Research Needs in Teleoperation

Reports of the Federal Highway
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Automotive Engineering F 166b

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Technical report of the working group “Research Needs in Teleoperation”

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and Transport Research Institute
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Abstract

Research Needs in Teleoperation

Today, both in-vehicle human drivers and automated driving systems (ADS) can be in charge of driving the vehicle. In addition, in the near future, it will be possible to drive a vehicle equipped with Level 4 or Level 5 ADS from a remote position, or to provide information to such a vehicle from a remote position. This new form of vehicle motion control is known as *teleoperation*. In 2021, Germany has introduced the possibility to provide information to a Level 4 or Level 5 ADS-equipped vehicle: According to the German Road Traffic Act (StVG), this so-called remote assistance is performed by the technical supervisor within the meaning of §1d (3) StVG. At the time of writing this report, the direct influence on the execution of vehicle motion control, i.e. remote driving, is not legally regulated yet, and has only been possible in the context of individually authorised test drives in public road traffic.

Remote driving covers a wide range of potentially possible future use cases: Examples are the distribution of car-sharing vehicles in public place via remote driving, or transporting goods via remote driving as "hub-to-hub" transport, and much more. It is also conceivable that remote driving adds value to Level 4 or Level 5 ADS-equipped vehicles when they are provided with remote driving to drive through complex trip sections that the ADS cannot handle yet.

This technical report formulates open research questions relevant to remote assistance and remote driving. For a *socially accepted, safe* introduction of this new form of vehicle motion control, the *functionally reliable design of the vehicle technology* is essential. Furthermore, it is crucial that the respective *task* that is to be performed remotely, *can be well performed by a person from a distance*, and that this person has appropriate *skills and fitness to drive for the tasks to be performed.* The *connection via communication technology between* the vehicle and the workstation is a constitutive component of teleoperation, and as such, is also focus of this report. This results in five focus areas into which this report is divided.

This report summarises the work and valuable contributions of a large group of experts and the many constructive discussions over the course of 2022 and 2023. The following experts from various institutions have contributed their time and experience with great commitment, for which thanks and recognition are due to all those involved:

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Contents

1 Introduction

Teleoperation as a new form of vehicle control is attracting increasing attention for use in public road traffic. The remote provision of information, or remote driving of vehicles raises questions with regard to the design and implementation of vehicles and control centres as well as with regard to society and user groups. With the aim to achieve teleoperation in an operative holistic system, this report highlights the need for research in the field of teleoperation on the basis of the current state of research and specific leading questions.

At present, the driving task can be performed by human drivers in the vehicle or by an automation function installed in the vehicle. Between these two controllers, there is a range of different forms of support for human drivers by assistance systems, ranging all the way to the complete substitution of human drivers by automated driving systems of Level 4 or Level 5 (see SAE Level; SAE International/ISO, 2021).

Teleoperation provides a third option for executing vehicle motion control (cf. Shi & Frey, 2021). The principle here is vehicle motion control or the provision of information from outside the vehicle. This can take on different forms. Analogous to the bandwidth that arises between vehicle control by human drivers or an autonomous driving function, teleoperation also opens up a new range of conceivable options for vehicle motion control.

Due to this range of conceivable options for the execution of vehicle motion control and the provision of advice or information by teleoperation, this report states the fundamental research questions based on defined use cases for teleoperation (Chapter 3). The various aspects related to teleoperation are first addressed in the five focus areas (so-called clusters; Chapter 4). Next, interdisciplinary research questions based on the aforementioned use cases are stated in a cross-cluster chapter (Chapter 5), considering specific application examples of teleoperation together with Level 4 or Level 5 automated driving, and in-vehicle human drivers.

This demonstrates how the compiled research questions can generally be applied to concrete practical implementation. To this end, current technical approaches to remote driving must be considered. For example, type-approved motor vehicles can be modified with available technical systems so that coherent interaction is realised in a complex socio-technical system. The temporal prioritization of the compiled research questions is determined by the concrete feasibility of the systems under consideration.

