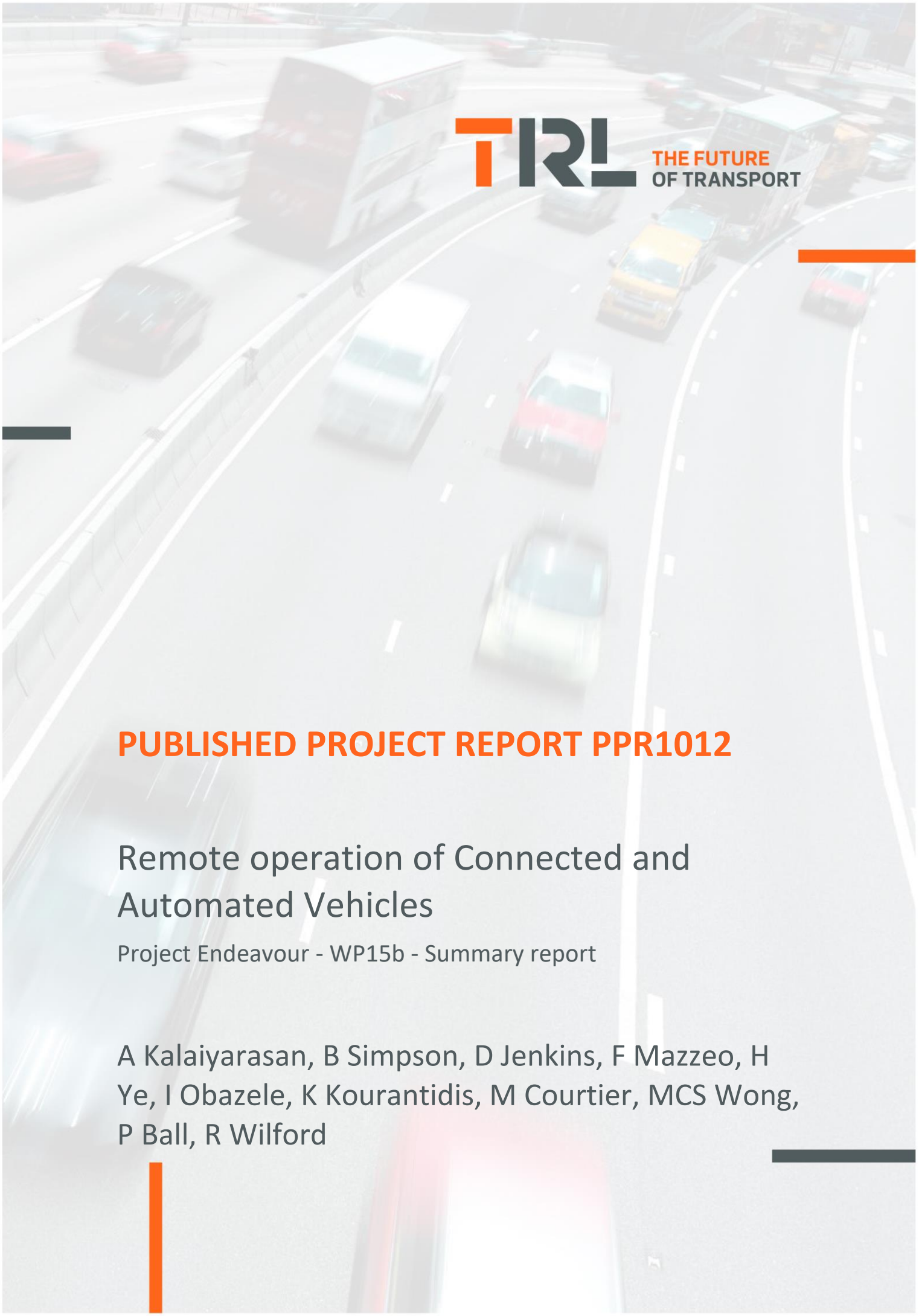

THE FUTURE OF TRANSPORT

PUBLISHED PROJECT REPORT PPR1012

Remote operation of Connected and Automated Vehicles

Project Endeavour - WP15b - Summary report

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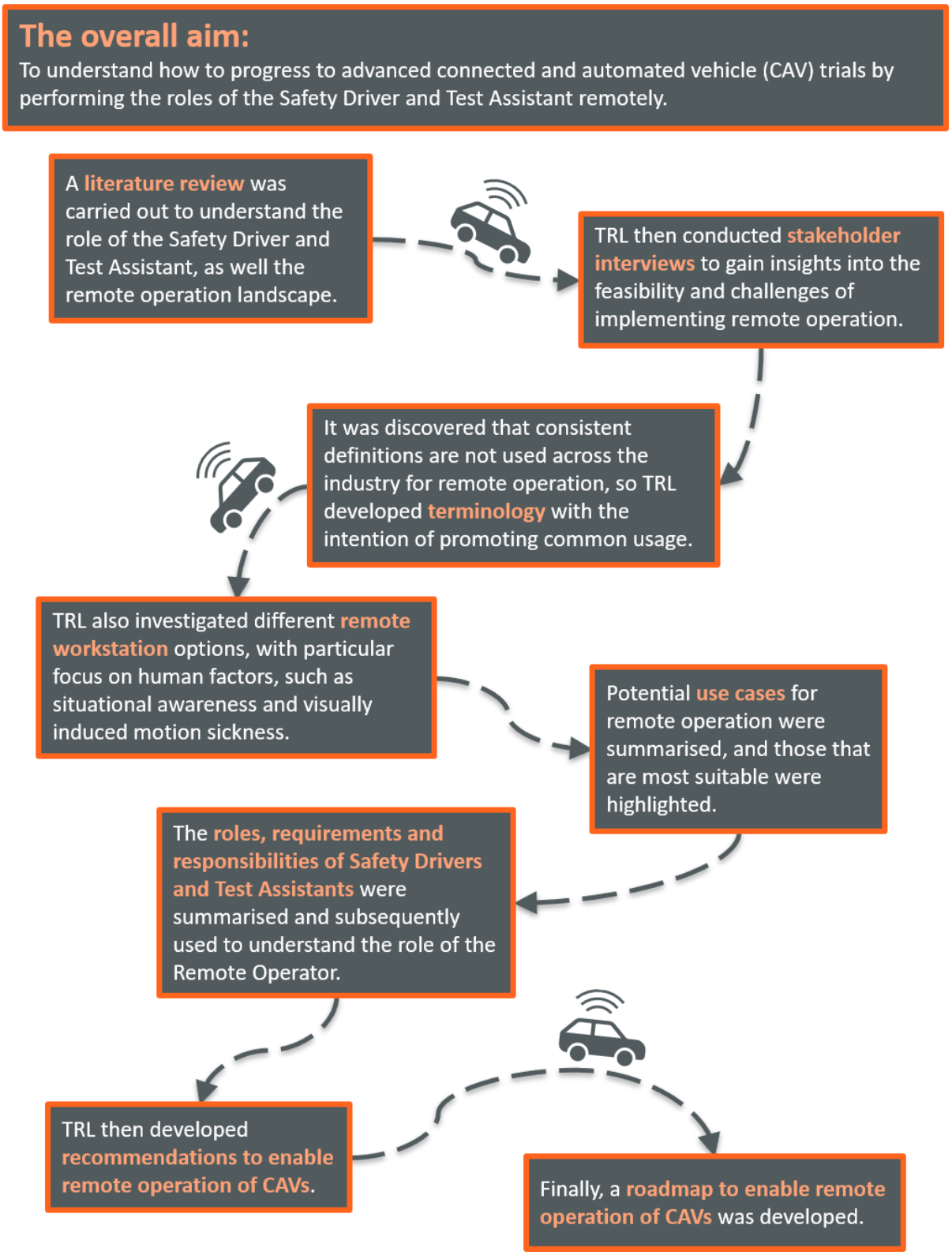
Executive Summary



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1 Introduction

Connected and automated vehicles (CAVs) offer numerous societal benefits, however, there is still a long way to go before CAVs can be considered reliable and safe. Currently, during typical automated vehicle (AV) trials and testing in the UK there are two personnel within each test vehicle: the Safety Driver and the Test Assistant. This study sought to understand the current roles of the Safety Driver and Test Assistant in order to recognise the legal, technical and safety assurance challenges of removing these roles from an AV and enabling remote supervision and operation of CAVs.

