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Remote driving as the Failsafe: Qualitative investigation of Users' perceptions and requirements towards the 5G-enabled Level 4 automated vehicles

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ABSTRACT

The Level 4 Automated Vehicles (L4 AV) potentially deliver social, economic, safety and environmental benefits. A key feature for the L4 AV is the failsafe mechanism which ensures the safety of the vehicle without human driver input when reaching system limitations. An important solution for the failsafe is the 5G-enabled teleoperation system controlled by a remote driver. However, understanding end-users' perception, needs and requirements towards the L4 AV is a significant under-researched area. To fill the research gap, this study conducted semi-structured interviews with 29 potential end-users to qualitatively explore the new driver-automation-remote driver interaction in the L4 AV. Results showed that end-users would like to understand how the remote driver operates the vehicle remotely and would not expect them to be multitasking or distracted. They also show that remote drivers' sensing and information about the driving environment are important. Remote drivers should also be qualified and experienced drivers and must have undergone background security checks before teleoperating the L4 AV. They require remote drivers based in the same country as the L4 AV to prevent issues such as unfamiliar road layouts, different traffic rules, cultural driving style variations, liability concerns, and time differences from affecting performance. They require the remote drivers to clarify what had happened and explain how they will deal with the situation and operate the vehicle in the situation of failsafe in the L4 AV. Dedicated remote drivers are preferred over random ones. A review and feedback system is important for the end-users to evaluate the services and choose preferred remote drivers. Finally, end-users are concerned about the liability and legal implications of utilising a L4 AV, especially during the period that the L4 AV is being operated by the remote drivers.

1. Introduction

Automated vehicles are potentially to redefine the future of the road transportation system, by 2035, it is projected that vehicles equipped with automated driving features will constitute 40 % of new cars in the UK HMGovernment (2022). Widely recognised as a prominent and revolutionary innovation in road transportation, vehicle automation has the potential to not only transform the way

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people drive and travel but also deliver tremendous benefits to the society. (Talebpour and Mahmassani, 2016; Li et al., 2021; Lu et al., 2022; Li et al., 2023). The positive implications of automated vehicles on society and the transportation system span various social, economic, safety, and environmental aspects. They are expected to remove driver errors such as driving too fast, distracted driving and driver fatigue (Tengilimoglu et al., 2023). Given that human errors contribute to a large percentage of car collisions (NHTSA, 2017), the impact of automated vehicles on road safety is profound (Sohrabi et al., 2021). Moreover, they play a significant role in enhancing fuel efficiency, potentially reducing global energy consumption and providing environmental benefits on a global scale (Vahidi, A.a.S., A, 2018). Additionally, automated vehicles are crucial in reducing traffic congestion, decreasing average trip times and enhancing road capability (Talebpour and Mahmassani, 2016; Mavromatis et al., 2020). They also have the potential to offer tailored support to enhance the mobility, independence and accessibility of user groups with special mobility needs, such as older people and individuals with disabilities, and to compensate for the limited transport capacities (Vahidi, A.a.S., A, 2018; Li et al., 2019c; Tengilimoglu et al., 2023).

As the positive implications of vehicle automation in the society and transport has been widely acknowledged, vehicles with automated driving features have not only become a major focal point of government-supported research and development activities but also captivated massive attention in the media and the news (Li et al., 2018; Shladover, 2018; Li et al., 2022). Although various terms have been used to refer to vehicles with automated driving features, such as driverless cars, self-driving vehicles, and autonomous vehicles, the nature of automation in vehicles is not homogeneous. Different sublevels of vehicle automation systems are differentiated by the type of driver-vehicle interactions and the automated system capabilities (SAE, 2016). The basic levels of vehicle automation systems (SAE Level 0 to Level 1) are primarily deployed on conventional vehicles. The main role of automation systems is to provide a wide range of aid and support to the driver, from enhancing driver sense of the environment to providing addition informational support and sustaining longitudinal or lateral control of the vehicle (SAE, 2016). However, in these systems, the human driver must be constantly physically and mentally engaged in the driving loop (SAE, 2016; Li et al., 2023). Drivers of the Level 2 automation systems are allowed to completely withdraw themselves from the physical driving loop of the vehicle, but they must remain constantly involved in the driving loop mentally by keeping their eyes and attention on the road (SAE, 2016; Li et al., 2023). Level 3 systems take one step forward, permitting human drivers to be completely disengaged from driving for some part of the journey. However, they are designed to be fail-silent, relying completely on the human driver to retake the vehicle control and be responsible for the overall safety when the Level 3 systems reach to the limitations (SAE, 2016; Vom Dorff et al., 2020; Li et al., 2023). Various factors could complicate the takeover process and potentially make it challenging for the drivers to regain control safely and effectively, such as, weather conditions, type of road, driver's different physical and cognitive capabilities, the amount of lead time. (Molnar et al., 2017; Gold et al., 2018; Li et al., 2018; Li et al., 2019b; Zhang et al., 2019; Li et al., 2021). This has created an urgent need to explore and develop automated vehicles with higher levels of autonomy (SAE Level 4 and 5).

The public vision regarding automated vehicle has predominantly centred on the ultimate level-the fully autonomous vehicle (SAE Level 5). At this level, the automation system is capable of safely operating the vehicle without any human driver intervention in all environments and at all times (SAE, 2016; Soteropoulos et al., 2020). However, there is still no definite prediction regarding when the complete autonomous vehicles will be commonplace (Shladover, 2018; Soteropoulos et al., 2020). Before reaching the highest level of vehicle automation, the Level 4 Automated vehicles (L4 AV) can release the human driver completely from the driving loop and drive the vehicle autonomously without human driver's assistance in specific operation design domains (Shladover, 2018; Soteropoulos et al., 2020; Li et al., 2023). The operation design domain is defined as the conditions under which a particular automated driving systems is designed to perform normal operations, such conditions are determined by various limitations including certain geographic, road, traffic, time and environmental features (SAE, 2016; Czarnecki, 2018; Soteropoulos et al., 2020). In opposite to just being fail-silent to system limitations among the lower levels of automation systems (SAE Level 0 to 3), the predominant feature of the L4 AV is its capability to automatically activate fail-safe or fail-operational mechanisms. This ensures the vehicle remains in a safe state or maintains a complete or decreased functionality without external support or assistance in the situation that the vehicle is beyond the scope of its operation design domains (SAE, 2016; Vom Dorff et al., 2020; Li et al., 2023). As such, exploring a reliable, effective, and safe failsafe strategy of the Level 4 automation systems has become a predominant issue strongly associated with the useability and popularity of L4 AVs.

1.1. Teleoperation as the failsafe of Level 4 automated vehicles

A practical and promising method that has been adopted as the failsafe strategy for the L4 AV is using the teleoperation system controlled by a specially trained remote driver (Goodall, 2020; Kettwich et al., 2021; Li et al., 2023). Teleoperation applied in the field of vehicle automation could be grouped into two categories as explained by Goodall (2020). The first type is a basic level referred as remote assistance in which the remote drivers do not provide direct longitudinal and lateral controls of the automated vehicle but only provide strategic assistance such as instructions and permissions regarding the recognitions of objects or obstacles as well as route planning (Goodall, 2020; Vreeswijk et al., 2022). A more demanding teleoperation is referred to as remote driving where the remote driver reassumes the complete control of the vehicle (including the longitudinal control, lateral control and monitoring driving environment) using a teleoperation workstation consisting of full vehicle controls and multiple displays projecting the real time driving environment captured by the cameras and sensors equipped on the automated vehicle (Goodall, 2020; Vreeswijk et al., 2022; Li et al., 2023). Unlike the remote assistance that could be operated using existing wireless cellular network (Goodall, 2020), remote driving strongly relies on ultra-low latency, more reliability and high capacity wireless network, such as 5G (Goodall, 2020; Marquez-Barja et al., 2021; Li et al., 2023). The application of teleoperation as the failsafe of automated vehicles has been investigated by previous research from different perspectives. Some research focused on the legal and operational environment as well as the long-

term implications. Goodall (2020) conducted a rigorous investigation about the legal and operational challenges regarding the teleoperation of vehicle automation as well as proposing a model to envision how many remote drivers would be needed to teleoperate massive deployment of automated vehicle fleets. The research estimated that automated vehicles equipped with teleoperation systems could potentially replace a significant percentage of professional drivers in the USA. Some other research explored the teleoperation from a conceptive and classification perspective. Majstorović et al. (2022) reviewed a series of teleoperation concepts which have been applied to enable the automated vehicle to be fail safe or fail operational in situations where the automated vehicle reaches the system limitation. Their research yielded a sixfold classification of the teleoperation concepts, including Direct Control, Shared Control, Trajectory Guidance, Waypoint, Guidance, Interactive Path Planning and Perception Modification. Bogdoll et al. (2022) proposed new taxonomy of teleoperation of automated vehicles, including clarification of the three sub-roles within the remote operator of automated vehicles- the remote driver, remote assistant, and remote observer. Existing studies also researched the teleoperation of automated vehicle from a technical solution perspective, for example research by Parsa and Farhadi (2018) and Zulqarnain and Lee (2021). Moreover, previous research also explored the teleoperation of automated vehicle from the design of human–machine interfaces (HMI) perspective. Kettwich et al. (2021) tested a multiple-screen design concept HMI to enhance the safety and performance of teleoperation system for the Level 4 automated vehicle with thirteen end-users and found that the design received positive feedback. In addition, Georg and Diermeyer (2019) proposed for a concept HMI for the teleoperation in automated vehicles that enables new elements to be integrated to the HMI based on operator's requirements. Finally, previous research has also tested the remote driver's performance and requirements when interacting with the teleoperation in automated vehicles in both simulated and real-world environment. Musicant et al. (2023) explored the effect of time delays (50 ms, 150 ms, 250 ms) in remote control of automated vehicles using a driving simulator with 72 participants. Results showed that even small delays significantly affected participants' performance, introducing challenges such as increased swerving, speed variability, and a higher potential for crashes, particularly at 250 ms. Participants' subjective assessment (measured by the NASA-TLX), reflected a higher rating with the 250 ms delay. Their findings emphasise the importance of a deeper exploration of teleoperation challenges for vehicle automation. Meanwhile, Li et al. (2023) investigated remote driver's requirements for support after teleoperating an authentic full-scale 5G enabled L4 AV in the real world. Their findings revealed that enhancing the field of vison for driving as well as improving the perception of physical motion feedback are two important needs that potentially enhance the performance of remote drivers of the L4 AV.

2. Research gaps and purpose of this study

Teleoperation stands out as an important solution for the failsafe mechanism for L4 AV and has the potential to facilitate the development of vehicle automation (Goodall, 2020; Li et al., 2023). In contrast to lower levels of automated vehicles (SAE 0–3), where vehicle control is shared between the on-board driver and the automated driving system (SAE, 2016; Li et al., 2023), Level 4 Autonomous Vehicles (L4 AVs) with teleoperation failsafe potentially involve the shared control of the vehicle among three parties—the on-board driver/passenger, the automation systems, and the teleoperation system controlled by the remote driver (Li et al., 2023). This necessitates urgent need for research to understand the dynamics of the new driver-automation-remote driver interaction in L4 AVs. However, as of now, knowledge about this interaction is limited, and key issues and topics within this new dynamic remain unclear. Furthermore, existing research regarding the teleoperation of the L4 AV predominantly focuses on the remote driver's perspective, for example, exploring remote driver's performance and requirements when teleoperating the vehicle. The acceptance, perception, needs and requirements of the potential end-users who would potentially be sitting in the L4 AV are significantly understudied. The absence of such knowledge could potentially diminish the expected social, economic and environmental benefits of the L4 AV. Neglecting the potentially end-users could also potentially prevent the L4 AV from being designed user-friendly and thereby negatively affect its useability.