1.1 Consideration of the overall socio-technical system

As the degree of driving automation increases, it will become possible with SAE Level 4 or Level 5 that no person in the vehicle is needed anymore to perform the driving task. The driving task is then completely taken over and carried out by the driving automation system. As these vehicles will be travelling in public road traffic, it is necessary to ensure their safe movement as well as the safety and acceptance of the vehicle users (and passengers) and other road users. In addition, a smooth journey is necessary for economical use. This is where teleoperation can come in as a new type of control function to supplement automated driving systems, for example when they reach the limits of their operational design domain, or to remotely solve problematic situations. This implementation of automated driving and teleoperation in one vehicle requires a complex, interconnected *system-of-systems*. This means that the individual subsystems inside and outside the vehicle, such as the workstation, the teleoperation control unit, the automated driving systems' sensors and actuators, etc., are connected by efficient communication systems (IT interfaces) to form a holistic system and exchange specific information in defined cases.

Teleoperation, as the operation of a (socio-)technical system from a distance, puts specific demands on the connection between all involved teleoperation subsystems. The criterion "availability of the communication link" plays a greater role than is the case for autonomous driving applications. While for automated driving, a loss of the communication link has little or no impact, the connection between the teleoperated vehicle and the workstation is an essential prerequisite without which the teleoperation service cannot be offered at all. Depending on the specific circumstances, on the one hand, the remote provision of advice to perform a driving manoeuvre can already be achieved by exchanging small amounts of data, on the other hand, continuous remote driving using high-resolution video streams will place higher demands on the latency, bandwidth, IT security and stability of the connection.

Teleoperation can be described by means of influence loops and control loops in which a number of factors must interact: Suitable selection, sufficient involvement and situational awareness of teleoperators, the communication technology's transmission quality, reliable sensors and actuators in the vehicle and a sufficient fit with the traffic environment, including vulnerable road users. This ensures that the operational objectives of teleoperated systems are achieved, and that teleoperation is sufficiently accepted by users, operators and society.

The subsystems are in constant interaction with each other and each has its own complex dynamics and reliability. These mechanisms serve to move the teleoperated vehicle safely and efficiently in the traffic environment (Operational Design Domain; ODD) or in the licensed area of operation. This includes interaction with other road users. Furthermore, a wide range of use cases can be pursued, from passenger transport to freight logistics.

The combination of teleoperation and automated driving within their respective operational limits will facilitate many applications in the future. For example, within its ODD/ its licensed area of operation, a vehicle may be operated by its in-vehicle Level 4 or Level 5 ADS, or via teleoperation, depending on the situation. If, for example, the mechanisms implemented for safe vehicle motion control and cooperation in SAE Level 4 or Level 5 automated driving are not successful, a minimal risk condition is entered in order to protect passengers and other road users. The automated driving system is no longer available after the minimal risk condition has been achieved, and a human operator can drive the vehicle out of the minimal risk condition using teleoperation.

Besides remote driving, there is also the possibility for the so-called remote assistance to approve driving manoeuvres suggested by the Level 4 or Level 5 automated driving system (ADS) which ADS executes independently within its ODD/ licensed area of operation.

This principle was already mentioned by Sheridan (1992) for various applications. Challenges for this human-machine system are also mentioned below.

> *"Robot teleoperation allows human operators to make different tasks in remote or hazardous environments. [...] Today, there are many applications for robot*

teleoperation, including telemedicine, exploration, entertainment, tele-manufacturing, rescue, UAV-teleoperation, and many more [Elhajj et al., 2003; Sanders, 2010; Lam et al., 2009]. However, it is known that the presence of time delay may induce instability or poor performance in a delayed control system [Niculescu, 2001; Richard, 2003; Sheridan, 1995; Sanders, 2009]." (Slawiñski et al., 2012, S. 67)

For successful implementation, it is therefore crucial that the design of the individual systems and their interaction does not lead to high-risk situations. Through appropriate design, parameterisation and coordination of the subsystems and communication paths, the necessary stability should be achieved, unnecessary high-risk states avoided and any risks that arise reduced. In this respect, the first documents have been published in various economic areas and transport systems, which indicate basic requirements. It therefore makes sense to compare the requirements for the holistic system and its subsystems from comparable applications (aviation, robot teleoperation, including telemedicine, space research, entertainment, telemanufacturing, defence) for which long-term experience already exists. This may be successful in general, but will not always fulfil the specific requirements of public road traffic in detail and must not hide the fact that there are still a number of unanswered questions regarding a justifiable, long-term and broad application.