This summary report is based on research undertaken by TRL as part of Project Endeavour. Project Endeavour is a mobility project that was designed to accelerate and scale the adoption of AV services across the UK.

The primary purpose of the research was to understand how to progress to advanced trials and perform the roles of the Safety Driver and Test Assistant remotely.

1.1 Report overview

This summary report is based on a larger full report (PPR1011) delivered to Innovate UK and the Centre for Connected and Autonomous Vehicles (CCAV). This report is split into nine sections, with the first eight containing the research and findings. Section 1 provides an overview of the study; Section 2 summarises the approach taken for the literature review and stakeholder engagement, and Sections 3 to 8 details the key findings. This summary report does not include information on the development of results, which can be found in the full report (RPN5079).

The following research areas were considered in this study:

- The current guidance, standards and regulations related to remote operation
- Definitions related to remote operation
- Applications and use cases for remote operation
- The role of the Safety Driver
- The role of the Test Assistant
- Safety considerations for the removal of the Safety Driver and Test Assistant roles from the AV

2 Methodology

To understand the roles of the Test Assistant and Safety Driver, as well as Remote Operators, the study comprised a review of relevant standards and literature together with stakeholder interviews. The key findings from these activities are presented in Sections 3 to 8 of this summary report.

2.1 Literature review methodology

The literature review was conducted following the principles and methods laid out by (Seidl *et al.* 2017):

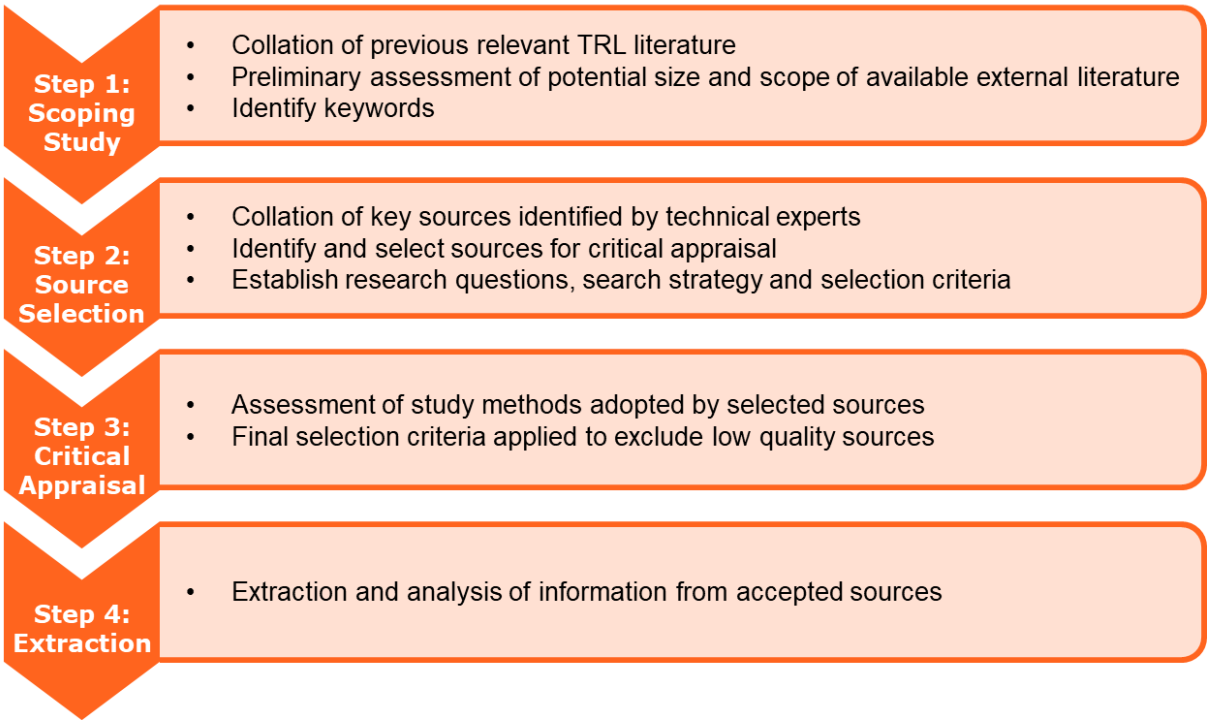


Figure 1: High-level overview of systematic literature review process

2.2 Stakeholder engagement methodology

A wide range of stakeholders were approached to provide their insight on the feasibility and challenges related to the implementation of remote operation. A total of 17 interviews were conducted and the stakeholders were classified based on their expertise and sector of operation:

- **Group 1** – This group comprised automated driving system (ADS) developers, including those looking at remote operation, and trialling organisations.
- **Group 2** – This group consisted of stakeholders involved in driver training and assessment, fleet management, original equipment manufacturers (OEMs), Tier 1 suppliers, and those conducting research either privately or in academia.
- **Group 3** – This group included stakeholders employed by public bodies, regulating agencies, standards developing organisations (SDOs), and insurers.

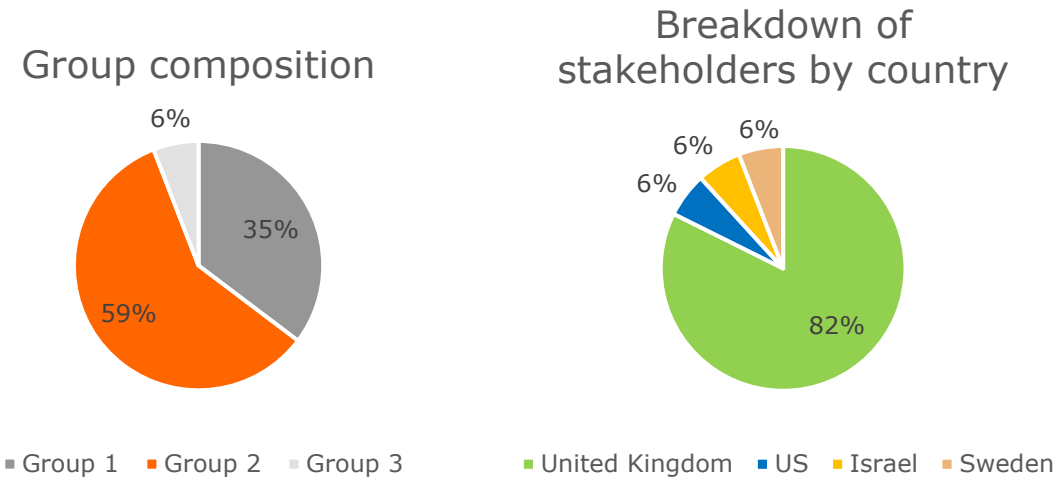


Figure 2: Stakeholder group composition and breakdown by country

3 Terminology

The literature review and stakeholder engagement demonstrated that the terminology used for remote operation remains largely undefined and companies across the industry apply terms inconsistently. This finding also corroborates with the response obtained from a public TRL blog (Lawson 2021) which aimed to initiate conversation on the creation of common terminology that could be applied consistently across industry. Through information obtained during the literature review and stakeholder engagement, the study investigated the various definitions of remote operation used by the industry. The themes that emerged were "location of the operator with respect to the proximity to the AV or the driving controls", "classification of activities", and "the authority or level of control of the activity". These themes were used to define some of the core activities described in Figure 3. The activities have been separated into driving or AV support activities as detailed in Sections 3.1 to 3.3. It is acknowledged that the definitions in this space will need to evolve as the industry matures, and new use cases and technology are developed.