To address the research gaps identified above, the overall aim of this study was twofold:

- To investigate user's perception, needs and requirements towards the Level 4 automated vehicles incorporating the 5G-enabled remote driving as the failsafe mechanism.
- To provide in-depth understanding towards the new driver-automation-remote driver interaction in the L4 AV with teleoperation as the failsafe as well as to identify related key topics and issues.

3. Methods

3.1. Participants

The participant recruitment was informed by the three-stage process for recruitment strategy proposed by MacDougall and Fudge

Table 1
Annual mileage driven by participants.

Annual mileage (miles)	*0–3000*	*3000–6000*	*6000–10000*	*10000–15000*	*15000+*	*Total*
Female	2	4	5	3	0	14
Male	1	5	4	4	1	15
Total	3	9	9	7	1	29

(2001). They were recruited from local communities in the UK. The eligibility criteria for participation are to have a valid UK driving license, to be an active driver at the time of participation in the study-use a car at least once every week, and to be interested in using automated vehicles. In total, 29 potential users participated in the study (n = 29, Mean = 43.14 years, SD = 16.90 years, Min = 20 years, Max = 79 years). Among them, 14 were females (n = 14, Mean = 40.86 years, SD = 13.54 years, Min = 25 years, Max 75 years). And 15 were males (n = 15, Mean = 45.27 years, SD = 19.78 years, Min = 20 year, Max = 79 years). Their annual mileage was displayed in Table 1.

4. Research design and data collection

This study focused on the 5G-enabled Level 4 automated passenger vehicle based on the definition provided by SAE (2016). As illustrated in Fig. 1, the L4 AV can perform automated driving and operate full dynamic driving tasks within its operational design domain. When the vehicle is in automated driving mode, the passenger in the vehicle can be completely disengaged from the driving loop and safely perform non-driving related activities (Li et al., 2018; Li et al., 2019b; Li *et al.*, 2019d). In situations that are out of the operation design domain of the L4 AV, it has the option to enable the passenger in-vehicle to take over control and to manually handle the system limitation. However, if the passenger on-board is not able to or not willing to retake the vehicle control, the L4 AV can still ensure driving safely by automatically initiating a failsafe mechanism (SAE, 2016; Li et al., 2018), in this case-remote driving, where the control of the vehicle will be handed to the teleoperation system powered by a 5G network and controlled by a specially trained human remote driver. The remote driver then controls the vehicle on the teleoperation workstation and handle the system limitation. Fig. 2 shows the remote driver was controlling the L4 AV via the 5G-enabled teleoperation system.

The current study attempted to develop a qualitative understanding towards end-users' requirements towards 5G enabled L4 AV. The most commonly adopted methods by previous qualitative research of vehicular applications are focus groups and interviews (Emmerson et al., 2013; Gesser-Edelsburg and Guttman, 2013; Buckley et al., 2018; Li et al., 2019c; Li et al., 2022; Li et al., 2023). Considering this study was targeting L4 AV, a relatively new road technology to the end-users, it was considered important to provide them with opportunities to thoroughly describe and communicate their attitudes, perceptions and requirements towards L4 AV. Therefore, semi-structured interviews were selected.

Prior to the study, the researchers received ethical approval from Newcastle University's ethics committee and a risk assessment was also performed. At the beginning of the data collection, the participants were informed that their participation was fully voluntary, and they could quit the study at any time for any reason. Also, they were also informed that all responses would be treated anonymously and access to the qualitative data is only restricted to the personals involved in t his study. No photograph or v ideo clip of their image will be collected. The consent for participation was obtained for all participants. Prior to conducting the semi-structured interviews, participants were informed about the definition of the L4 AV and introduced to the concept of using remote driving as a failsafe for L4 AV. The DCMS 5G Connected and Automated Logistics (5G CAL, see Fig. 2) was presented as an illustrative example of a L4 AV integrating remote driving as its failsafe mechanism. This enables them to develop a clear understanding the passenger-vehicle-remote driver interactions in the L4 AV. After that, the data collection for the interview investigation started. The interviews were recorded to facilitate the transcription. The interviews lasted no more than 30 min for each participant (Li et al., 2019c). The interview adopted a semi-structured format, incorporating predefined themes related to the interaction between passengers, vehicles, and remote drivers in the L4 AV. These key themes include general opinions about L4 AVs, non-driving related tasks and takeover control scenarios in L4 AVs, remote driving failsafe in L4 AVs, and advice for manufacturers of L4 AVs. This method enables the exploration of more in-depth questions and topics arising from participants' responses (DiCicco-Bloom and Crabtree, 2006; Li et al., 2019c). The participants were tasked to share their understandings, opinions, experiences, perspectives, and insights related to the predefined themes regarding the L4 AV along with any emerging themes or topics that surfaced during their discussions.

4.1. Data analysis

The qualitative data collected from the participants via semi-structured interviews was analysed using thematic analysis. The qualitative data analysis software NVivo was used to administer the thematic analysis (Castleberry and Nolen, 2018; Li et al., 2019c). The instructions suggested by Braun and Clarke (2006) was adopted to guide the implementation of the thematic analysis. To begin with, participants interviews were firstly transcribed manually. And then researchers read through the transcripts to be familiar with

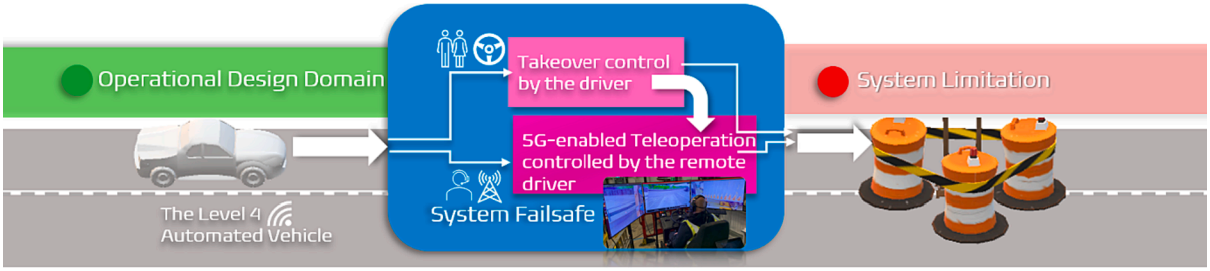

Fig. 1. Illustration of the 5G-enabled Level 4 automated vehicles with the teleoperation as the failsafe.

Fig. 2. An example of a remote driver operating a teleoperation workstation for remote driving (left) of a 5G-enabled Level 4 automated vehicle (right) in the DCMS 5G Connected Automated Logistics project.

the qualitative data as well as to capture any initial ideas and perceptions regarding the data. Next, the data coding was implemented using NVivo by inductively reviewing and identifying the semantic characteristics of participants' comments. A summative and concise name were given to each code. The coding exercise was performed by two researchers to minimise subjective bias and ensure the validity and reliability of the coding (Boyatzis, 1998; Li et al., 2019c). Significant consistency in coding was reached between the two researchers (intercoder reliability = 0.86), as they agreed that the coding labels they used represent similar emerging themes in the data (Li et al., 2019c; Armstrong et al., 2020). The next stage was to group the codes to initial sub-themes and then combine sub-themes to core themes. Themes were identified and generated based on the qualitative depth and significance of the topic in relating to the research purpose and questions (Braun and Clarke, 2006; Vaismoradi et al., 2016; Li et al., 2019c). After that, the identified core themes and sub themes were examined and reviewed against the original participants interview data. The research process and key findings were illustrated in Fig. 3.

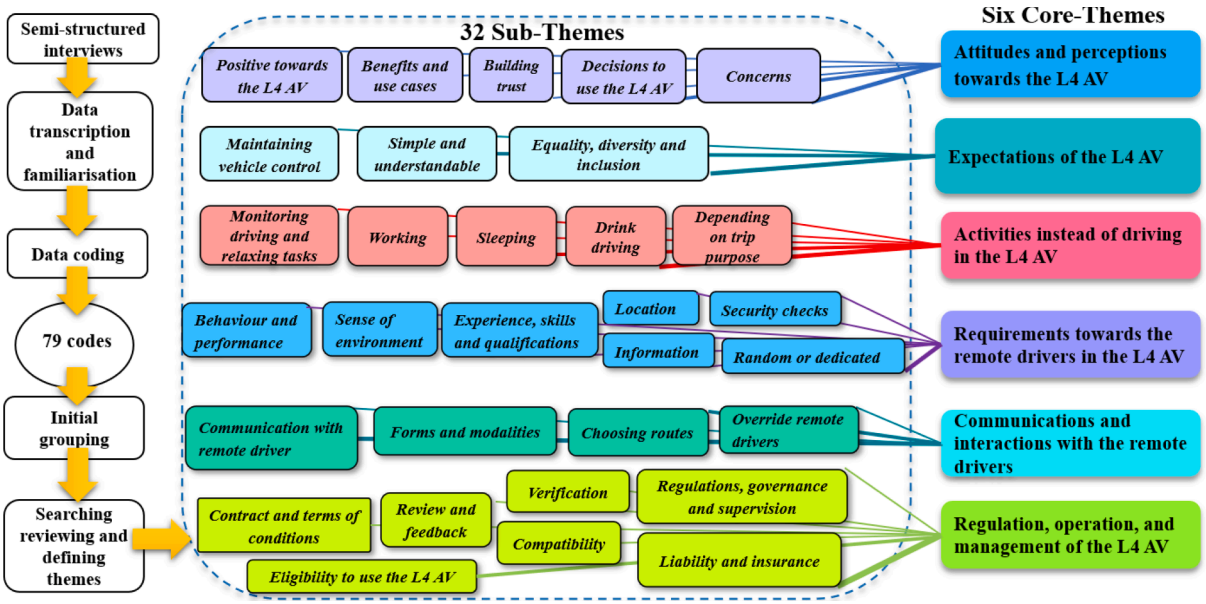

Fig. 3. Illustration of the thematic analysis.

Table 2
Summary of thematic analysis.