Implementation and, above all, long-term successful operation require the coordinated answering of research questions so that a stable and demonstrably verifiable operating concept is created. The complexity of the system-of-systems is the guiding principle here in order to highlight the range of research needs in the field of teleoperation. The chosen structure of this report reflects this complexity. The diagram shows the clusters 1-5 considered in this report and places them in an internal context (Figure 1).

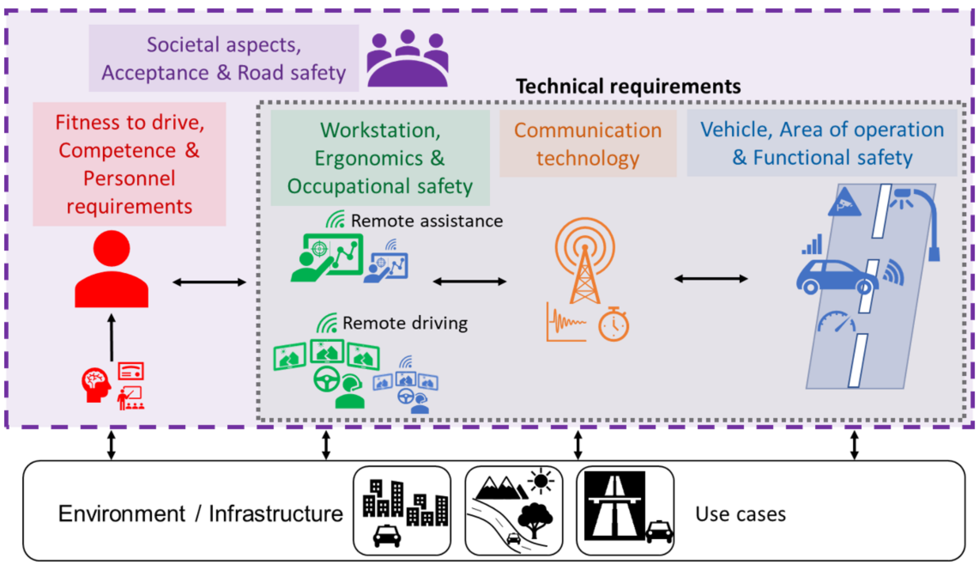

Figure 1: Teleoperation diagram

Within each so-called cluster, a sub-area is considered separately and the need for research is identified by formulating specific, detailed and concrete questions and the respective state of research is presented. Due to the existing complex control loops, interdependencies and interconnections between the clusters, these are also analysed in an over-arching manner. In the course of the work, cross-cluster aspects were discussed and developed in part on the basis of so-called edge cases, which are explained in more detail in the relevant sections. The aim is therefore to define the extensive need for research in the field of teleoperation and to open up the discussion by specifically addressing research gaps and thus providing points of reference and guidelines for future research projects and working groups.

2 Definitions

The following definitions apply to this report.

2.1 Teleoperation

Teleoperation is the provision of information for driving or the execution of vehicle motion control from outside the vehicle. The basic possibility of recommending individual driving manoeuvres to a vehicle from a spatially separated control station is referred to as *remote assistance*, while taking over complete (remote) control is referred to as *remote driving*.

Teleoperation is another form of vehicle motion control alongside driving automation systems and human drivers.

2.1.1 Remote assistance (SAE J3016)

In this document, the term “remote assistance" refers to the term as defined in SAE International Standard J3016 in the current version of 2021 is defined under 3.23: “*Event-driven provision, by a remotely located human (…), of information or advice to an ADS-equipped vehicle in driverless operation in order to facilitate trip continuation when the ADS encounters a situation it cannot manage*.” (p. 18). In contrast to SAE Standard J3016, this document specifies that the remotely assisting person does not have a direct view of the vehicle from their position.

2.1.2 Remote driving (SAE J3016)

In this document, the term “remote driving" refers to the term as defined in SAE International Standard J3016 in the current version of 2021 is defined under 3.24: “*Real-time performance of part or all of the DDT and/or DDT fallback (including, real-time braking, steering, acceleration, and transmission shifting), by a remote driver*.” (p. 19). In contrast to SAE Standard J3016, this document specifies that the remotely driving person is in a relative to the vehicle distant position, and does not have a direct view of the vehicle from their position. [1]

Remote driving can be used both as an intended primary form of control and on demand following the failure of another primary controller (human in-vehicle driver or the ADS of Level 4 or 5 are "primary controllers" in this sense). Remote driving as the intended primary form of control (from the start of the journey until the vehicle is parked in a road-worthy manner) is referred to as *continuous remote driving.* Remote driving on demand after the failure of another primary controller is referred to as *event-based remote driving.*

[1] According to SAE J3016, the remote driver may also be within the vehicle and may or may not have a direct view of the vehicle (see SAE J3016, definition 3.31.1.2, note 1). For remote assistance, there are no comparable specifications for a remote assistant’s location and direct view of the vehicle in the current SAE standard J3016 (see SAE J3016, 3.31.5 and 3.23).