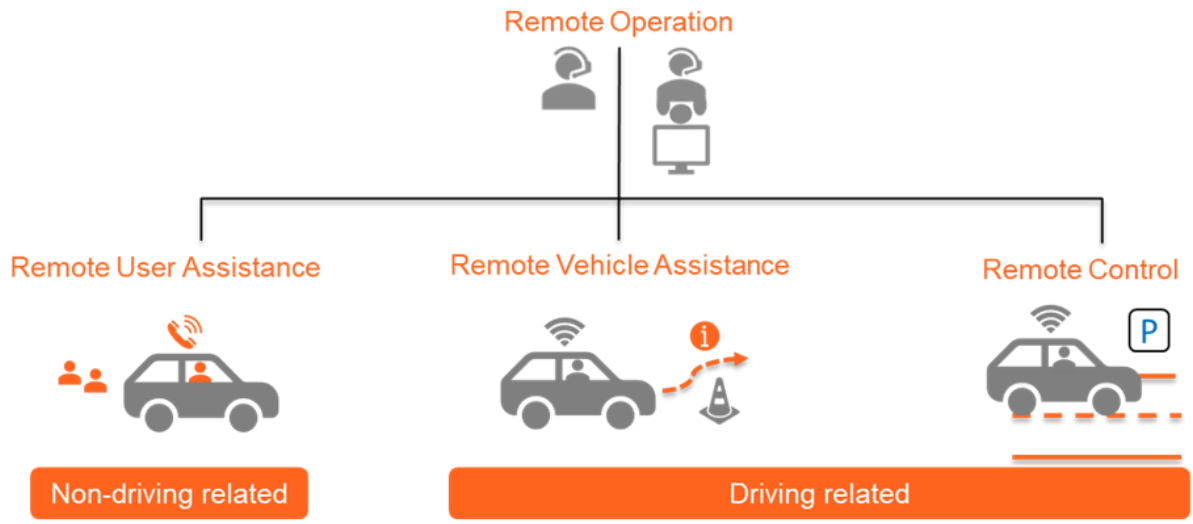


Figure 3: Classification of remote operation activities

3.1 Remote operation

3.1.1 Remote

The term 'remote' refers to operations such as supervising, assisting, controlling, and driving AVs from a location that can be within the AV (but not in the driver's seat), or outside of the

AV from within visual line of sight (VLOS[1]) or beyond visual line of sight (BVLOS[2]) of the AV. The term assumes that hard-wired connection to the AV is not used.

3.1.2 Remote operation

Remote operation is an umbrella term that encompasses the functions needed to support the operation of an AV or a fleet of AVs by a Remote Operator (see 3.1.3). Remote operation includes both driving and non-driving related tasks. During remote operation, the Operator may have full authority for the AV's actions, the AV may retain final authority, or it may be split depending on the system design, maturity and safety assessments of the ADS developer and trialling organisation.

3.1.3 Remote Operator

A Remote Operator is a generic term for a human who supervises the operation of an AV from a remote location (see 3.1.1). Supervision can comprise monitoring the AV, intervening in the AVs' operation, assisting passengers, or managing part of the AV service. The supervision of operations may need to be real-time, such as for remote driving (see 3.2.1.1), and the Remote Operator may or may not have final authority for control of the AV. A Remote Operator may only be able to perform one or several of the remote operations defined in Section 3.2 and 3.3.

3.2 Driving related remote operation activities

3.2.1 Remote control

Remote control comprises the continual oversight of an AV's operation by a Remote Operator who is performing a safety-critical role and has the ability to intervene in the AV's operations. This could range from performing the full dynamic driving task (DDT[3]) (see 3.2.1.1) to bringing the AV to an emergency stop (see 3.2.1.2).

3.2.1.1 Remote driving

Remote driving is a sub-set of remote control and is the activity of remotely conducting part or all the DDT. This means conducting any combination of the following:

[1] VLOS is an operating principle that involves a continuous maintenance of direct unaided visual contact of the subject AV during its operation.

[2] BVLOS is an operating principle where the Operator is unable to maintain direct unaided visual contact of the subject AV and relies on external aids (such as cameras) to maintain oversight of the AV's operation.

[3] The DDT is defined by BSI as the *"real-time operational and tactical functions required to operate a vehicle safely in on-road traffic* **BSI (2020a).** *Connected and automated vehicles – Vocabulary v3.0.* British Standards Institution.*".*

- Lateral motion control – steering.
- Longitudinal motion control – braking or accelerating.
- Environment and object monitoring and response.
- In-the-moment path planning (but not the strategic tasks of deciding the final destination).
- Changes to conspicuity – use of indicators, lights, horn.

3.2.1.2 Remote emergency intervention

Remote intervention is the act of intervening to change the movement, status or conspicuity of the AV in response to an event. Remote emergency intervention differs from remote driving. Remote driving may be used to manoeuvre an AV from a safe location onto a recovery vehicle whereas remote emergency intervention may involve the use an emergency stop as a safety control. The requirements for remote emergency intervention may be significantly different (based on the trial, use case, ADS maturity, etc.) so is considered a separate activity.

3.2.2 Remote vehicle assistance

Remote vehicle assistance is the act of providing assistance to an AV or intervening in a way that changes the path or movement of the AV without directly conducting the driving tasks. It is likely to be intermittent and could be reactive in response to a request/demand from the AV or system, or proactive in response to monitoring and observations. 'Assistance' describes the high-level AV interventions to be able to continue or complete a trip such as permissions to proceed, instructions to change lane or take a path around an object, rather than low-level instructions for how to conduct a manoeuvre. It may be important to respond to these requests in a timely manner, however, remote vehicle assistance activities should not be time and safety-critical and therefore should not require instantaneous intervention. As a result, there are likely to be less demanding remote monitoring requirements, for example on latency, bandwidth or datasets which are needed as part of remote vehicle assistance.

3.2.3 Remote monitoring

Remote monitoring comprises observing the AV's operating environment (including the surroundings, other road users, weather) or data from the AV and supporting systems and can vary depending on the type of remote operation it is supporting. A single person may monitor one or more AVs, or multiple people may monitor the same AV. Monitoring may be intermittent to check correct operation or continuous with the possibility of intervening reactively if required. At the point of intervention, the remote monitoring activity changes to remote assistance or remote driving when response is required. Whilst it is likely that a large part of a Remote Operator's time will be spent monitoring, it is expected they will also be available and capable to conduct one or more of the other types of remote operation listed above (3.2.1 and 3.2.2).