Core themes and sub themes	*Codes and frequency of codes*
1. Attitudes and perceptions towards the L4 AV	
1.1 Positive towards the L4 AV	a. The L4 AV is a great technology (n = 12, 8F, 4 M)
	b. I like the failsafe of the L4 AV (n = 3, 2F, 1 M)
1.2 Perceived benefits and positive use cases of the L4 AV	a. L4 AV is good for driving at night (n = 1, 1F)
	b. L4 AV is good for long distance trips (n = 6, 4F, 2 M)
	c. L4 AV is good for motorway driving (n = 8, 2F, 6 M)
	d. L4 AV is good for recurring journeys (n = 1, 1 M)
	e. L4 AV is good for short trips (n = 1, 1 M)
	f. L4 AV reduces driving fatigue (n = 1, 1 M)
	g. L4 AV is good for unfamiliar drive (n = 1,1M)
1.3 Building trust towards the L4 AV	a. Public confidence is important (n = 1, 1 M)
	b. Build trust of the L4 AV over time (n = 10, 5F,5M)
	c. Need to see more evidence of safe operations to trust the L4 AV (n = 3, 1F, 2 M)
1.4 Decisions to use the L4 AV	a. Decision to use the L4 AV is affected by friends and family (n = 2, 1F, 1 M)
1.5 Perceived concerns and challenges of the L4 AV	a. Reluctant to use the L4 AV (n = 7, 3F, 4 M)
	b. Privacy issues in the L4 AV (n = 1, 1F)
	c. Cyber security issues of the L4 AV (n = 4, 2F,2M)
	d. Concerns about the 5G enabled teleoperation of the L4 AV (n = 9, 3F, 6 M)
	e. Challenges of the L4 AV (n = 3, 2F, 1 M)
	f. 5G network connection (n = 5, 3F, 2 M)
2. Expectations of the L4 AV	
2.1 Maintaining control of the vehicle	a. I like driving (n = 4, 1F, 3 M)
	b. I prefer to take over myself in the L4 AV (n = 16, 7F, 9 M)
	c. Maintaining certain level of control of the vehicle (n = 5, 3F, 2 M)
2.2 Simple and understandable L4 AV	a. Make the L4 AV simple and understandable (n = 3, 1F, 2 M)
2.3 Equality, diversity and inclusion of the L4 AV	a. Ensure gender equality for remote drivers (n = 1, 1F)
	b. Ensure the L4 AV is inclusive for everyone (n = 1, 1F)
3. Activities instead of driving in the L4 AV	
3.1 Monitoring driving and relaxing tasks	a. I would like to use my mobile phone in the L4 AV (n = 9, 3F, 6 M)
	b. I would like to play with kids in the L4 AV (n = 1, 1 M)
	c. I would like to look at scenery in the L4 AV (n = 3, 1F, 2 M)
	d. I would like to read a book in the L4 AV (n = 1, 1 M)
	e. I would like to watch a film in the L4 AV (n = 2, 1F,1M)
	f. I would not do demanding tasks in the L4 AV (n = 7, 4F, 3 M)
	g. I still want to be in the driving loop of the L4 AV (n = 2, 1F, 1 M)
	h. I would like to eat and drink in the L4 AV (n = 3, 2F, 1 M)
	i. I would like to monitor driving in the L4 AV (n = 7, 3F, 4 M)
3.2 Working	a. I would like to do some work in the L4 AV (n = 8, 3F, 5 M)
3.3 Sleeping	a. I would not be sleeping in the L4 AV (n = 5, 2F, 3 M)
3.4 Drink driving	a. Is drink-driving allowed in the L4 AV (n = 2, 1F, 1 M)
3.5 Preferred tasks depend on trip purpose	a. What I would do in the L4 AV depends on the trip purpose (n = 4, 1F, 3 M)
4. Requirements towards the remote drivers in the L4 AV	
4.1 Remote driver's behaviour and performance	a. I want the remote driver to be always on standby (n = 3, 3F)
	b. Remote driver to potentially be dealing with multiple situations (n = 1, 1F)
	c. The remote driver is doing nothing for most of the time (n = 1, 1F)
	d. Remote drivers should not be multitasking and distracted (n = 2, 1F,1M)
	e. I need to know the remote driver is doing what they said they are doing (n = 4, 2F, 2 M)
	f. I would need to understand what the remote driver is doing (n = 9, 5F, 4 M)
4.2 Remote driver's sense of the environment and information about journey	a. Remote driver's sense and information of the environment and situation (n = 7, 2F, 5 M)
	b. Remote driver knows what I want about my journey (n = 2, 2 M)
4.3 Experience, skills and qualifications of the remote driver	a. Experience, skills and qualifications of the remote driver (n = 19, 9F, 10 M)
	b. Teleoperation companies make sure the remote driver is qualified (n = 4, 1F, 3 M)
4.4 Location of the remote driver	a. Remote drivers are living in the UK (n = 7, 2F, 5 M)
	b. It is not practical to ensure remote drivers always be in the UK (n = 1, 1 M)
4.5 Information about the remote driver	a. I feel better if the remote driver is someone I know (n = 4, 1F, 3 M)
	b. I feel comfortable if the remote driver is recommended by someone I trust (n = 2, 2F)
	c. I need to know beforehand who the remote driver is (n = 1, 1 M)
	d. I would need to know who the remote drivers were employed by (n = 1, 1 M)
	e. I would not need to know my remote driver individually (n = 1, 1 M)
	f. Remote drivers are hired by approved companies (n = 1, 1F)
4.6 Security checks for remote drivers	a. Security check for the remote driver (n = 3, 2F, 1 M)
4.7 Random or dedicated remote drivers	a. Dedicated or random remote drivers (n = 3, 1F, 2 M)
	b. Random remote drivers would be more feasible (n = 2, 2 M)
5.Communications and interactions with the remote drivers	
5.1 Communication with the remote driver	a. I would like to communicate with the remote driver in the L4 AV (n = 13, 4F, 9 M)
	b. Remote driver explains to the user what had happened and the next move (n = 15, 9F, 6 M)

(*continued on next page*)

Table 2 (*continued*)

Core themes and sub themes	*Codes and frequency of codes*
	c. I need to communicate with the remote driver only if something went wrong (n = 6, 2F, 4 M).
5.2 Forms and modalities for communication and interaction with remote drivers	a. Verbal communication with the remote driver (n = 12, 5F, 7 M) b. Visual communication with the remote driver (n = 4, 2F,2M) c. Alarm button to contact the remote driver (n = 2, 1F, 1 M)
5.3 Choosing routes when using the L4 AV	a. I would like to choose the route when using the L4 AV (n = 2, 1F,1M)
5.4 Options to override remote drivers	a. I want to have the option to override the remote driver (n = 3, 1F, 2 M)
6. Regulation, operation, and management of the L4 AV	
6.1 Contract and terms of conditions of the L4 AV	a. Define roles and responsibilities in pre-contract agreement of the L4 AV (n = 1, 1 M) b. Clear 'terms of conditions' for the L4 AV (n = 1, 1 M) c. Purchase contract of the L4 AV states who is the remote driver (n = 1, 1 M)
6.2 Review and feedback mechanisms	a. Review and feedback mechanisms of the remote drivers (n = 4, 4 M)
6.3 Compatibility between L4 AV makers and teleoperation companies	a. Compatibility between automated car makers and teleoperation company (n = 1, 1F) a. Compatibility between factory and third-party garages (n = 1, 1 M)
6.4 Cost of using remote driver services	a. Is using the remote driver free (n = 1, 1F)
6.5 Verification process	a. Verification process of the remote driver (n = 2, 2F)
6.6 Regulations, governance, and supervision of the L4 AV	a. Legislation and regulation of the L4 AV (n = 2, 1F, 1 M) b. independent body to supervise teleoperation companies (n = 1,1M)
6.7 Liability and insurance of the L4 AV	a. Liability insurance of the L4 AV (n = 3, 3 M)
6.8 Eligibility to use the L4 AV	a. Eligibility to use a L4 AV(n = 1,1M)

Note, n = number of participants, F = female, M = male, L4 AV = Level 4 Automated Vehicles.

5. Ē3. Findings and discussion

The key findings were highlighted in the Table 2 (Note: n = number of participants, F = female, M = male, L4 AV = Level 4 Automated Vehicles). The 29 end-user interviews transcripts resulted in 79 codes. They were classed into 32 sub-themes and further grouped into 6 core themes. The frequency of a code (number of participants mentioning) is for the description of qualitative data.

5.1. Attitudes and perceptions towards the L4 AV

The first theme is about people's attitudes and perception towards the L4 AV. The sub-themes and example quotes are outlined in Table 3. Some participants exhibited positive attitudes towards the L4 AV and believe it is a fantastic innovation (n = 12, 8 female, 4 male, Table 3, a.i-iii). They pointed out that they especially appreciate the failsafe strategy in the L4 AV (n = 3, 2 female, 1 male, Table 3.a.iv and v). Considering that ensuring an effective and smooth transition control from automated driving to manual driving has been recognised as a major challenge of the L3 AV (Li et al., 2018; Bellet et al., 2019), the introduction of the failsafe mechanism in the L4 AV could potentially enhance the safety and accessibility of automated vehicles. Participants also envisioned the positive impact of the L4 AV on their driving experience. Common responses were that the L4 AV could be useful for motorway driving (n = 8, 2 female, 2 male, Table 3.b.iii) and long journeys (n = 6, 4 female, 2 male, Table 3.b.ii). This corresponds to a study by Ashkrof et al. (2019) who found the public expressed great interest in using automated vehicles for long-distance leisure trips. Other use cases of the L4 AV perceived by the participants include night driving (n = 1, 1 female, Table 3.b.i), recurring journeys (n = 1. 1 male, Table 3.b.iv), short trips (n = 1, 1male, Table 3.b.v) and unfamiliar driving (n = 1, male, Table 3.b.vii).

In terms of trust in Level 4 Autonomous Vehicles (L4 AVs), a significant number of participants expressed that their trust would be established over time, either through safe usage of the L4 AV for a period or by observing more evidence of its safe and effective operation (n = 10, 5 female, 5male, Table 3.c.i-viii). One participant pointed out that public confidence is the key to ensure the long-term adoption of the L4 AV (n = 1, 1 male, Table 3.c.ix). This finding corresponds to the previous study by Paddeu et al. (2020) who found that end-user's trust of the automated vehicle was significantly enhanced after interacting with it in-person in the real-world environment. Overall, this finding emphasises the importance of exploring user trust of automated vehicles in daily life circumstances using an ethnographic approach (Raats et al., 2020). They also stated that their decision to use the L4 AV could be influenced by family, friends, and someone they respect (n = 2, 1 female, 1male, Table 3.d.i and ii). This is consistent with previous findings that social influence has been recognised to be an imperative factor in determining user acceptance in automated vehicles (Sener et al., 2019; Zhang et al., 2020).

The participants also discussed the concerns they have regarding the L4 AV. One common concern is about the capabilities and effectiveness of the teleoperation system and the remote driver (n = 9, 3 female, 6 male, Table 3.e.i and ii), especially towards the remote driver's sense of the driving environment. The remote driver's information and sense of the driving environment will be discussed in detail in section. Participants also expressed concerns about the reliability, speed, and latency of the 5G network, (n = 5, 3 female, 2 male, Table 3.e.iii-vi) that may affect the performance and reliability of the teleoperation system in the L4 AV. This may be due to the lack of real-world in-person interaction with or seeing more successful real-life demonstration of the 5G-enabled L4 AV. Apart from the network connection, cyber security (n = 4, 2 female, 2 male, Table 3.e. vii-ix) and privacy issues (n = 1, 1female, Table 3.e.x) of the L4 AV are also discussed by participants. This is in compliance with the fact that cyber security violations and privacy breaches could negatively influence public acceptability of automated vehicles (Liu et al., 2020).

Table 3
Selected quotes relevant to the theme 1.