2.2 Teleoperator

Person who, depending on the design of the system, continuously or situationally takes over the driving task and drives a vehicle (remote driver), or supports an ADS of Level 4 or 5 in the event of failures or limits of the ADS (emote assistance), and may also be responsible for other tasks (e.g. communication with passengers).

2.3 Workstation

The workstation of the teleoperator, which is equipped with the appropriate controls for the task (such as a steering wheel, pedals and screens for viewing the vehicle surroundings). A vehicle can be driven remotely from here. Remote assistance does not usually require classic control elements, but rather dedicated hardware and software, for example to create and securely send driving recommendations to the Level 4 or Level 5 ADS-equipped vehicle via a WAN network.

2.4 Control Centre

The control centre for the vehicle fleet. The control centre is where the overview, assignment of tasks, scheduling, organisation of maintenance and service calls take place. The control centre includes the respective workstations from which remote assistance or remote driving of a vehicle is provided. Driving orders are assigned to the respective control centres - automatically if necessary. The teleoperators are monitored and/or supported in the control centre.

2.5 Teleoperated vehicle

The vehicle to be driven or assisted, which is located in a separate environment to the control centre and the workstation. Depending on the use case, it offers interaction possibilities between the teleoperator and the passengers and the surrounding road traffic. It includes systems for implementing remote driving.

2.6 Automated driving, autonomous driving

The term "autonomous driving" refers to the operation of a vehicle using an ADS of SAE Level 4 or SAE Level 5. To date, autonomous driving has been regulated in the StVG at Level 4.

The term "automated driving" refers to the operation of a vehicle using an ADS of SAE Level 3. (cf. www.bast.de/autonomesfahren, Bundesanstalt für Straßenwesen, 2020)

2.7 Operational Design Domain, licensed area of operation

In this report on research questions relating to teleoperation, the terms "licensed area of operation" and "operational design domain" are used for teleoperation in analogy to current definitions around automated and autonomous driving (e.g. in German legislation).

As defined by SAE Standard J3016, the operational design domain (ODD) refers to the conditions for which an ADS has been specifically designed (e.g. all motorways in an EU member state).

Similarly, an ODD can also be described for teleoperation, i.e. conditions for which teleoperation has been specifically designed.

In contrast, the licensed area of operation, analogous to Section 1d (2) StVG, refers to the spatial area of use of the entire vehicle.

The relation of the term ODD to the ADS distinguishes it from the term licensed area of operation in the present case: The licensed area of operation for the entire vehicle includes the spatial area in which an ADS can control the vehicle. Here, the licensed area of operation for the entire vehicle is not limited to the ODD of the ADS, as manual vehicle motion control and, in particular, teleoperation are also possible. It is expected that teleoperation will make it possible to extend the range in which the vehicle is capable and legally permitted. Teleoperation can bridge non-adjacent ODDs of ADSs. The ODDs of the ADS and, similarly, of teleoperation are thus part of the vehicle's licensed area of operation.

3 Applications considered for remote assistance and remote driving

The use cases described below do not exhaustively represent the conceivable range of possibilities for the application of Level 4 or Level 5 ADS in combination with remote assistance and remote driving. For the purpose of this report, the focus is on individual use cases that are currently considered more likely to be implemented in public road traffic. Based on the use cases described below, research questions are specified, the clarification of which serves to prepare requirements. These research questions form the core of this report.

The following general description of the use cases is based on the perspective of the ego vehicle. Within the cluster-specific chapters, a different perspective on these use cases is inevitably adopted. In some clusters, variations of the following use cases are also considered. For these use cases research questions are specified in this report.