3.3 Non-driving related remote operation activities

3.3.1 Remote passenger and road user assistance

Remote passenger and road user assistance describes a range of services that can be provided by a Remote Operator to support the welfare of an AV user/passenger such as by answering queries and providing safety and security information. It also includes interactions with passengers or other road users as a result of an incident such as providing guidance in the event of an evacuation.

3.3.2 Remote logistics management

There are a number of other activities needed to manage the operation of a single AV or fleet of AVs from a remotely-located centre which is referred to as remote logistics management. As trials scale-up and services start to be deployed it is anticipated that this term and list of associated activities may need to evolve. Currently remote logistics management comprises similar activities that are carried out as part of conventional vehicle fleet management but with the information or instructions communicated to a computer (the AV) rather than a human, which may change or increase the safety implications.

3.4 Other terminology

3.4.1 Safety Driver

According to (BSI 2020a) a Safety Driver has been described as a person who:

- Is situated within an AV with access to its controls.
- Pays attention to the AV's operating environment.
- Ensures the rules of the testing area are followed.
- Identifies risks.
- Identifies deviations from expected behaviours and is able to take full control of the DDT of an AV when necessary.

3.4.2 Test Assistant

The role of a Test Assistant is not widely defined. According to (Belguim FPS Mobility and Transport 2016) and (Isle of Man DoI 2017) a Test Assistant is a person who assists the Safety Driver when conducting trials. This could be done by, for example, monitoring the behaviour of an AV through digital information displays, or other information feedback devices, and by observing other road users. The details of this role are often dependent on the type of test or trial.

4 Remote workstations

4.1 Human factors concepts

Table 1 describes the key human factors concepts that must be considered when designing remote workstations for remote operation.

Table 1: Human factors concepts relevant to remote operation

Situational Awareness	Situational awareness is a dynamic process in which elements of the environment are perceived and interpreted, and implications of their future states are drawn. It describes how humans perceive a situation and interpret it to form their response. Information from all senses contribute to gaining situational awareness.
Embodiment	Embodiment refers to sensory perceptions (hearing, vision, haptic, vestibular) experienced while in a vehicle that could be lessened or missing in another environment and context.
Visually induced motion sickness (VIMS)	Visually induced motion sickness is a type of motion sickness caused by the exposure to dynamic visual displays and simulated travel scenarios. Besides oculomotor disturbances, it's symptoms (e.g., nausea, vomiting and sweating) are principally like those of general motion sickness.

4.2 Remote workstation setup

This section summarises the potential remote workstation setups for Remote Operators found during the literature review and stakeholder engagement. Figure 4 summarises the options for the display of information, while Figure 5 summarises the options for control interfaces.

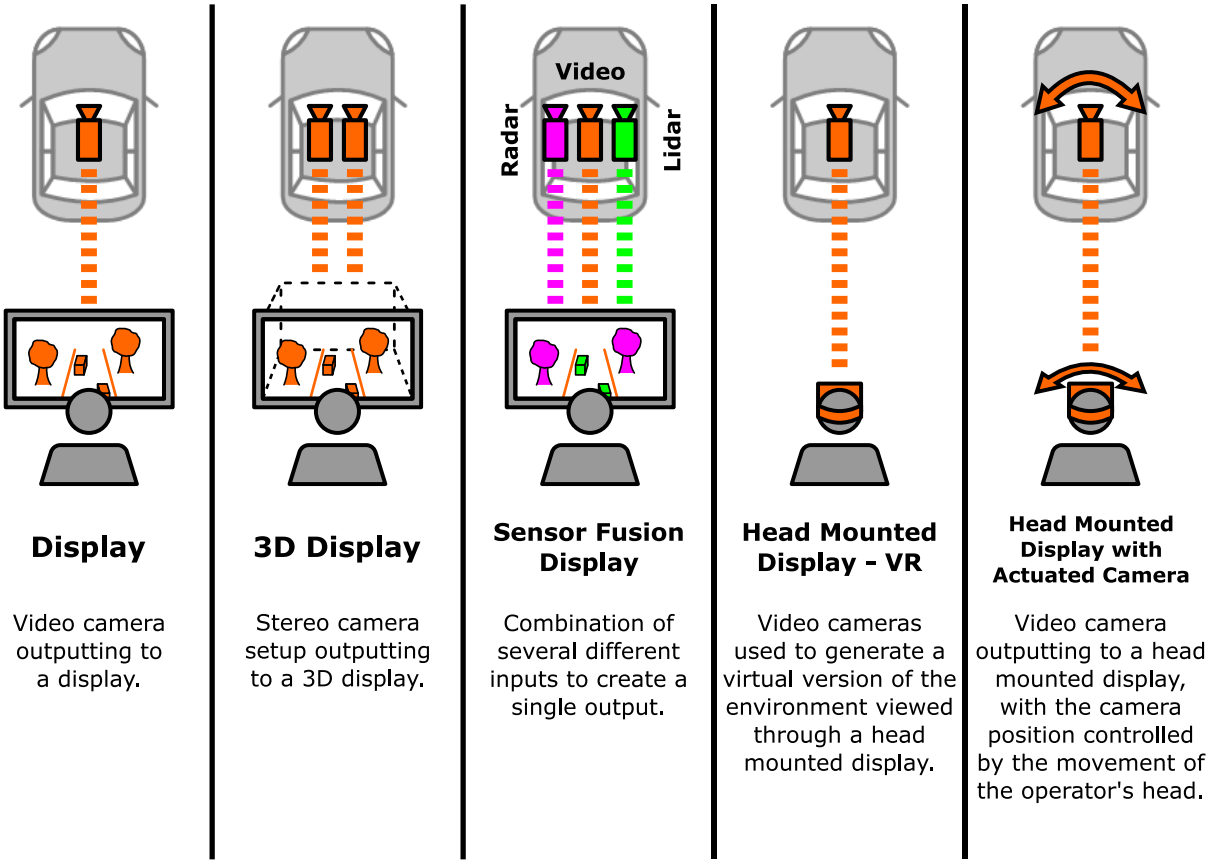


Figure 4: Options for information display for remote workstations (Fong *et al.* 2001; Hoffman *et al.* 2008; Gnatzig *et al.* 2013; Shen *et al.* 2015)