Theme 1. Attitudes and perceptions towards the L4 AV	
Sub themes	***Example quotes***
a. Positive towards the L4 AV	***i.*** *" Well, I think this is a fantastic innovation."(No.14, Female)* ***ii.*** *" Um, it sounds like a good idea to see Um, it can, Um, obviously it allows people to get on with what they're doing, but then doesn't harm them by putting them in unsafe environments such as, uh, going down country roads where the software is not suitable."(No.19, Male)* ***iii.*** *"I welcome it. It's something I think it will be extremely valuable to people when it does come in. Um the technology doesn't bring any fear to me. Um, I actually think the technology works better than human. So, um, yean, I'm looking forward to the day that happens, and I can actually do some work in a car."(No.23, Male)* ***iv.*** *" The backup plan is good. The drawback system gives me the confidence and comfort, a peace of mind I would say."(No.5, Female)* ***v.*** *" I think it's good idea that there is drawback system for it. When it enters a bad area, like a work area."(No.6, Male)*
b. Perceived benefits and positive use cases of the L4 AV	***i.*** *"I was night time driving sometimes, it takes a lot more concentration. So, I could see in that situation, it would be beneficial." (No.17, Female)* ***ii.*** *"if somebody was there in the long journeys, say I was driving from Newcastle to London, because we all know you should break up your journey but most people don't, so that would be a kind of ideal time for it.(No.18, Male)* ***iii.*** *"So, it's good. I think it depends on the kind of area that I was driving, the type of road I was on and the journey I was doing. If it was a long journey, well it's kind of a lot of long straight motorways, I think it would be brilliant." (No.12, Male)* ***iv.*** *"It sounds pretty good. Um, I do a lot of journeys which are the same journey, say from Newcastle to Sheffield. Um, they are very boring, and I've seen it all before."(No.20, Male)* ***v.*** *"Maybe short trip to the shops that could be automated perhaps for example."(No.1,Male)* ***vi.*** *"I suppose the problem at the moment is drivers getting tired. Also, extra longer drive, say, from Newcastle to London. Um, you know, no one wants to sit behind the wheel and concentre five and a half or six hours. No.20, Male)* ***vii.*** *" Um, I think it depends on situation. So, if it was, I was in the middle of nowhere, I didn't have any idea, then probably a combination of both.(No.12, Male)*
c. Building trust towards the L4 AV	***i.*** *" I will be comparing my thoughts and my actions with what the vehicle is doing. If after a period of time, we correlate and I have confidence, that will be different."(No.10, Male)* ***ii.*** *"I think in the first instance I'll be nervous about being in a level four vehicle so I would probably be watching the road and be very careful, I think. Maybe over time you get to trust the technology, like you have now with electric vehicles, and you become more relaxed."(No.15, Male)* ***iii.*** *"I'd probably have to see it in action quite a lot, seeing the car make clever decisions about when to stop before I actually let go of that control and trust it.."(No.16, Female)* ***iv.*** *"Like the situation where all of a sudden traffic comes out of nowhere and it knows how to stop or do you know what i mean, like all of a sudden, there's a blizzard, I have to see it's working, probably over the course of about a year before I actually like totally took my eyes off the road and read a book or something.."(No.16, Female)* ***v.*** *"At the beginning I might want to keep on eye on them when they are driving my car remotely. But I guess I would develop trust over time and then constantly watching them won't be necessary." (No.28, Female)* ***vi.*** *"if you can show me that your level 4 autonomous vehicle is operated for years and there's never been a serious incident and the system always work. I would be more willing to trust it. I think what I would do would also change, depending on how bedded in the system was. If it's a brand new level 4 autonomous vehicle and I've never been in one before, I probably goanna be watching the outside world like a hawk, watching what the vehicle is doing. If we are talking what I might be doing in a level 4 autonomous vehicle in five years time. You know, I probably asleep because I trust the vehicle and the teleoperator to get on and do what they need to do." (No.3, Female)* ***vii.*** *"Like the situation where all of a sudden traffic comes out of nowhere and it knows how to stop or do you know what i mean, like all of a sudden, there's a blizzard, I have to see it's working, probably over the course of about a year before I actually like totally took my eyes off the road and read a book or something…"(No.16, Female)* ***viii.*** *"I don't think I would go into it until a lot of people had already used it sort of thing.."(No.21, Male)* ***ix.*** *"Um, basically, they've got one opportunity to make this technology work, if there are any significant accidents, the public confidence would be obviously reduced. Public confidence is the key, so making sure a system like this is accepted over long term."(No.23, Male)*
d. Decision to use the L4 AV	***i.*** *"I would probably feel more enthusiastic about using one I knew that friends, colleagues, family had used it and had no problems with it and were totally happy." (No.2, Female)* ***ii.*** *"I mean if it was someone I knew and trusted and they used it and said it was good, then I would potentially be persuaded." (No.21, Male)*
e. Perceived concerns and challenges of the L4 AV	***i.*** *" I'm not sure the idea of, um, someone driving your car remotely. A lot of roads in the UK are quite basic that maybe not complete road markings."(No.13, Female)* ***ii.*** *" I'm not too sure about how well the remote driver would be able to, uh, interpret the situation. He's not goanna have a sound cue and I presume the vision be limited."(No.19, Male)* ***iii.*** *" I think the idea of a remote driver connecting to your computer, is quite a scary one, do you know what I mean. Like a, one thing I was worried about as well is what if there's like a latency issue, a speed issue, a delay. No.22, Male)* ***iv.*** *" I am concerned about how reliable or unreliable this teleoperation can be. We've all got 4G communications, we've all got pretty fast networks. And we've still got drop-outs in Zoom conversations. There are still people switching their cameras off and said that I haven't got bandwidth for this. (No.3, Female)* ***v.*** *" I don't really trust it. I can see some risk. Obviously, you have no idea in what situations that you need to take over the control back to yourself. You will have somebody remotely take control of your vehicle; we need to consider the network. What will happen if there is no network, I may end up in staying in the hard shoulder for ages. (No.4, Female)* ***vi.*** *" I am concerning how stable the network connection. Your Team meeting loses connection sometimes, let alone the remote driving."(No.7, Female)* ***vii.*** *" I really do not want to be in a position where somebody can automatically hack and stop my car when I am out*

(*continued on next page*)

Table 3 (*continued*)

Theme 1. Attitudes and perceptions towards the L4 AV *Sub themes*	*Example quotes*
	somewhere, especially if I'm out in the countryside or my wife is out on her own. Because now people can, with a laptop, steal cars. They could bypass security systems and don't need a key. So, the security of the system, we need a lot of proving." (No.10, Male) ***viii.*** *" How would I be able to tell if it's a genuine remote driver is behind controlling the vehicle or someone else, a hacker?" (No.29, Female)* ***ix.*** *" But straight away came to head was if someone else hack the car and I would lose control of the vehicle completely, which can be quite scary." (No.5, Female)* ***x.*** *" If that's the case, if you've got somebody in the car with you they can listen to your conversation, can they? Well, that's a bit like 'big brother is watching you', everybody wants their privacy to some degree." (No.17, Female)*

5.2. Expectations of the L4 AV

The second theme concerns participants' expectations towards the L4 AV. Theme 2 consists of several sub themes including Maintaining control of the vehicle, Simple and understandable L4 AV, and Equality, diversity, and inclusion of the L4 AV. Example quotes are outlined in Table 4.

Participants expressed an expectation that they still like to maintain some level of control of the vehicle in the L4 AV. They stated that they like driving (n = 4, 1 female, 3 male, Table 4.a.i-iii) and would like to maintain a certain level of control of the vehicle (n = 5, 3 female, 2 male, Table 4.a.vii-xi). When discussing the takeover control situations in the L4 AV, the majority of participants indicated that they would like to take over control by themselves if possible (n = 16, 7 female, 9 male, Table 4.a.iv and v). This expectation is supported by a previous study that found that retaining the ability of manually controlling the vehicle is necessary for elderly end-users when using the highly automated vehicles (Li et al., 2019c). Another expectation expressed by participants is a desire for the L4 AV to be simple and understandable (n = 3, 1 female and 2 male, Table 4.b.ii-iii). This expectation could be interpreted by previous research findings, suggesting that effort expectancy is strongly associated with end-user's adoption of automated vehicles (Leicht et al., 2018).

The last expectation suggested by the participants is regarding the equality, diversity, and inclusion of the L4 AV. One participant pointed out that the remote drivers of the L4 AV should not only include male drivers but also female drivers (n = 1, 1 female, Table 4. c.i). This expectation highlights the significance of considering gender equality when developing smart and sustainable future mobility and automated vehicles (Levin, 2019; Campisi et al., 2022; Li et al., 2022). Furthermore, another participant argued that the L4 AV should be inclusive and ensure the accessibility of older user group. This aligns with the fact that it is imperative to consider older people's requirements and performance when developing automated vehicles (Li et al., 2018; Li et al., 2019b; Li *et al.*, 2019d; Li *et al.*, 2021b).

Table 4
Selected quotes relevant to the theme 2.

Theme 2 Expectations of the L4 AV *Sub themes*	*Example quotes*
a. Maintaining control of the vehicle	***i.*** *" I've been driving normal vehicles for more than fifty years. I am brainwashed, I am programmed to be in charge. My reaction time is an old person. I've got a rough idea what they like now compared to what they used to be."(No.8, Male)* ***ii.*** *" I've just been talking to a neighbour, and I said I was going to be doing this and she said oh I like to drive, I like to feel in control."(No.17, Female)* ***iii.*** *" Well, I think it sounds good, erm for many potential applications. I mean I am thinking of myself as a private motorist, I would probably prefer to have more opportunities for manual control of the vehicle because I enjoy doing that."(No.1, Male)* ***iv.*** *" But yean for me as a driver I would like to have, if automation was the default, I'd like manual to be the second choice, the fallback position rather than the teleoperator, you know what I mean." (No.1, Male)* ***v.*** *" In most circumstances, I would prefer to take over myself, um, but again, if depends on what activities I was engaged at the time." (No.1, Male)* ***vii.*** *" Well, I'm quite old fashioned, so uh uh, I'm a kind of person who likes control. I wouldn't personally be attracted to an automated car." (No.18, Male)* ***viii.*** *" Um, also I think from having driven for so many years, initially it could be probably quite disconcerting to disengage especially in busy situations. The feelings of loss of control maybe very disconcerting." (No.24, Male)* ***xi.*** *" It takes time, it just need some time for you to get back to the driving mode, but doesn't mean I am giving up my chance to take the control. You see, if the system could pull over at a hard shoulder, then I got a plenty of time to get ready to start the car, start driving myself." (No.5, Female)*
b. Simple and understandable L4 AV	***i.*** *" I think it's making sure that it's relevant and relatable to people who don't know much about technology. Because for me, it's such a scary concept, I don't understand how I put it all away and I can imagine that's not just me and people will freak out about it. I think it's explaining kind of how that concept can totally happen from a relevant and relatable point of view."(No.11, Female)* ***ii.*** *" I would say make the interface as simple as possible. People are always reluctant with new technology."(No.20, Male)* ***iii.*** *" Make the system very simple and easy to work with, nothing complex for the user. To be introvertive and easy to understand." (No.6, Male)*
c. Equality, diversity, and inclusion of the L4 AV	***i.*** *"He's goanna know what he's doing. If it's a 'he'. I think you should have a 'she." (No.17, Female)* ***ii.*** *" I think public awareness probably needs to come a long way, otherwise they probably going to find most of their drivers are in their 20 s rather than you know, older age groups." (No.16, Male)*

5.3. Activities instead of driving in the L4 AV

The third theme considers the non-driving related activities participants would perform in a L4 AV. It consists of five subthemes, including relaxing and performing non-demanding tasks, working, sleeping, drink driving, or preferred tasks depending on trip purpose. The example quotes are shown in Table 5.

