task/ general need	**Specific need**	**Related barrier**	**Ideas/ solutions**	**Excluded group(s)**
Notification of journey end	Knowing when journey is ending	*Information and interactions exclusion* – inaccessibility -visual-only information	Vibrotactile feedback Audio announcements	visually impaired people
Ensuring suitable drop-off location	Selecting safe drop-off location	*Psychological exclusion* – fear – when alone, at night *Psychological exclusion* – fear – sharing personal information e.g. address.	App – Map interfaces, adjusting end point	Women
	Selecting accessible drop-off location	*Physical exclusion* – built environment – *difficult* to move through for disabled people	Audio description of exterior obstacles Vehicle stops automatically in accessible locations	visually impaired people Wheelchair users

Appendix 1.7 END OF THE JOURNEY

Leaving the vehicle

TABLE 43 NEEDS OF EXCLUDED GROUPS – LEAVING THE VEHICLE

Journey stage	6. End of the journey
Journey activity	**Leaving the vehicle**

Task/ general need	Specific need	Related barrier	Ideas/ solutions	Excluded group(s)
Getting from your seat to the door	Time to move from seat to door	Service exclusion – vehicle operation-prioritising speed and excluding groups that take longer for certain tasks		visually impaired people
Operating ramp/ lift	Reliable and efficient operation of ramp/lift	Psychological exclusion – Stigma – delaying or inconveniencing other passengers		Wheelchair users
Returning adapted interior to default	Folding seating automatically returns to folded position to ensure clear space	Physical exclusion – interior layout – difficult to move through for disabled people	Folding seating-default folded	Wheelchair users

Getting from vehicle to destination

TABLE 44 NEEDS OF EXCLUDED GROUPS – GETTING FROM VEHICLE TO DESTINATION

Journey stage	6. End of the journey
Journey activity	**Getting from vehicle to destination**

Task/ general need	Specific need	Related barrier	Ideas/ solutions	Excluded group(s)
Onward navigation	Navigation instructions for onward journey	Physical exclusion – built environment – difficult to move through for disabled people	Audio announcement – onward navigation instructions	visually impaired people

Security after leaving the vehicle

TABLE 45 NEEDS OF EXCLUDED GROUPS – SECURITY AFTER LEAVING THE VEHICLE

Journey stage	End of the journey
Journey activity	**Security after leaving the vehicle**

Task/ general need	Specific need	Related barrier	Ideas/ solutions	Excluded group(s)
Feeling safe when getting from vehicle to destination	Knowledge about safety of area	*Psychological exclusion* – fear – walking alone, at night		Women
	Monitoring their location	*Psychological exclusion* – fear – walking alone, at night	App sharing location with friends, family, or service	Women
	Communicating that they are safely home	*Psychological exclusion* – fear – walking alone, at night	App – home safe feature pressed when arrived at home/ trigger responses if not	Women
	Rating safety of the journey	*Psychological exclusion* – fear – walking alone, at night	App – simple rating system to inform future safety of service	Women

Appendix 2 RESEARCH TOOLS & DATA

Appendix 2.1 QUESTIONS AND RESPONSES FROM AUTOMOTIVE AND TRANSPORT INDUSTRY SURVEY

TABLE 46 QUESTIONS AND RESPONSES FROM AUTOMOTIVE AND TRANSPORT INDUSTRY SURVEY

Question	Type of question/ conditions	Choices/ section	Number of respondents/ average Likert response
What type of organisation do you work in?	(Select one of)	Car manufacturer	22
		Commercial vehicle manufacturer	2
		Design consultancy	7
		Other (write in)	3
		Rail rolling stock manufacturer	0
		Motorcycle manufacturer	0
		Bicycle manufacturer	0
What department/ area do you work in?	(Select one of)	Vehicle engineering/ architecture/ packaging	8
		Vehicle exterior design	6
		Vehicle interior design	3
		HMI/ UI/ UX design	3
		Design management	3
		Quality	3
		Other (write in)	4
		CMF design	0
		Studio engineering	0
		Service design	0
		Experience design	0
		Product planning & research	0
What is the title of your role?	(write in)		
The needs of the following groups should be specifically addressed in the design and development of vehicles:	(5pt Likert scale for each group) Strongly disagree Disagree Neither agree nor disagree Agree Strongly agree	Older people	4.3
		Children	4.1
		Disabled people	4.4
		Women	4.0
		Ethnic minorities	3.5
		People in low income households	3.5
		People living in rural communities	3.7
The needs of excluded people groups should be addressed in the following areas of vehicle development:	(5pt Likert scale for each area) Strongly disagree Disagree Neither agree nor disagree Agree Strongly agree	Product planning & research	4.3
		Vehicle packaging & engineering	4.1
		Vehicle styling	3.5
		Interior design	4.1
		HMI design	4.2
		CMF design	3.6
The needs of excluded people groups should	(5pt Likert scale for each type)	Privately owned cars	3.8
		Shared/ hire cars (e.g. Zipcar service)	4.2