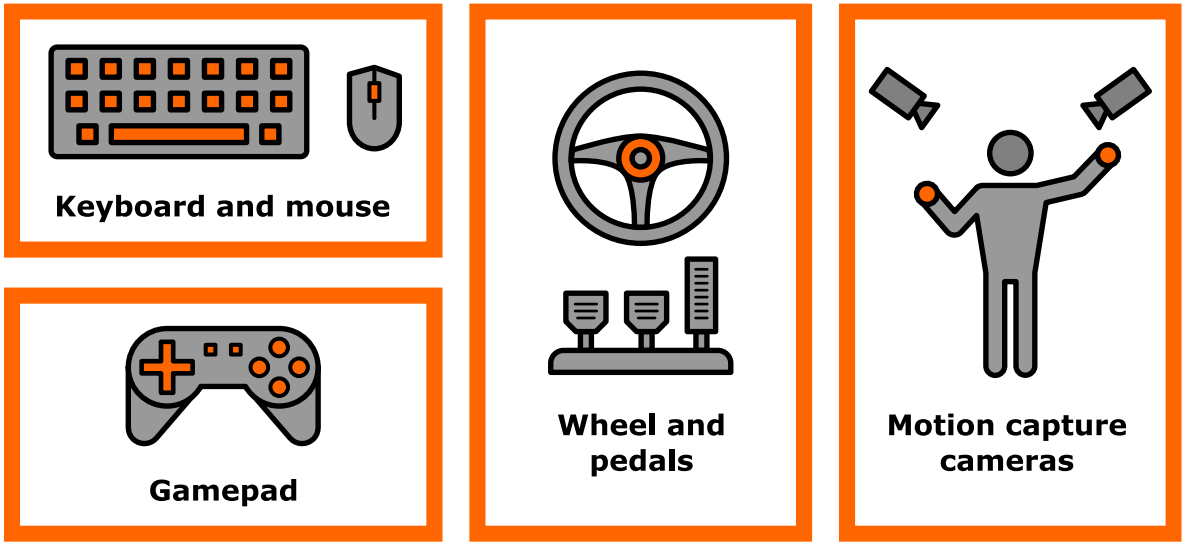


Figure 5: Options for control interfaces for remote workstations (Ha *et al.* 2015)

5 Use cases for safe remote operation

An AV with remote operation capabilities must always be driven in a safe manner, whether this is by the ADS or the Remote Operator, including during any transitions of control. These considerations are true in all situations, and these criteria are the foundations for determining the suitability of any particular use case or scenario.

There are three fundamental requirements for successful application of remote operation:

1. **Operator's situational awareness of the environment**

   The Operator must have sufficient situational awareness to understand the environment.

2. **Operator's level of control over the AV**

   The Operator must have sufficient control to be able to influence the AV's actions.

3. **Connection between the Operator and AV**

   The connection (a communications link or video feed) between the Operator and the AV must enable sufficient control and situational awareness to be achieved when required.

A generic use case gives a description of the type of activity and the broad environment in which it is being conducted. An example of this is providing remote vehicle assistance to an AV which is stuck along its route in a city. These use cases contain generic attributes which have inherent high-level risks and constraints that may apply differently in different circumstances. An example of a generic attribute is operating in a busy environment; this typically brings an increased risk of collision, but this generically labelled environment can present a broad range of challenges for individual instances of remote operation.

Some use cases are more challenging than others for remote operation since they present increased difficulty in satisfying one or more of the three fundamental requirements. Four initial categories of use case attributes, which significantly impact these requirements, have been proposed:

1. **The type of remote operation in use.** The Operator's required level of control and situational awareness, and by extension the required quality of the connection between the AV and Operator, are different for each mode of remote operation. These are generally highest for remote driving and lowest for remote passenger assistance services.
2. **Environmental features.** Remote operation is likely to be conducted in a broad range of environments, some of which present additional challenges. For example, weather conditions can affect sensor performance which may impact the level of situational awareness a Remote Operator has by partially obscuring their view. They may also affect the level of control over the AV in remote driving situations.
3. **Activities being performed by the AV.** Activities such as carrying passengers or significant loads can affect the Operator's requirements to control the vehicle safely.

4. **ADS capability and transition of control between the ADS and Operator.** The capability of the ADS also has an impact on the environments, activities, and types of remote operation which can be conducted safely. For AVs where control of the vehicle transitions between the ADS and a Remote Operator, this transition must be controlled and must happen at an appropriate time.

A brief list of initial generic use cases which may be suitable for remote operation, along with potential risk attributes from one of the four categories listed above, are illustrated in Table 2. Also included are risk ratings which give an indication of risk level before specific mitigations strategies are employed. Further work is required to develop further suitable use cases and mitigation strategies, and to align stated risks with existing regulation and standards.

Table 2: Initial generic use cases

High-level use case	Typical operating environment	Type of remote operation	Potential risk attributes	Risk rating
Rerouting an AV when an obstruction is present. This may involve the AV committing a minor traffic violation which it is not able to do on its own	On-road AV. May or may not take passengers. AV with conventional controls and would travel on public roads with other vehicles.	Remote vehicle assistance	• Remote vehicle assistance • Busy environments • Interaction with VRUs • Poor connectivity • AV carrying passengers • Intermittent supervision • Operator unable to respond to intervention request.	Amber
Conducting the complete DDT for a vehicle in a dangerous environment or carrying hazardous substances. Vehicle may not be automated	Off-road machinery (mines, quarries, construction sites, road works, etc). Likely to be large, heavy duty machinery. May include workers on foot.	Remote driving	• Remote driving • Unstructured environments • Busy environments • Interaction with VRUs • Poor connectivity • Uneven terrain • AV carrying significant loads.	Red
Last-mile delivery services	Pavement, cycle lane, or any other low-speed environment which may be shared by cyclists, pedestrians, and other VRUs, but not generally by other vehicles.	Remote vehicle assistance	• Remote vehicle assistance • Interaction with VRUs • Poor connectivity • AV carrying passengers • Intermittent supervision • Operator unable to respond to intervention request.	Green
Using an e-call system to call for roadside assistance or information from a call centre	Privately owned on-road vehicles.	Passenger assistance services	• Passenger assistance services • Operator unable to respond to intervention request.	Green

6 Summary of roles, requirements, and responsibilities

To safely remove the Safety Driver and Test Assistant from an AV for remote operation it is important to firstly identify the requirements and responsibilities that they perform within an AV. This is then be followed by identifying which of these responsibilities could be performed remotely and the requirements of the Remote Operator to safely carry out the responsibilities.

The Safety Driver and Test Assistant both perform key roles in ensuring the safety of a given AV test or trial. While the Safety Driver performs their role by observing the AV's environment and behaviour in the real-world, and intervening when necessary, the Test Assistant performs their role using digital feedback devices and relays key information (including anomalies) to the Safety Driver.

A summary of the requirements of the Safety Driver and Test Assistant is shown in Table 3, while Table 4 summarises their responsibilities. The summaries are based on various countries' guidelines for AV trialling, various trialling organisations' job descriptions for Safety Drivers and stakeholder consultation (FPS Mobility and Transport 2016; DGT 2017; Lovdata 2017; Risksdag 2017; Sano 2017; DfT 2019a; Lee and Hess 2020; National Transport Commission 2020).

Table 3 and Table 4 also summarise the key requirements and responsibilities of a Remote Operator which were deduced during the stakeholder consultation. The role of the Remote Operator was split into two based on the level of control they have over the AV. The tables combine the responsibilities and requirements of the remote vehicle assistance and remote user assistance activities, as they are likely to be performed by the same person. However, when performed by separate people the responsibilities and requirements of the roles may differ. The best practice for remote vehicle/user assistance is to hold a driving licence but it might not be necessary in every application especially in remote user assistance. Remote user assistants may however need to be trained on how to interact with the user and monitor their welfare. They may also need to be trained on how to actuate aspects of the AV to support the users, such as the doors and boot. Data handling or technical tasks, such as debugging the software, may not be required for remote user assistance.