Some participants expressed a desire to monitor the driving (n = 7, 3 female, 1 male Table 5.a.i-ii) when the L4 AV is in automated driving mode. They also indicated that they would not engage in demanding tasks and would still prefer to remain in the driving loop (n = 7, 4 female, 3 male, Table 5.a.viii-x). These requirements suggest that participants may not fully trust the L4 AV to disengage mentally from the driving loop completely. By monitoring driving and not conducting demanding tasks, they would still be engaged in the driving loop of the L4 AV. This corresponds to the point discussed in Theme 1, where end-users' trust is built over time by accumulating evidence of the L4 AV's safe performance. Future research could explore whether monitoring system driving could impact on end-user's trust towards the L4 AV. In addition to monitoring driving, participants expressed a desire to perform relaxing tasks, for example, looking out of the window and enjoying scenery (n = 3, 1 female, 2 male Table 5.a.iii and iv), eating and drinking (tea or coffee) (n = 3, 2 female, 1 male Table 5.a.iv and v), using mobile phones and browsing the Internet (n = 9, 3 female, 6 male Table 5.a.v-vii). These preferences align with end-users' preferred relaxing tasks in the Level 3 automated vehicle (Li et al., 2019c) and reflect the public's keen interest in using automated vehicles for leisure and recreation travel (Thomopoulos et al., 2021).

Apart from relaxing tasks, working has been mentioned as a preferred activity in the L4 AV by serval participants (n = 8, 3 female, 5 male, Table 5.b.i-iii). These findings align with the predicted future prospect of automated vehicles enhancing vehicle user's productivity, pleasure and driving efficiency proposed by previous research (Chan, 2017; Ryan, 2020).

Additionally, sleeping in the L4 AV was discussed by the participants, who expressed that they would not sleep in a L4 AV (n = 5, 2 female, 3 male, Table 5.c.i-iii). This corresponds to the previous mentioned requirement that participants still want to be part of the

Table 5
Selected quotes relevant to the theme 3.

Theme 3* Activities instead of driving in the L4 AV** ***Sub themes	***Example quotes***
a. Monitoring driving and relaxing tasks	***i.*** *" I think in the first instance I'll be nervous about being in a level four vehicle so I would probably be watching the road and be very careful, I think. Maybe over time you get to trust the technology, like you have now with electric vehicles, and you become more relaxed."(No.15, Male)* ***ii.*** *" But to be honest, I would still rather be focusing on the road and other cars around me without any distractions.."(No.2, Female)* ***iii.*** *" Maybe look outside the window, enjoy the scenery." (No.14, Female)* ***iv.*** *" I'll probably just relax, to be honest, just look out the window. Maybe drinking a cup of tea. (No.13, Female)* ***v.*** *" Depends on what I am allowed to do. I may do some work, browse social media, eat and drink." (No.29, Female)* ***vi.*** *" You know, just most likely, navigating on your phone, looking at emails, or you know, just social media or the news just something like that. So it would probably just be doing stuff on your mobile phone, I would imagine." (No.27, Male)* ***vii.*** *" Then, I don't know maybe you could be doing something on a mobile phone, a laptop or taken in the view or whatever, but nothing specific." (No.9, Male)* ***viii.*** *" I struggle to trust it up to maybe watch a movie or fall asleep. I would do something that I can have a sort of level of engagement with what's going on the road. I mean I would like to do the task that doesn't take too much focus away from what's going on on the road.." (No.22, Male)* ***ix.*** *" Even if I was in a video conference, I didn't have to always focus my eyesight on the screen. I could still occasionally monitor the system and get myself back to the driving loop." (No.7, Female)* ***x.*** *" But I wouldn't be able to concentrate. I would still have to, you heard the term 'back seat driver'? I would be a back seat driver."(No.8, Male)*
b. Working	***i.*** *" So, it would nice actually, particularly everyone is so busy at the moment, to be able to actually use that time, not driving but actually may be doing some work, or, um, you know, catching up one of the things. It's kind of in a way waste of time where you can't really doing anything but stare at the road."(No.20, Male)* ***ii.*** *" I would do some work, such as reading a document or having video meetings with colleagues."(No.7, Female)* ***iii.*** *" If I was getting in to a Teams meeting or some other activities where I'm interacting with other people, it might be better to let the remote driver to just take over." (No.24, Male)*
c. Sleep	***i.*** *" Maybe have a nap. I think it would take a while to get used to being relaxed with the automation, so that you could fall asleep." (No.20, Male)* ***ii.*** *" I'm not sure. Is it allowed to fall asleep in the automated car? I just don't have enough trust to be able to fall asleep in automated cars.." (No.28, Female)* ***iii.*** *" I'm not sure, maybe just relaxing, watching a movie, listening to music, listening to radio. But I won't sleep." (No.28, Female)*
d. Drink driving	***i.*** *" My question is, is this remote driver thing goanna be a free service? Let's say if I drove to a pub and had three pints of lager, can I ask the remote driver to drive me home?" (No.29, Female)* ***ii.*** *" If I have a level 4 vehicle, I go out with my friends. Can I stop and have a drink with them? Can I socialize a meal in a restaurant, some wine, then get into my car and say take me home.." (No.8, Male)*
e. Preferred tasks depend on trip purpose	***i.*** *" It depends on, I mean, if I was to use it to travel to work or university or whatever, I potentially do some work. But otherwise, I mean if I was just travelling so much for leisure, probably just be on my phone." (No.21, Male)* ***ii.*** *" It depends on the nature of the trip. If it was my driving to work in the morning, I would probably be catching up on emails and getting ready for the day ahead. If I was driving down to XXX to see my daughters, I might read a book, I might watch BBC iPlayer or Netflix whatever." (No.24, Male)* ***iii.*** *" That's context dependent. That would depend on what the purpose of my trip was. If it's going to work, I might be working. If it's leisure, I'll probably get my eyes close and listen to music. Yean, it's a lot, is it a short journey, is it a long journey, is it a work trip, is it a leisure trip." (No.3, Female)*

Table 6
Selected quotes relevant to the theme 4.

Theme 4 **Requirements towards the remote drivers in the L4 AV** ***Sub themes***	***Example quotes***
a. Remote driver's behaviour and performance	***i.*** *" It would be helpful, I think, to understand what they are doing.."(No.1, Male)* ***ii.*** *" If they start controlling my vehicle, we have agreed. What is the destination, where they are going to take me, for example, I said can you drive my vehicle to my home, so they said ok and I gave them permission to control the vehicle, take me home."(No.5, Female)* ***iii.*** *" I could possibly multitask, look out of the window and see what's going on and listen to what somebody says and then if I see something different to what the remote driver said. I could tell the remote driver that blah blah blah, this is different, this is ok or I don't see what you say." (No.8, Male)* ***iv.*** *" Yes, I need to know where they are going to take me and I like to have my eyes on the navigation, on the map, to know they are doing what they said they are doing.. (No.5, Female)* ***v.*** *" It will not be a person sitting at home controlling my car while doing other things. It must be someone continuously monitor my travel." (No.14, Female)* ***vi.*** *" Well, you know there was that story in the newspaper yesterday about someone who tried to deal with a traffic court thing while he was operating on someone, did you see that? He was the surgeon in the middle of an operation and he tried to attend traffic court remotely during the surgery and he told the judge 'no no I'm fine I can deal with this' and the judge said 'no I don't think this is appropriate.' So you kind of want to make sure that they are not trying to multitask. You probably expect the company to be really strict about monitoring them." (No.16, Female)* ***vii.*** *" It's what happens if you have multiple problems at the same time. Does the teleoperator have sufficient rampant capacity to say okay we need to call in another teleoperator quickly because we've now got multiple situations to deal with." (No.3, Female)* ***viii.*** *" Not exactly what they're doing, but I would like to have a piece of mind to know what they are not doing. You know, they're not in the supermarket doing their shopping while controlling my vehicle. So I need to know they are in a quite space, concentrating, no distractions. As you would, you know, the conditions you'd be in if you were driving that car for real." (No.20, Male)* ***ix.*** *" Ideally would want your remote controller to be on standby for all of your journey. But that's probably not practical." (No.3, Female)*
b. Remote driver's sense of the environment and information about journey	***i.*** *"Where are the cameras in these vehicles? How could the remote driver possibly see 360 degrees to see like everything going on?" (No.16 Female)* ***ii.*** *"Um I think they must have a full two hundred and seventy degree images around the car so they can see what's going on, the size and instructions, um can see cyclists coming from back, etc. And I think they should have knowledge of the roads that they are driving on. Obviously, they are not able to see, say if there's a bump in the road, they're not goanna feel it, whereas the person driving the car, the person being a passenger in the car, will. So they're not goanna sense these extra forces." (No.19 Male)* ***iii.*** *"Cos, obviously when you're sitting in a vehicle, you've got much better vision, perception of what's around. I need a level of understanding of what the system actually means and how a remote driver would be able to manage the situation effectively." (No.23 Male)* ***iv.*** *"I suppose the idea was to automatically switch to the teleoperator but they need to know what my intentions were with the journey and how it programmed into the vehicle and whether they were continue doing what I wanted from the vehicle." (No.1 Male)*
c. Experience, skills and qualifications of the remote driver	***i*** *" The very least this company has trained them up for a long period of time and they are not someone who just had three-week induction course. You have to be an expert, somehow, don't you?." (No.16, Female)* ***ii.*** *" The remote drivers should all take their advanced driving test, they need to be fully qualified, not just taking a driving course to prove that they can driver, they need to be an advanced level." (No.17, Female)* ***iii.*** *" I think what you need to do is, know somebody who has done it for a long time, for instance, a driving instructor would be a good idea. It should be the highly professional person to get there for you, not somebody who just passed the driving test or maybe just driving for a couple years." (No.18, Male)* ***iv.*** *" Um I like to know that they have at least, let's say, ten years on their driving license. Um they are qualified drivers; they do lots of miles. Potentially they need to do a more difficult driving test, maybe like advanced driving course. You wouldn't want someone with just a regular driver's license to take control of your life effectively." (No.19, Male)* ***v.*** *" Um, I wouldn't want a newly qualified driver taking control. I guess if there was a kind of extra driving test to check these people are safe and skilled drivers. You know, lots of people can pass the driving test but doesn't mean you're a safe driver." (No.20, Male)* ***vi.*** *"So, you would be comfortable with somebody's experience in managing those situations. I certainly wouldn't want someone who have just passed the driving test to take over my car remotely. So, there would be a level of expectation in terms of experience." (No.23, Male)* ***vii.*** *"So, if low wage low skill call centres are behind doing remote driving, I wouldn't have any confidence. But if it was someone with police training, I would have high degree of confidence. Someone with technical and police kind of driving skills, I would be comfortable." (No.25, Female)* ***viii.*** *"They should be skilled drivers with a lot of driving experience. Also, they should be well-trained to operate a vehicle remotely." (No.28, Female)* ***ix.*** *"Well, I would hope that there would be a set of regulations and rules in place to make sure whoever does that is fully trained and safe and foolproof." (No.15, Male)* ***x.*** *"I would want some levels of assurance in terms of their qualifications, the number of hours they've got on that type of system, et cetera.." (No.23, Male)* ***xi.*** *" I think the remote operation company should give extra test to see if a remote driver is suitable. They need to have years of experience on the road and maybe even know the area." (No.19, Male)* ***xii.*** *" No, I put a level of trust into a system. Obviously, whoever is providing that system would have to make sure*