be addressed in the design of the following vehicle types:	Strongly disagree Disagree Neither agree nor disagree Agree Strongly agree	Goods vehicles	3.6
		Buses and minibuses	4.5
		Trains, trams, underground	4.6
		Taxis	4.3
		Bicycles	3.7
In my department, the needs of the following groups are specifically addressed:	(5pt Likert scale for each group) Strongly disagree Disagree Neither agree nor disagree Agree Strongly agree	Older people	3.4
		Children	3.2
		Disabled people	3.0
		Women	3.3
		Ethnic minorities	2.9
		People in low income households	2.7
		People living in rural communities	2.9
When considering the needs of excluded people groups, where do you normally find information about their needs? (Select all that apply)	(select multiple of)	Anthropometric data	19
		Internal user research (user testing, focus groups, questionnaires etc.)	23
		Market research (reports on trends etc.)	22
		Academic sources (research papers, academic conferences etc.)	12
		Books	7
		Online resources (websites, videos, blogs etc.)	25
		Experts/ consultants	15
		Other (write in)	4
		N/A	0
How do you consider the needs of excluded people groups in your work? (Select all that apply)	(select multiple of)	Designing specific solutions to meet the needs of specific excluded people groups	15
		Considering excluded people's needs throughout the development process	26
		Communicating excluded people's needs to other employees	16
		Testing and evaluating prototypes with members of excluded groups	13
		Creating tools to help further consider excluded people's needs (e.g. personas)	9
		Other (write in)	3
Which of the following resources would be most useful to you in learning about the needs of excluded people groups? (Select up to 3)	(select 3 of)	User profiles/ personas demonstrating the needs of excluded people groups with images and storyboards	16
		Videos of members of excluded people groups explaining/ demonstrating the exclusion they face	17
		Opportunities to meet and talk with members of excluded groups	19
		Case studies of key general issues of exclusion in transport	13
		Examples of existing inclusive vehicle design solutions	17
		Examples of potential inclusive vehicle design solutions (sketches, renders, images of prototypes etc.)	4
		Other (write in)	1

Please add any additional ideas you have for useful resources for learning about the needs of excluded people groups	(Write in)	
What do you think are the main barriers to creating more inclusive vehicles?	(Write in)	

Appendix 2.2 DISCUSSION GUIDE FROM AUTOMOTIVE OEM DESIGN TEAM FOCUS GROUP

1. Welcome and Introduction (5 mins)

- **Objective**: Introduce the project, explain the purpose of the discussion, answer any initial questions
- **Discussion**:
    - 'This session is intended to be an open discussion about inclusivity in automotive design. I'll ask some questions and test a few ideas, and I'd love your honest input.'
    - Give a brief project overview.
    - Q&A: 'Do you have any initial questions about the project or its purpose?'

2. Designers' general perceptions of inclusivity (10 mins)

- **Objective**: Understand designers' views of inclusivity and how it might be considered in their work, or the automotive industry in general.
- **Discussion**:
    - 'How could inclusivity be considered in the design of vehicles?'
    - 'Are there any examples of when you have considered inclusivity in the design process?'

3. Influence of the initial design brief and direction (15 mins)

- **Objective:** Understand how initial decisions in the vehicle development project can impact the extent to which the design is inclusive.
- **Discussion**:
    - 'How do you initially determine the types of people a particular vehicle is designed for?'
    - 'What information do you use to focus your design work on the defined target group(s)? How clearly and specifically are the needs/ desires of these groups defined?'
    - 'How much control do designers have over the scope of the brief/ defined target group?'

4. Ways of applying inclusive design in industry (15 mins)

- **Objective**:
    - Understand the ways in which inclusive design might be applied in automotive design studios in a way that aligns with current constraints and priorities.
- **Discussion**:
    - 'Are there any ways that considering the needs of excluded groups could influence your day to day design work within current constraints?'
    - 'What might be the most effective ways of providing inclusive design information and insights to designers in industry?'

5. Barriers to inclusive design in industry (15 mins)

- **Objective**:
    - Understand the barriers to applying inclusive design in an automotive industry context.
- **Discussion**:
    - 'What are the main barriers you might experience in considering inclusivity throughout the design of a vehicle.

Appendix 3 RCA RESEARCH ETHICS APPROVAL

This project has been conducted according to RCA Research Ethics policies and procedures. The following ethics approval letters correspond to four separate ethics approvals for interviews and focus groups with industry experts, the industry inclusive design survey, exploratory workshops, and focused workshops respectively.

[The following text that appeared in the thesis was removed due to its sensitive nature regarding personal data]