Table 3: Comparison between the requirements of a Safety Driver, Test Assistant, and the suggested requirements for a Remote Operator

Category	Requirements	Safety Driver	Test Assistant	Remote Operator	
				Remote vehicle/ user assistance	Remote control
Licensing requirements	Hold a driving licence for the vehicle category.	Yes	No	Yes	Yes
	Hold the nearest equivalent licence for prototype vehicles that are not easily categorised.	Yes	No	Yes	Yes
	Have held the driving licence for a given minimum number of years prior to the trial commencement.	Yes	No	No	Yes
	Have skills over those of regular drivers of conventional vehicles.	Yes	No	No	Yes
Training requirements	Basic training including how to turn on the vehicle, location of the controls etc.	Yes	Yes	Yes	Yes
	Covers the trialling organisation's risk management processes and the type of test to be carried out.	Yes	Yes	Yes	Yes
	Covers sufficient understanding of the system, including its capabilities, performance, and limitations.	Yes	Yes	Yes	Yes
	Understanding of when to intervene through training covering potential hazardous situations and how to react to them. This includes being able to detect deviations from expected behaviours and being able to take full control of the AV's DDT if necessary.	Yes	No	No	Yes
	Understanding of how to transition between manual mode and automated mode and vice versa.	Yes	Yes	No	Yes

	Training on how to monitor the vehicle/system in automated mode in a controlled environment.	Yes	Yes	Yes	Yes
	Training on how to debug the system.	No	Yes	Yes	No
	Training on how to perform minor repairs to the AV.	Yes	Yes	No	No
	Training on how to stop the AV in case of an emergency.	Yes	Yes	Yes	Yes
	Data handling training, including data logging and data marking.	No	Yes	Yes	No

Table 4: Comparison between the responsibilities of a Safety Driver, Test Assistant, and the suggested responsibilities of a Remote Operator

Category	Responsibilities	Safety Driver	Test Assistant	Remote Operator	
				Remote vehicle/ user assistance	Remote control
Risk assessment and vehicle control	Always responsible for driving and operating the vehicle. Expected to be able to drive, operate or control the AV safely and under any operating condition.	Yes	No	No	Yes
	Always monitor the AV regardless of its mode of operation (i.e., manual or automatic), constantly ensuring its safe operation.	Yes	Yes	No	Yes
	Must remain alert and ready to intervene if necessary.	Yes	Yes	No	Yes
	Pay attention to the AV's environment, observing the traffic laws, the safety laws as well as laws restricting vehicle access.	Yes	No	Yes	Yes
	Must take full control of the AV under circumstances that may be detrimental to the AV's occupants or other road users.	Yes	No	No	Yes

	Comply with the trialling organisation's risk management processes in place and use the knowledge and skill gathered during prior training to mitigate safety issues and ensure the safe operation of the system.	Yes	Yes	Yes	Yes
	Monitor the AV's behaviour/system's performance through software other than the display showing the AV's environment.	No	Yes	Yes	No
	In the case of an emergency, disengage autonomy and bring the AV to a stop using an emergency stop button.	Yes	Yes	No	Yes
	Localise the AV and provide verbal feedback/directions to the AV's operator concerning the AV's environment.	No	Yes	Yes	No
	Monitor the cybersecurity status.	No	Yes	Yes	No
Liability	Bears some liability for incidents that may occur due to failure to regain control of the AV when prompted.	Yes	No	No	Yes
Public engagement	Engage with emergency services and the public when required.	Yes	Yes	Yes	Yes
	Passenger management/interact with users such as passengers.	Yes	Yes	Yes	No
Data handling, debugging and repairs	Log data related to the trial, which may include starting and stopping recording of data by the sensors.	No	Yes	Yes	No
	Data mark and perform minor debugging operations when needed.	No	Yes	Yes	No
	May carry out repairs to the AV in case of malfunctioning during the trials.	Yes	Yes	No	No

7 Recommendations to enable remote operation of CAVs

This section outlines the recommendations made from this study. The recommendations were drawn from the conclusions of the literature review and stakeholder consultation.

7.1 Enablers and challenges

There are various factors affecting the safe removal of the Safety Driver and Test Assistant from the AV during remote operation. This study has identified some of the key factors and has recommended actions to address these factors. The factors relate to legal requirements, standards and certifications, and technological requirements. Table 5 summarises these factors and the recommended actions for CCAV.

Table 5: Summary of the enablers and challenges, and the recommended actions for CCAV

Category	Enablers/Challenges	Recommendations	Benefits
Legal	Legal documents written before remote operation was considered a possibility, such as the Road Traffic Act 1988 and The Road Vehicles (Construction and Use) Regulations 1986, could inhibit progress of remote operation.	Conduct a review of the Law Commission's recommendations and findings to identify possible gaps related to remote operation of CAVs in the UK that have not been addressed.	Identifying and addressing these gaps could help provide legal certainty for remote operation, encouraging investment, research, and development.
	There are unclear guidelines in some best practice documents, such as PAS 1881 (BSI 2020b) and the DfT Code of Practice for AV trials (DfT 2019b), including the lack of safety measurements for remote operation systems.	Collaborate in the review of best practice documents and support research aimed at quantifying safety levels for remote operation.	This would help ensure that ADS developers can develop their systems to be safe enough to avoid incidents during public trials.

	The requirement for Safety Drivers and Operators to be conscious of their appearance to other road users to avoid distractions cannot be met by Remote Operators.	A study could be coordinated on how to mitigate the risk of distracting other road users due to the absence of a driver in the driver's seat.	This could help ensure that the absence of a driver in the driver's seat does not cause distractions that could lead to an incident.
	Liability is an issue being faced by the entire CAV industry, including for remote operation.	Conduct a review of the Law Commission's recommendations and findings aimed at addressing legal issues related to AVs to identify possible gaps on liability.	Clarifying issues related to liability could encourage investment, research and development.
	Legal factors related to remote operation may differ across the UK's domestic and international borders and could potentially affect the safety of remote operations.	Liaise with relevant stakeholders to understand how laws across the UK could be aligned and how these could be further aligned with those of other countries to facilitate remote operation.	This would help ensure that remote operation can be conducted across the UK and across international borders without legal uncertainty and complexity.
Standards and certifications	There are issues related to inconsistent use of terminology and lack of definitive sources for terminology in the remote operation field.	Initiate dialogue with relevant stakeholders to identify requirements and develop common terminology for use within the remote operation and wider CAV field.	This would help ensure industry-wide adoption of the terminology and potentially promote collaboration.
	There are also issues related to inadequate coverage of remote operation in CAV standards and general established standards. This also includes the lack of certification for key elements of remote operation, such as the human machine interfaces (HMIs),	Initiate dialogue with relevant stakeholders to identify the gaps in current standards related to remote operation and potential requirements for remote operation system certification.	Facilitating the development and adoption of standards and certification that includes minimum safety requirements could help ensure consistency, security, compliance, and data sharing.

	to provide assurance that the elements are compliant with established standards.		
	The Teleoperation Consortium is in the process of developing a teleoperation professional credential course, and BSI PAS 1884 (which is in preparation) includes a section on Remote Operator training.	Promote these efforts and other similar efforts by recommending them to trialling organisations in guidance documents for remote operation.	This would help ensure that trialling organisations are informed of best practice on how to train their Remote Operators.
Technology	Latency has a huge impact on remote operation with the associated risk increasing as the operational speed of the AV increases.	Support research aimed at investigating effective methods for dealing with latencies experienced during remote operation.	Supporting such research could provide information that could be included in industry guidance for remote operation.
	Organisations may feel reluctant to share data (including lessons learnt) for commercial reasons.	Host workshops aimed at promoting the sharing of remote operation system trial results and research findings.	Sharing data could facilitate learning from incidents and trials, which could aid in improved efficiency and safety of system development.
	The situational awareness of a Remote Operator may be affected by various factors including their activeness, their trust in the system and the design of the HMI.	Coordinate the development of guidance documents that cover how Remote Operators could stay active and how to design appropriate HMIs.	This would help to ensure that Remote Operators are well trained and equipped with appropriate HMIs to maintain acceptable levels of situational awareness during operation.