(*continued on next page*)

Table 6 (*continued*)

Theme 4 **Requirements towards the remote drivers in the L4 AV** ***Sub themes***	***Example quotes***
	there is a level of assurance that the consumer would feel comfortable in that situation, um, nobody is going to risk putting somebody inexperienced." (No.23, Male) ***xiii.*** *" I should imagine whoever is employing them, they know what they're doing when they employed these people." (No.8, Male)*
d. Location of the remote driver	***i.*** *" I guess ideally someone is familiar with the road you are driving on. Maybe someone knows the area. Certainly, someone living in the UK. (No.13, Female)* ***ii.*** *" You kind of need to have trust that they really knew what was happening in the UK roads. The idea of someone driving my car from a different country that would make me really nervous. You need to feel that they were very trained in that technology, in that department, maybe that specific country that they knew all of the road layouts. You know the way in London, how the black cabs, they need to know the whole city" (No.16, Female)* ***iii.*** *" I do care where they are physically located, you know, say drive in Bangkok would be completely different with drive in the UK. I've been to Bangkok before and it's you know it's everything's going on at once and you have no idea how to navigate through it. I think there's definitely cultural difference with driving styles." (No.20, Male)* ***iv.*** *" I want them to be based in the local area that I'm in or at least, you know, within the same country I'd say. They feel more of a sense of liability over, you know, of the car you're in. Because they are in the same country, they're under the same laws and rules and everything else. I think it's just a fact that they know they're controlling a car, possibly made them a bit more careful." (No.21, Male)* ***v.*** *" Another sort of problem I have would be a time-zone one. So let's say, in England is 8o'clock at night, and then whereas the remote driver from U.S. is 4(o' clock) in the morning, I would be worried about them being too tired. They need to be in normal working time wherever they live." (No.22, Male)* ***vi.*** *" But having said that you could probably train somebody in another country if they were, I wouldn't expect somebody if they're operating it from another country to be switching between different remote operating in different countries. I think they need to know a lot about the road rules and how people drive because it's also about people's attitude on the roads and things like that, how big a gap people leave and all that kind of stuff they need to know about that to be able to fully remotely operate the vehicle." (No.27, Male)*
e. Information about the remote driver	***i.*** *" It would be less stressful if you knew the person who's doing it. So, if there is the option, I'll go for that." (No.13, Female)* ***ii.*** *" In terms of the person, maybe someone you can trust with, someone has connection with you." (No.12 Male)* ***iii.*** *" If remote driver is someone I know that would probably make me feel a little bit better." (No.10, Male)* ***iv.*** *" If someone I trusted recommended a remote person or company to me, I may use it." (No.14, Female)* ***v.*** *" I need to know beforehand he will be taken control. Maybe when you purchase the vehicle, part of that kind of contract saying this is going to be your person that take control if the drawback happens." (No.12, Male)* ***iv.*** *" I probably wouldn't need to know who they are individually, but I need to know who they were employed by, where they worked." (No.1, Male)*
f. Security checks for remote drivers	***i.*** *" What I want to say is, you know, when you talk to the bank, you have to go through some security check, so you know that person is from the bank, and the person know you are definitely the real account holder, that's what I meant." (No.5,Female)*
g. Random or dedicated remote drivers	***i.*** *" A dedicated remote controller would be better than a random one." (No.12, Male)* ***ii.*** *" If there's an option of a dedicated remote driver, that would be brilliant. Then, you can learn to trust them." (No.13 Female)* ***iii.*** *" I prefer a dedicated remote driver, or not necessary one, but I don't want completely random, if you had few, but not too large number." (No.21, Male)* ***iv.*** *" I think I would have seen it would be random remote driver, yean if you could have a set of remote drivers and you get a different one depending on the situation. I wouldn't expect to have the same one every time." (No.27, Male)* ***v.*** *" Given the nature of travel patterns, I think realistically, it would be random. Because I can't expect someone to, having a dedicated one would limit where I can drive, because I have to worry if the remote driver is available. I imagine remote drivers would be doing lots remote driving for lots of people. So my remote driver is at work doesn't mean they are available to drive me." (No.24, Male)*

driving loop in L4 AV. This could be explained by the idea that sleeping could be a crucial factor in quantifying trust in automated vehicles, as people only fall asleep in environments they perceive safe and controlled (Detjen et al., 2020). At this stage, their trust towards the L4 AV is not sufficient to feel comfortable sleeping in it. Considering sleeping in automated vehicles could be a practicable option for long distance/duration journey (Pudāne et al., 2019), future research could explore whether exposure to actual automated driving has any impact on people's preferences towards sleeping in the automated vehicles.

Moreover, participants also expressed interest in drink driving in the L4 AV (n = 2, 1 female, 1 male, Table 5.d.i-ii). Drink driving has been found to negatively affect the takeover performance of participants (mean age = 33 years, SD = 9.22 years) (Wiedemann et al., 2018). It is not allowed in vehicles equipped with Level 3 and lower systems. However, the teleoperation system controlled by the remote driver enables the L4 AV operate safely without human input. Therefore, it has the potential to be a useful solution for combating drink driving. Future research could explore the role of the L4 AV being the 'designated driver' in reducing alcohol-impaired driving and identify which user group would benefit most from this feature.

Finally, participants mentioned that their preferred activities in the L4 AV depend on the trip purpose (n = 4, 1 female, 3 male, Table 5.e.i-iii). Trip purpose has been found to be strongly associated with the public adoption of automated vehicles (Krueger et al., 2016). One implication of these findings is that future research should quantitatively explore whether trip purpose affects people's preferences towards the non-driving related tasks in AVs.

5.4. Requirements towards the remote drivers in the L4 AV

Theme 4 is about participants' requirements towards the remote drivers. The sub-themes and example quotes are highlighted in Table 6.

Participants have expressed a set of requirements regarding to the remote driver's behaviour and performance. One common requirement is that they would like to understand what the remote driver is doing (n = 9, 5 female, 4 male, Table 6.a.i and ii), and they need to know that the remote driver is doing what they said they are doing (n = 4, 2 female, 2 male, Table 6.a.iii and iv). These requirements could be explained if the remote-control situation in the L4 AV is perceived as uncertain by the participants, increasing their stress level. To reduce perceived uncertainty and stress, obtaining information plays an important role (Peters et al., 2017). Understanding remote driver's performance and knowing they are doing the right job may help the people to obtain more information about uncertain situations and potentially decrease their stress. In addition, Bandura (1994) argued that reducing stress contributes to modifying people's perceived self-efficacy, an important factor in influencing people's satisfaction with automated vehicles (Li et al., 2021). This creates a need for the future research to explore further how the knowledge of remote driver's behaviour and the perception of uncertainty in the L4 AV affects people's satisfaction and trust towards the L4 AV.

Participants also indicated that the remote drivers should not be multitasking and distracted (n = 2, 1 female, 1 male, Table 6.a.v-viii). The negative impact of multitasking and distraction on driving the conventional vehicles has been recognised (Strayer et al., 2011). Previous research also evidenced the negative influence of multitasking and distraction on people's performance when taking over control from automated vehicles (Li et al., 2019; Li et al., 2019a; Li et al., 2019b). However, to date, there is limited evidence regarding what behaviour should be prohibited among remote drivers when teleoperating the automated vehicle. Therefore, one direction for future research is to quantify the impact of multitasking and distraction on remote driver's performance.

Moreover, some participants believed that their remote driver should always be on standby (n = 3, 3 female, Table 6.a.ix). This requirement corresponds to the previous research by the authors exploring remote driver's view on teleoperating the 5G-enabled L4 AV, where remote driver stated that they would like to constantly monitor driving even though they are not operating the L4 AV remotely (Li et al., 2023). However, long periods of standing by and constantly monitoring the driving environment could make remote drivers feel bored. Being in monotonous driving environment could potentially put them in a state of cognitive underload, leading to drowsiness (Saxby et al., 2013; El Khatib et al., 2019). It is important to further explore whether constantly standing by and monitoring driving is safe and practical for the remote drivers of the L4 AV.

In addition, participants were concerned about remote driver's sense of the driving environment (n = 7, 2 female, 5 male, Table 6.b.i-iii), particularly two aspects-the field of vision and the perception of the feedback from the vehicle and the driving environment. Coincidentally, research into remote driver's requirements by the authors also revealed that these two aspects are the most urgent required by the remote drivers when interacting with 5G L4 AV in the real world (Li et al., 2023). This provides an important direction for the future research to explore possible measures for improving the fidelity of teleoperation system and enhancing the remote driver's perceptions (Wynne et al., 2019; Li et al., 2023). Participants also expressed that the remote driver should have some information regarding the journey, e.g., journey intentions (n = 2, 2 male, Table 6.b.iv).

Experience, skills, and qualifications of the remote drivers are the most mentioned topics among the participants. They would like their remote driver to be experienced, advanced and qualified drivers (n = 19, 9 female, 10 male, Table 6.c.i-x). Participants expressed that their remote drivers should not be someone who have just passed their driving licenses or just have few years of driving experience. They should be experienced drivers. One participant mentioned the remote drivers should have at least ten years of driving experiences (Table 6,c.iv). Also, they expect that people who are qualified to be remote drivers should have advanced driving skills (e.g. a driving instructor or a police) and have passed a more difficult driving test. They stated that the teleoperation company should be responsible to ensure the competence of the remote drivers (n = 4, 1 female, 3 male, Table 6.c.x-xiii). These requirements raised a question of whether the skills and experience of normal driving is transferable to remote driving of a L4 AV. A real world study by the authors revealed that remote drivers still perceived some difference between controlling the L4 AV remotely and driving a conventional vehicle (Li et al., 2023). To date, knowledge regarding the remote driver's experience, skills and qualification is still underdeveloped. Future evidence-based research are urgently needed to inform policymakers to develop the qualification framework and to enhance relevant standards, such as (bsi PAS, 2021), for the remote drivers of the L4 AV.

Another point participants were interested in is the location of the remote drivers. Participants required the remote drivers to be physically located in the UK (n = 6, 2 female, 4 male, Table 6.d.i-vi). They were concerned that if the remote drivers were not psychically located in the UK, there could be several factors negatively affecting the operation of the L4 AV, including unfamiliarity with the road layout, different traffic rules and laws, cultural difference in driving styles, sense of liability, time difference. This requirement provides an important implication in terms of the operation of L4 AV. Future research is needed to evidence the feasibility of remote controlling the L4 AV from a different country. Also, it is important for future research to quantitively investigate the impact of the physical location of the remote driver on end-users' perception towards the L4 AV.

Participants also discussed the information about the remote drivers. Some indicated that they would feel better if the remote driver is someone they know (n = 4, 1 female, 3 male, Table 6.e.i-iii) or recommended by someone they trust (n = 2, 1 female, 1 male, Table 6.e.iv). One participant mentioned that they need to know who the remote driver would be beforehand of the journey (n = 1, 1 male, Table 6.e.v). Security check for remote driver was also mentioned by some participants (n = 3, 2 female, 1 male, Table 6.f.i and ii). To ensure the security, the enhanced background check that the government used to check taxi drivers could also be applied to the remote drivers of the L4 AV (GOV.UK, 2012).

Finally, another topic identified by the participants is that whether they could have random or dedicated remote drivers (n = 4, 1female and 3 male, Table 6.g.i-iv). Some participants believed that a dedicated remote driver or a set of dedicated remote drivers

Table 7
Selected quotes relevant to the theme 5.