3.1 Assumptions for remote assistance

Use case A: Assistance on demand

In the remote assistance use case, it is assumed that the vehicle motion control is executed by an ADS of SAE Level 4 or Level 5. Vehicle motion control capability is therefore provided by the vehicle. The remote assistance does not take direct influence on vehicle motion control, but issues releases as required or provides advice or information based on events. The decision on and execution of respective advice, information or release by the remote assistance is made by the in-vehicle ADS of Level 4 or Level 5. Remote assistance is therefore not provided continuously during driving, but is triggered by an event. Remote assistance includes, for example, the release of trajectories suggested by the ADS, the temporary specification of waypoints or the modification of perception (Majstorovic et al., 2022). Alternatively, the trajectory can be specified by remote assistance. The vehicle's execution of a trajectory is always carried out by a sensor range-dependent, accident-preventing vehicle-based control function.

Table 1: Tabular representation of use case A

Actor	Vehicle
Description	A vehicle equipped with an ADS of Level 4 or Level 5 that is operated by the respective ADS within its licensed area of operation only requires remote assistance in exceptional situations The technical equipment or remote assistance can put the vehicle into the minimal risk condition, as the trip cannot be continued

	due to a traffic situation. Leaving the of minimal risk condition takes place with the support of the remote assistance.
Input	The vehicle's Level 4 or Level 5 ADS can initially suggest possible driving manoeuvres for continuing the trip and provide sufficient data to assess the situation.
Output	The remote assistance can suggest a driving manoeuvre to the Level 4 or Level 5 ADS; the manoeuvre must be validated by the ADS.
Notes	The final decision to leave the minimal risk condition lies with the Level 4 or Level 5 ADS.

3.2 Assumptions for remote driving

As described above, it is generally assumed in this report that remote driving of a vehicle is provided by a person who is outside the vehicle and has no direct view of the vehicle. In the following, a distinction is made between two use cases of remote driving:

- the entire trip is driven remotely (use case B),
- remote driving is limited to the execution of remote driving after triggering by an event (use case C).

Use case B: The vehicle is driven remotely from start to end of a trip.

In this use case, remote driving covers the start of the trip until the vehicle is parked in a roadworthy manner. At no time is the vehicle operated in any other way than by remote driving. Continuous operation by means of remote driving always requires the vehicle to be equipped with an emergency braking function that prevents accidents or at least minimises the consequences of accidents in accordance with the state of the art in science and technology (see, e.g. Euro NCAP, 2016). In addition, the maximum speed travelled and the design of the vehicle environment are of decisive importance. This results in stabilising factors (e.g. the display of latency in the workstation, the selection of teleoperators according to perception and reaction performance).

Table 2: Tabular representation of use case B

Actor	Remote driver
Description	Remote driving covers the start of the trip until the vehicle is parked in a roadworthy manner. At no time is the vehicle operated in any other way than by remote driving. Continuous operation by means of remote driving always requires the vehicle to be equipped with an emergency braking function that prevents accidents or at least minimises the consequences of accidents in accordance with the state of the art in science and technology.
Input	The remote driver controls all functions for the safe execution of the driving task over the entire trip using a workstation.
Output	During the entire trip, the vehicle provides sufficient data for the remote driver to assess and perform the driving task.
Notes	Stabilising factors, cf. analysis of research needs.

Use case C: remote driving triggered by an event

In this use case, it is assumed that the vehicle motion control is executed by an ADS of SAE Level 4 or Level 5. Vehicle motion control capability is therefore provided by the vehicle. If the ADS available on the vehicle side cannot drive through a given driving situation, a remote driver is requested. The explicit request for remote driving and its spatially and temporally limited use in a specific driving situation characterise event-based remote driving. In contrast to the above use case B of continuous remote driving, event-based remote driving does not take place from start to end of a trip, but is limited to a section of the trip that cannot be resolved by the ADS and would otherwise lead to a transition into a minimal risk condition, meaning the execution of a minimal risk manoeuvre. At this point, there are no restrictive assumptions about the nature of the triggers for event-based remote driving. Thus, for example, unexpected events, as well as recurring events, such as ODD limitations of the ADS on the route, can trigger event-based remote driving. Since event-based remote driving, in contrast to continuous remote driving, takes place upon request, event-based remote driving requires separate consideration of the complexity of the driving task to be mastered by the remote driver.