7.2 Safety assurance

Various risks are involved in the removal of a Safety Driver and Test Assistant from an AV during the development of a remote operation system. Trialling organisations will need to demonstrate that these risks have been considered and various mitigating actions have been taken to adequately address them which may include providing evidence in the safety case. This study has identified some of the key risks and recommended actions for CCAV and they are summarised in Table 6.

Table 6: Safety assurance recommendations

Safety assurance issue	Details	Recommended action	Benefit
Redundancies to handle failures/disengagements	Remotely-operated AVs undergoing early trials may pose an increased risk to the public in the absence of either a Safety Driver or external operator within VLOS of the AV.	A mandate could be made that during early trials, remote operation systems of any technological level can be tested if there is a Safety Driver or an external operator present (with a real-time view of the AV) overseeing operation who can at any point either take back full control of the AV or bring the AV to a stop.	This would help ensure that in events where the remote operation system fails, risk mitigation strategies are in place to any avoid incident.
Remote Operator working hours	The recommended working hours for remote operation may differ from those of an in-vehicle Safety Driver.	Guidelines on appropriate working hours for each remote operation use case could be developed.	The guidelines would aid trialling organisations when setting limits for time that Remote Operators perform their role per day.
Licensing requirements	Remote Operators may need to prove that they are qualified to safely perform their roles on publicly accessible roads by holding special	Special licences could be developed for each remote operation use case that reflects the responsibilities of the Remote Operator.	Licencing Remote Operators would help ensure that they are fully qualified to perform their respective roles safely.

	licences.		
Training requirements	Remote operation HMIs may differ from those used for conventional driving.	It could be mandated that Remote Operators are adequately trained on how to perform their roles using the HMIs before undergoing a trial on publicly accessible areas.	This would help ensure that Remote Operators are fully prepared to deal with the safety challenges in publicly accessible areas.
Behaviour requirements	Special laws regarding a Remote Operators' behaviour for each use case may need to be developed (or updated) as some laws regarding driver's behaviour may not be easily met by Remote Operators.	A requirement could be made that for public trials, trialling organisations should demonstrate how their Remote Operators will comply with the special laws.	This would help provide assurances that a remote operation trial is compliant with the law and potentially improves the safety of the operation.
AV requirements	AVs are expected to comply with the general road vehicle requirements which includes having appropriate rear-view mirrors.	For remote operation, it could be mandated that the AV's sensors should provide at least the same level of depth and view of the AV's environment as an in-vehicle driver.	This would help ensure that the Remote Operator can adequately view the AV's environment.
Mitigation strategies	Remote operation might fail if there is a wider communication network failure, if access to the communication network is impeded, or if unmanageable latencies occur.	To avoid risks associated with communication network failure, mitigation strategies may need to be in place, and it could also be mandated that trialling organisations are required to provide sufficient evidence that their AV can perform mitigation manoeuvres (e.g., an emergency stop) when such an event occurs.	This would help ensure that risks associated with the network are appropriately managed to reduce the possibility of an incident occurring.
Transition	Transitioning between remote	Recommendations such as ease of	The recommendations would provide

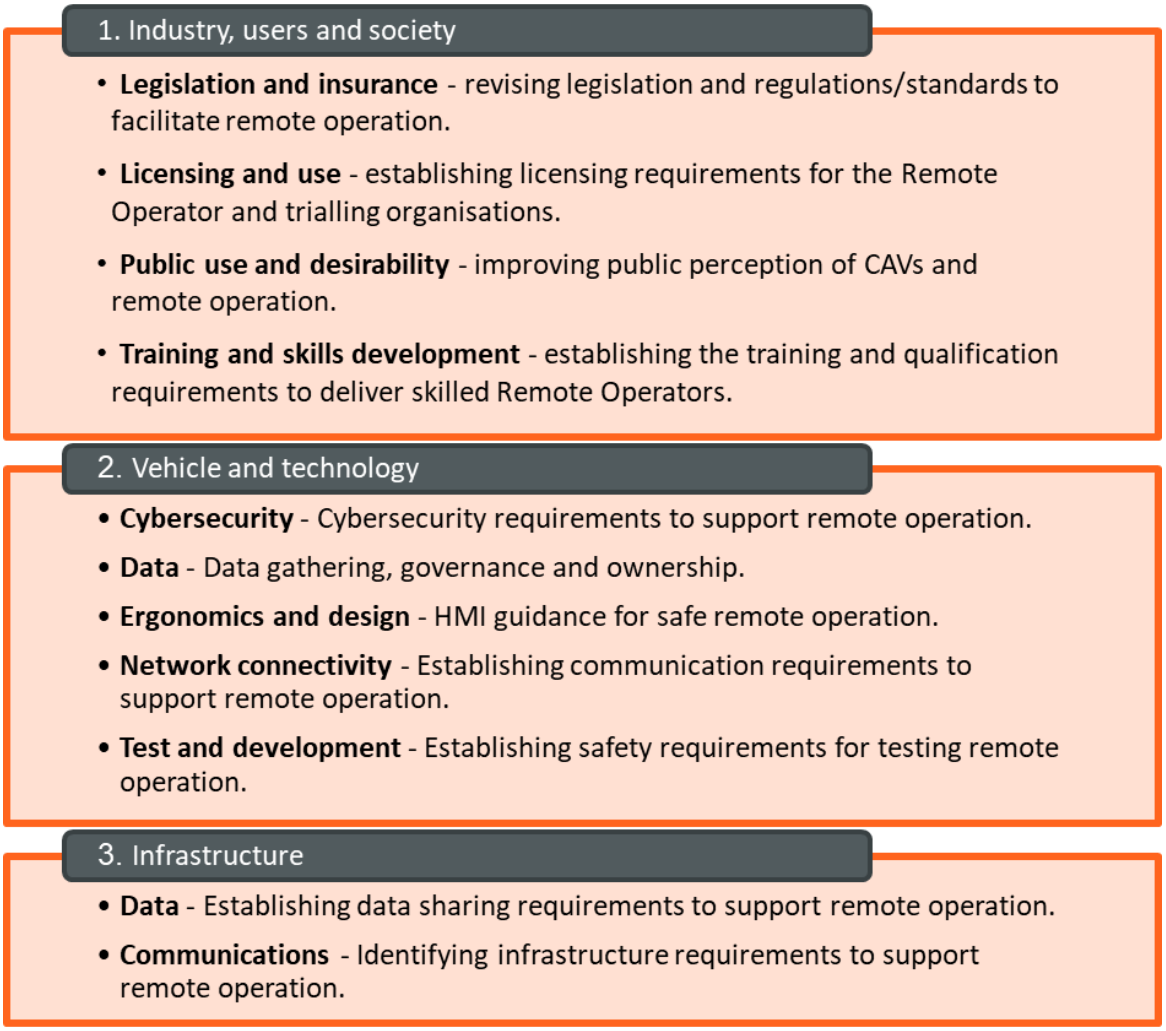
between driving modes	operation and automated or manual driving modes is an important safety issue.	transition between driving modes, clear indication of the current driving mode, and the use of audible, visible, or haptic signals to indicate take over demands to the Remote Operator, similar to those in the latest DfT Code of Practice for AV trials (DfT 2019b), should be made to trialling organisations for remote operation.	key safety information on what trialling organisations should consider during mode transition to avoid an incident.
Minimum engagement	Some stakeholders that may have to review a trial's safety case could find such safety cases challenging. There are tools designed to support stakeholders during such engagements.	CCAV could promote support tools for stakeholder engagements (such as TRL's guidance documents and CAM-SAT) (TRL 2021a; TRL 2021b; TRL 2021c) by recommending them in guidance documents for remote operation.	Promoting such tools would help ensure that stakeholders are aware of available support for remote operation engagements.