Theme 5* Communications and interactions with the remote drivers** ***Sub themes	***Example quotes***
a. Communication with the remote driver	***i.*** *" Could they talk to you? Is there a facility that they can speak to you and say I'm goanna to do this, I'm goanna do that. And if you felt confident that they were doing it, you could switch that off so that you didn't have to listen to them. Or if you felt uncomfortable again, you could press the button to interact with them."(No.17, Female)* ***ii.*** *" I guess to be able to have, you know, talkback system, you know what happens if you want to stop and someone needs to go to the toilet or going too far from the country lane and someone feels carsick." (No.20, Male)* ***iii.*** *" If I felt that the vehicle was doing the wrong thing I thought I'd say why are we going into this no entry or why are we on the wrong side of the road, or have you seen that big train over there? But I would need a piece of mind if something started going wrong or if I perceived something is going wrong, how do I then interact with my remote driver. Um, is that by pressing the button to say I'm uncomfortable or is there a speaker, you know, how is that interaction accomplished. To give me the confidence I can communicate if I need to." (No.24, Male)* ***iv.*** *" It doesn't need a great deal of interaction, just communication to say 'we goanna be taking over the autonomous driving, because there's roadworks and that expects to go on for five miles at which case we'll be handing back to the system. (No.23, Male)* ***v.*** *" I hope there is a way for the remote controller to communicate with the person inside the vehicle, and to communicate, can I remotely drive the car to somewhere? you know, get the permission from the person inside the vehicle before they take over the control. I want to have a kind of, like a navigation. If they start controlling my vehicle, we have agreed. What is the destination, where they are going to take me, for example, I said can you drive my vehicle to my home, so they said ok and I gave them permission to control the vehicle, take me home." (No.5, Female)* ***vi.*** *" erm and someone potentially have control of my vehicle. I need to know a little bit about them, and I need to be able to communicate with them.* *Well, I like some sorts of erm, if were park to side of the road and handed over to the teleoperator, I like to have some sorts of initial conversation about the what's the planning for the rest of the journey and how do we goanna do it."(No.1, Male)* ***vii.*** *" So I suppose like if something came up that this remote driver would know about, that I wouldn't know about, like accidents or traffic that they were trying to avoid and they would need to take a different route. I suppose you want (them) to tell you about that." (No.16, Female)* ***viii.*** *" Then, it would be good for them to be able to explain to me what had happened and what they were going to do to enable me to continue on my journey.." (No.2, Female)* ***ix.*** *" I think an important part of it is maybe a line of communication between the remote driver and the actual driver in the vehicle. So he or she can explain what's he or she is doing. They need to explain what they are doing." (No.22, Male)* ***x.*** *" Maybe it's to say okay, to ring the vehicle up and say and I'm sorry, we're monitoring the situation on the road, it looks like we can't give you a fully autonomous journey today, I am goanna have to take over in ten minutes time or a hundred yard's time in order to guide the vehicle through the situation. Please don't be alarmed, this is routine operation. This would allow you to know what's going on, rather than the vehicle just doing something." (No.3, Female)*
b. Forms and modalities for communication and interaction with remote drivers	***i.*** *" Yean, maybe to have a hand-free call. Just to have a chat about what's going on and what the issue is, where we're heading." No.12, Male)* ***ii.*** *" Just some verbal communication. It would be good if the remote person knew what's coming up. So they can kind of describe the situation. So, you are aware of that. I think they can do that verbally, they can just tell me."(No.13, Female)* ***iii.*** *" Could they talk to you? Is there a facility that they can speak to you and say I'm goanna to do this, I'm goanna do that. And if you felt confident that they were doing it, you could switch that off so that you didn't have to listen to them." (No.17, Female)* ***iv.*** *" I guess to be able to have, you know, talkback system, you know what happens if you want to stop and someone needs to go to the toilet or going too far from the country lane and someone feels carsick. This open channel thing could be in terms of like, um, voice communication, to press a button straight away and say, oh, can you just slow down a bit, or can you take the comers less harshly." (No.20, Male)* ***v.*** *" Certainly, obviously verbal communication. Because I think it depends on how developed these systems are. If it was an early stage of development, I would like to say, have you notice this? Or can you see this? I'll be quire apprehensive of, you know, with this being done remotely." (No.9, Male)* ***vi.*** *" Yes, they need to let me know if there's anything I have to do from my side. Video communication would be ideal, but audio is enough." (No.14, Male)* ***vii.*** *" And you probably need some kind of screen with feedback to say, okay, today your teleoperator is 'Bob', he will be monitoring your journey." (No.3, Female)* ***viii.*** *" I would like to have a screen, like face time, to see some person's face. And ask what they goanna do next. The situation I'm in now, what's their plan." (No.6, Male)* ***xi.*** *" I think you probably need an alarm button in the vehicle that puts me in direct contact with my teleoperator." (No.3, Female)*
c. Choosing routes when using the L4 AV	***i.*** *" So I suppose all of this, would you program your journey in beforehand and you say the exact route that you wanted to go." No.16, Female)* ***ii.*** *" I think before the journey, definitely the route they're planning to take. Um, maybe some preferences and um you could say well, wherever you rather go down motorway or country road etc. I would like to have a bit more control over my journey."(No.19, Male)*

(*continued on next page*)

Table 7 (*continued*)

Theme 5* Communications and interactions with the remote drivers** ***Sub themes	***Example quotes***
d. Options to override remote drivers	***i.*** *" I want to simple fault code what is it stopped. And then the next thing is it's a simple question can I override yes or no. IF the answer is 'fault code one you can override' yes I will immediately override and continue." (No.10, Male)* ***ii.*** *" If the control did go to the remote driver and you are aware that there were doing it, there should be some facilities, I would think, that if you didn't feel happy with what was going on, you could press a button and take control yourself." (No.17, Female)*

could make them feel better and potentially enhance their trust (n = 3, 1 female, 2 male, Table 6.g.i-iii). Future research is needed to explore how many vehicles per dedicated remote driver would optimise this sense of security and trust. However, some participants believed that random remote drivers would be more flexible as dedicated one may affect where they can drive (n = 2, 2 male, Table 6.g. iv and v). This implies that the future development of the remote driving matching algorithm of L4 AV should consider different preferences towards different users.

Table 8
Selected quotes relevant to the theme 6.

Theme 6* Regulation, operation and management of the L4 AV** ***Sub themes	***Example quotes***
a. Contract and terms of conditions of the L4 AV	***i.*** *" I'm just thinking off the top of my head here. I guess a lot of this would be dealt with in a kind of pre contract before you actually purchased the vehicle. You know this is what happens in certain situations and the teleoperators will take over in certain situations and this is where they instructed to do, and they won't do this, they will do that, you know so you have some sorts of confidence from the original purchase of the vehicle in the contract you took out I guess."(No.1, Male)* ***ii.*** *" That's a difficult question. Erm, I think my advice would be that they would need to, in kinds of terms of conditions or whatever they would provide, they would need to explain very carefully how the teleoperation would be done and who would do it to just generate confidence."(No.1, Male)* ***iii.*** *" I need to know beforehand he will be taken control. Maybe when you purchase the vehicle, part of that kind of contract saying this is going to be your person that take control if the drawback happens."(No.12, Male)*
b. Review and feedback mechanisms	***i.*** *" And I think you should be able to report them if you are not comfortable with the driving. I have experienced some awful taxi drivers who really don't know the area, there was one asked me for directions on where to go. Afterwards, you should be given the option to review this person. Um, just so if you have a bad experience, you know that your information goanna get pass on and be investigated. Maybe like a star rating. I think if a remote driver's score is great, they should be recommended and put to a high priority list." (No.19, Male)* ***ii.*** *" After the journey, I guess like the Uber style feedback system where, you know, how friendly were they, what's their driving like. Maybe a bit more details in terms of their driving's you know, how hard they took corners, speed, acceleration and sort of how that fits with how you like to travel."(No.20, Male)* ***iii.*** *" I suppose there would be circumstances after the journey where the remote drivers themselves may want to feedback on how the experience was." (No.24, Male)* ***iv.*** *"I think communication afterwards would be good. To have a conversation about what went wrong and then also give a chance to get feedback. So that they can continuously progress, and things can improve from the driver's perspective and then I'll see from the remote control perspective as well."(No.12, Male)*
c. Compatibility of L4 AV	***i.*** *" Just make sure the good compatibility between the automated car makers and whoever is responsible for the remote driving. You've just bought an automated car and then the remote driving company tells you that they are not able to control that brand or that model remotely, you know, this kind of issue makes it complicated for the users." No.28, Female)* ***i.*** *" How many garages would get the equipment to check the MOT status of a level 4 automated vehicle? I think it would be only the manufacturer agents who would have it. Independent garages wouldn't have anything like that." (No.8, Male)*
d. Cost of using remote driving services	***i.*** *" My question is, is this remote driver thing goanna be a free service? Let's say if I drove to a pub and had three pints of lager, can I ask the remote driver to drive me home?." No.29, Male)*
e. Verification process	***i.*** *" At least I need to be told who is taking over my car. Maybe a brief introduction, hi my name is XXX and I'm taking over your car because of bad weather or losing network connection, that will do." No.28, Male)* ***ii.*** *" There needs to be a matching process, a verification process, so that I would know they are who they say they are. Whoever is controlling my vehicle remotely, a face ID must be shown to me. I need them to tell me who they are, why the remote control is necessary, and probably show me some photo ID if the remote driver is someone I've never dealt with."(No.29, Female)*
f. Regulations, governance and supervision of the L4 AV	***i.*** *" Well, I would hope that there would be a set of regulations and rules in place to make sure whoever does that is fully trained and safe and foolproof. You expect that some rules and regulations that defines what a remote driver would be and how skillful they need to be."(No.15, Male)* ***ii.*** *" All I need to know is that this particular teleoperation company who is looking after my journey are accredited by whatever body to this particular standard that are approved safe."(No.3, Female)*
g. Liability and insurance of the L4 AV	***i.*** *" I mean I don't know whether it would have any sorts of impact on insurance or sorts of legal position anything like that as well, that might be quite important. It does need to be clearly stated in concrete legal terms." (No.1, Male)* ***ii.*** *" Perhaps, a remote driver takes over my vehicle that my vehicle hits a person in the road. Who's responsible?."(No.3, Female)* ***iii.*** *" Who is responsible for these sort of liabilities?"(No.24, Male)*
h. Eligibility to use the L4 AV	***i.*** *" Would a level 4 vehicle allow people to travel with the vehicle if they haven't passed the driving test?." (No.23, Male)*

5.5. Communications and interactions with the remote drivers

The fifth theme reflects participants' requirements regarding communications and interactions with the remote drivers. The sub-themes and selected quotes were highlighted in Table 7.

Participants showed a strong requirement for having the option and facility to communicate with the remote drivers when they need to (n = 13, 4 female, 9 male, Table 7.a.i-iii), which would potentially make them feel comfortable. They would expect the remote drivers to explain what had happened and inform what they are planning to do to next (n = 15, 9 female, 6 male, Table 7.a.iv-x). These requirements correspond to the first sub-theme of Theme four (Section 3.4) that participants need to understand what the remote driver is doing. L4 AV enables the users to be completely disengaged from the driving loop so that they may have little information and awareness regarding the driving task and environment (Li et al., 2023). Communicating with the remote drivers regarding what had happened, and their next move could not only enable the participants to understand what the remote driver is doing but also enhance their situation awareness. This requirement is also in line with a previous finding that elderly end-users required the Level 3 automated vehicles to explain the reason to take over (Li et al., 2019c). In addition, this requirement corresponds to previous findings that providing explanations regarding vehicle driving status and reasons for takeover leads to lower perceived workload and highly positive attitudes among participants in the Level 3 automated vehicles. This has pointed a direction for future research to quantify the impact of communication with the remote drivers on people's perceived workload and acceptance of L4 AV.