8 Roadmap to enable remote operation of CAVs

The high-level roadmap (Figure 6) developed in this section aims to provide a pathway to enable the removal of the Safety Driver and Test Assistant roles from an AV for remotely operated on-highway operation in the UK. It provides a high-level overview of the actions required to achieve this and can be used by organisations in industry or for research purposes.

The roadmap is developed based on an extensive literature review, industry stakeholder consultation, expert opinion from TRL, and reference to other CAV roadmaps (such as (Zenzic 2020),(TRL *et al.* 2020)). The contributors to this roadmap considered the gaps and challenges in the development and adoption of remote operation for CAVs and the recommendations (Section 7) that could address these gaps; these recommendations form the basis of the roadmap.

The roadmap brings together eleven thematic streams organised around three broader themes to be delivered through UK Government and industry-wide collaboration. The themes are subject areas for research and development, the streams are topics within each theme, and the milestones are individual elements (actions or outcomes) within a specific stream. The three themes (and associated streams) are:



It should be noted that the milestones included in the roadmap offer a high-level overview of the steps required to enable remote driving-related remote operation activities (see Section 3.2). Essentially, it is possible to break down each milestone presented here into smaller steps, providing an additional level of detail. However, providing a list of shorter, more specific tasks at a granular level was out of scope of this study. Instead, the milestones included in this roadmap function as “umbrella” actions and have a minimum duration of one year. A comprehensive list of tasks providing additional detail on the actions needed to facilitate remote operation should be part of future work.

Another limitation to be considered is that the timeline provided in this roadmap is purely knowledge-based and should only be viewed as an estimate. The successful completion of each milestone is dependent on the progress made by the industry and government bodies. Nevertheless, the fact that work for most of the milestones included in the roadmap is already underway has been considered in the development of the roadmap.

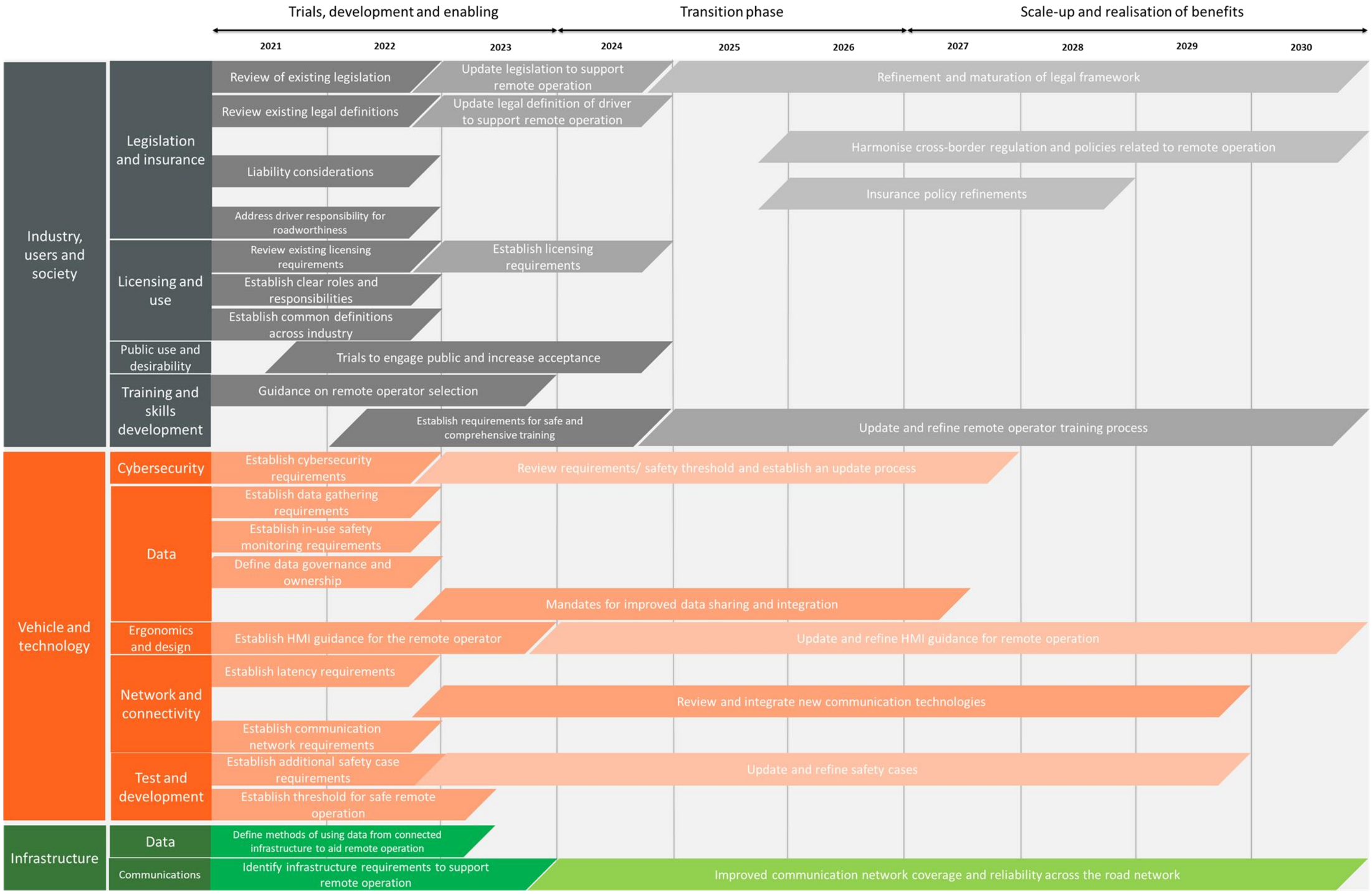


Figure 6: Roadmap to enable remote operation of CAVs in the UK

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Remote operation of Connected and Automated Vehicles

Currently, during automated vehicle trials there are two personnel present within each test vehicle: the Safety Driver and the Test Assistant. This summary report presents recommendations on how to progress to advanced trials and perform the roles of the Safety Driver and Test Assistant remotely. The recommendations are based on a literature review and a stakeholder engagement.

It was found that the terminology relating to remote operation used by the industry is inconsistent, so key terminology has been produced with the aim of promoting common use. The summary of roles, requirements and responsibilities of Safety Drivers, Test Assistants, and the Remote Operators (who would replace them) are presented. Following this, recommendations are given to enable remote operation of connected and automated vehicles (CAVs). Finally, these recommendations have been used to generate a roadmap to enable remote operation of CAVs in the UK.

Other titles from this subject area

PPR1011 Remote operation of Connected and Automated Vehicles: Project Endeavour – WP15b. A Kalaiyarasan, B Simpson, D Jenkins, F Mazzeo, H Ye, I Obazele, K Kourantidis, M Courtier, MCS Wong, P Ball, R Wilford. (2021)

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