In addition, participants also discussed the forms and modalities of the communication with the remote drivers. A considerable number of participants preferred verbal communication (n = 12, 5 female, 7 male, Table 7.b.i-v) and some would like visual communications (n = 4, 2 female, 2 male, Table 7.b.vi-viii). They also mentioned that they would like an alarm button to contact remote drivers urgently (n = 2, Table 7.b.ix). V ideo call enables speaking and seeing another person at the same time (Naudé et al., 2022), which potentially facilitate social connection, especially among older people (Van Orden et al., 2021). With this, it is advised that to ensure the useability of the L4 AV, future design of the vehicle passenger communication should adopt a user-centred methodology and to provide tailored design to different user groups with different needs.

Participants also indicated that they want to have the option to choose routes in the L4 AV before a trip (n = 2, 1 female, 1 male, Table 7.c.i and ii). This corresponds to previous research findings that end-users require the level 3 automated vehicles to allow them to choose routes.

Finally, some participants mentioned they would like to have the option to override the remote drivers (n = 3, 1 female, 2 male, Table 7.d.i and ii). This could reflect the requirements discussed in section 3.1 (Theme 2.c.) that participants would like to maintain control of the vehicle. However, it is important to further explore whether it is safe and feasible to provide the option allowing the remote driving to be overridden by the passengers sitting inside the L4 AV.

5.6. Regulation, operation, and management of the L4 AV

Theme 6 is about regulation, operation, and management of the L4 AV. The subthemes and example quotes were displayed in Table 8.

Participants expressed requirements regarding the contract and terms of conditions of the L4 AV (n = 3, 3 male, Table 8.a.i-iii). They would like the pre-contract agreement or terms of conditions of the L4 AV to clearly define the roles and responsibilities of the teleoperation system as well as specifying who will be remote drivers. They also indicated that they would need a review and feedback mechanism, in the Uber style, to allow them to rate the remote driving services and provide feedback (n = 4, 4 male, Table 8.b.i and iv). This would also allow end-users to choose better remote driving services based on the rating and feedback from other users. Future research could adopt quantitative methods to assess the impact of a feedback and review mechanism on people's acceptance of L4 AV.

Apart from that, participants concerned about the compatibilities of the L4 AV, particularly towards the two aspects: compatibility between the L4 AV manufacturers and teleoperation service providers; and compatibility between the L4 AV manufacture official garage and third-party garage. Therefore it is important for the manufacturers and service providers to take compatibility into account when developing L4 AV, as it is strongly linked to users' trust towards automated vehicles (Motamedi et al., 2020). In addition, participants are also interested to know if the remote driving in the L4 AV a free service (n = 1, 1 female, Table 8.d.i). It is important for future research to explore the business models for the L4 AV to determine if the teleoperation service is a free s upplementary service together with the L4 AV or a chargeable service (like breakdown assistance).

Verification and Security check for remote driver was also mentioned by some participants (n = 3, 2 female, 1 male, Table 6.f.i and ii). Participants stated that there should be a security check or a verification process to ensure whoever behind controlling the vehicle is a genuine remote driver. A possible solution could be displaying the face ID of the remote drivers on the in-vehicle display.

Participants also discussed the regulation and legislations regarding the L4 AV, especially towards the teleoperation system and remote drivers (n = 2, 1 female, 1 male, Table 8, f.i-ii). They would expect there would be relevant regulations and rules in place to ensure the teleoperation companies are accredited to certain standards and to ensure qualification and competence of the remote drivers. In addition, participants are also concerned about the liability and insurance of the L4 AV (n = 3, 3male, Table 8, g.i-iii). They would expect that it is clearly stated in legal terms who is responsible and the implications on insurance if any accidents happened when travelling with the L4 AV. They are also concerned about the eligibility of using the L4 AV, particularly regarding if people without driving licenses would be eligible to use it as the L4 AV still have the capability to be manually driven by human drivers. These requirements reflect that to ensure the end-user's trust and to optimise benefits of the L4 AV, it is imperative for all stakeholders of vehicle automation, policymakers, end-user's advocacy bodies, engineers, and designers, fully understand the implications of regulations on the design of L4 AV and additional safety risks bought with new passenger-vehicle interactions (Lee and Hess, 2020).

6. Conclusion

Automated vehicles have the potential to revolutionise mobility, delivering significant benefits, such as safer roads, enhanced transport accessibility, increased productivity, economic growth, and contributions to transport decarbonisation HMGovernment (2022). Vehicles equipped with lower levels of automation systems can support drivers with sensory, informational and vehicle control assistance or provide automated driving. However, they still require human drivers to be fully responsible for the overall safety of the driving (SAE Level 0 to Level 2) or rely on human drivers to handle the critical situations (SAE Level 3) (SAE, 2016; Li et al., 2018). The Level 4 automated vehicles are capable to perform self-driving without requiring on-board driver input in their operational design domains and activate the failsafe mode to ensure safety in critical situations (SAE, 2016; Soteropoulos et al., 2020; Li et al., 2023). An important failsafe solution for the L4 AV is remote driving through a teleoperation system controlled by a remote driver (Goodall, 2020; Kettwich et al., 2021; Li et al., 2023). This concept envisions a dynamic shared control scenario involving three key entities—the on-board driver/passenger, the automation systems, and the teleoperation system controlled by a remote driver. However, significant knowledge gaps remain regarding exploring and researching the L4 AV and especially towards its new driver-automation system-remote driver interaction. To address this research gap, this paper qualitatively investigates end-users' needs and requirements for a 5G-enabled Level 4 automated vehicle incorporating a teleoperation system controlled by a remote driver as the failsafe mechanism. The resulting user requirements from this study have the potential to enhance the safety, usability, and accessibility of L4 AVs. Additionally, they highlight important implications for the design, development, and operation of L4 AVs that adopt a remote driver as the failsafe system. The key findings are:

- End-users welcome 5G-enabled Level 4 Automated Vehicles, valuing the failsafe mechanism of remote driving. They envision positive use cases for night driving, long distances, motorways, recurring journeys, short trips, unfamiliar routes, and fatigue reduction.
- The exploration of L4 AV serving as the 'designated driver' to reduce alcohol-impaired driving is a topic that warrants further investigation.
- Concerns of L4 AV include reliability of teleoperation system, performance of remote drivers, the 5G network connection, cyber security, and privacy issues.
- They need more safe demonstrations and hands-on experiences with the L4 AV to build trust.
- They expected inclusive and understandable design for the L4 AV, with remote driver recruitment considering gender equality.
- They need to understand the remote driver's behaviour, expecting them not to multitask or be distracted while operating the L4 AV remotely, and they also emphasise the importance of remote drivers' sense and information about the driving environment and situation.
- They also require the remote drivers to be qualified and experienced drivers and have undergone background security check before teleoperating the L4 AV.
- They require remote drivers being physically located in the same country as the L4 AV to avoid negative influences on performance caused by issues like unfamiliar road layout, different traffic rules, cultural differences in driving styles, sense of liability, and time differences.
- Dedicated remote drivers are preferred over random ones by the end-users.
- In remote driving situations, they require the remote drivers to clarify what had happened and explain how they will deal with the situation and operate the vehicle; the communication could be verbal, or verbal combined with visual. And they need an alarm button to contact the remote drivers urgently.
- They require clear terms and conditions for L4 AV, defining roles, responsibilities, and identifying remote drivers.
- A feedback system is seen as necessary for end-users to evaluate remote driving services and choose preferred drivers.
- They express concerns about liability and legal implications when utilising L4 AV, particularly when operated by remote drivers.

This study highlighted that for a L4 AV incorporating the remote driver as the failsafe to be accessible, trusted and accepted by end-users, it is imperative that the design of passenger-vehicle interaction to meet their requirements. Therefore, adopting user-centred design is strongly advocated for the future development of L4 AV. It is highly recommended that the innovative user-requirements identified in this study are explored further by the key stakeholder of the L4 AV, including policymakers, vehicle and equipment manufacturers, engineers, innovators, designers, service providers, academics, and researchers. With this, the new knowledge and ideas gained from the current research could provide new insights into improving existing automated vehicle regulations, facilitating safe and user-friendly L4 AV designs, providing high quality L4 AV services.

Although the research yielded useful knowledge, limitations still exist. Firstly, the current study is qualitative research that is not aimed for generalization but focused on identifying a rich, contextualized understanding of end-user requirements towards the passenger-vehicle-remote driver interaction in the L4 AV (Polit and Beck, 2010). Therefore, it is important for further research to design quantitative research to explore the statistical generalization of the knowledges derived from this study. For example, to quantitatively investigate whether factors like, experience or qualifications of remote drivers, communications with remote drivers, location of the remote drivers, feedback mechanism of remote drivers, as well as dedicated or random remote drivers have any statistical impact on passengers' acceptance, adoption, and intention to use towards L4 AV. Another direction of further pursuit is that the key features of passenger-remote driver interaction suggested by end-users are applied in the L4 AV and tested further by automated vehicle designers and innovator. For instance, to quantitatively evaluate and assess the passenger-vehicle-remote drivers' interfaces of different modalities on end-user's perceived usability. Alternatively, researchers could design and develop an auditory and visual

interface for passenger-remote driver communication and then evaluate its impact on remote drivers' performance, attention, and behaviour when teleoperating the L4 AV in real life.

Secondly, the participants of this study did not experience the L4 AV as it has not been available in the market during time of this study. Future research could explore the end-users' attitudes, acceptance, needs and requirements after interacting and engaging with a full-scale L4 AV in the real-world condition. Furthermore, the participants of this study were all actively drivers when participating the researcher. However, considering a key feature of L4 AV is potentially ensuring safety and operation even without human drivers' input in situations out of the designed operation domain, there are possibilities to enable people without driving licenses or have ceased driving to travel with the L4 AV. Therefore, an important direction for future research to explore for L4 AV is to explore the needs and requirements of end-users who do not hold valid driving licenses.

In addition, the investigation into the potential role of of L4 AV as the 'designated driver' to mitigate alcohol-impaired driving represents a compelling area that merits further in-depth exploration. This concept raises significant implications for enhancing road safety and addressing the societal challenge of alcohol-related incidents.

Finally, this studied aimed to explore the L4 AV end-user requirements without specifically focusing on specific user-groups of passengers. Future research could investigate how the remote driving failsafe system of L4 AV could be designed to support passengers with diverse mobility requirements (Li *et al.*, 2021b).

CRediT authorship contribution statement

Shuo Li: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Yanghanzi Zhang:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. **Phil Blythe:** Conceptualization, Funding acquisition, Methodology, Project administration, Resources, Supervision, Writing – original draft, Writing – review & editing. **Simon Edwards:** Conceptualization, Funding acquisition, Project administration, Supervision, Writing – review & editing. **Yanjie Ji:** Conceptualization, Supervision, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.trf.2023.11.018.

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