Table 3: Tabular representation of use case C

Actor	Vehicle
Description	A vehicle with an ADS of Level 4 or Level 5 that is operated by the respective ADS within its licensed area of operation only requires interaction with the remote driver if necessary. The technical equipment puts the vehicle into the minimal risk condition because the trip cannot be continued due to a traffic situation. The remote driver is responsible for leaving the minimal risk condition. In the case of remote driving, the vehicle is only controlled by the remote driver.
Input	The vehicle provides sufficient data to assess the situation and to carry out remote driving in the requested section.
Output	The remote driver carries out the driving manoeuvre in the requested section and then hands back the driving task to the vehicle's Level 4 or Level 5 ADS.
Notes	If there are no suitable driving manoeuvres, the vehicle can continue to be steered by the remote driver. The final decision to leave the minimal risk condition lies with the remote driver.

3.3 Interaction of the control options

Remote driving can be used as a new type of vehicle motion control function if the vehicle’s ADS reaches its limits. In this case, the vehicle's ADS is deactivated. Depending on the technical equipment, the remotely driven vehicle has driver assistance functions corresponding to SAE Level 2, Level 1 or Level 0. The automatic function for minimising risk by stopping must be considered separately. The proper implementation, both in the legal context and in the technical context, of ADS and the remote driving system in a single vehicle is necessary in order to operate these vehicles safely across all separate control functions.

Figure 2 shows an example of the interaction between the individual control options for a single vehicle. The figure is based on the following assumptions:

- The vehicle (1) has driver assistance functions in accordance with SAE Level 2.
- The vehicle (2) has an automated driving function in accordance with SAE Level 3.
- The vehicle (3) is equipped with a remote driving system.

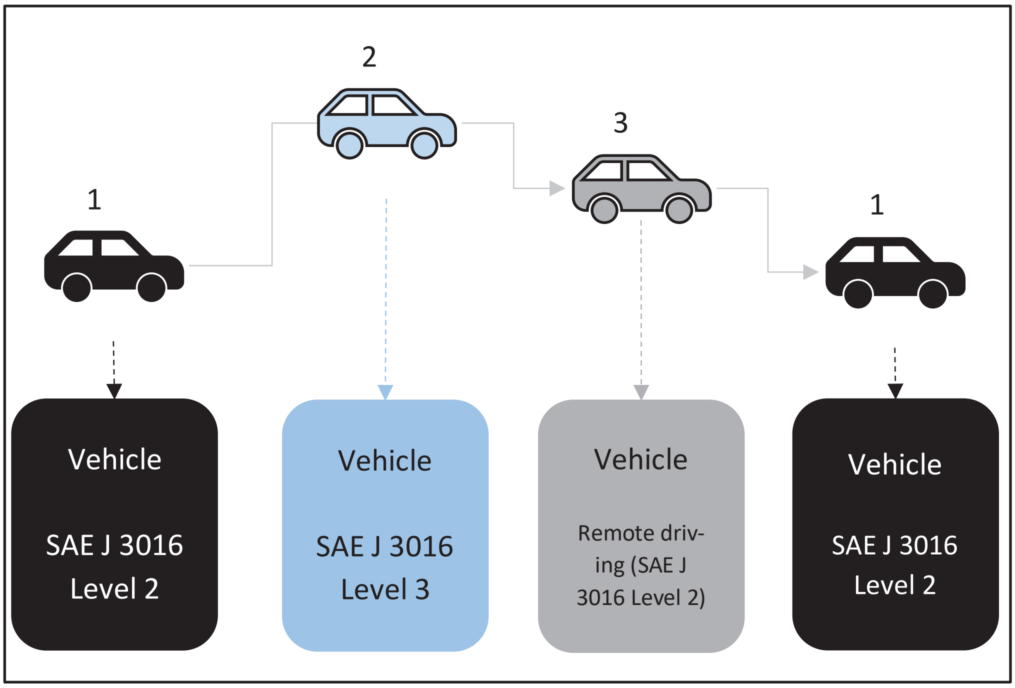

Figure 2: Exemplary transitions between different control options.

Vehicle with the designation 1

The person driving the vehicle has overall control and responsibility for the vehicle; longitudinal and lateral vehicle motion control is carried out by the in-vehicle human driver. Assistance systems support the person driving the vehicle.

Vehicle with the designation 2

The ADS of SAE Level 3 enables the person driving the vehicle to hand over the entire driving task to the ADS. The entire control and responsibility for the vehicle motion control no longer lies with the human driver. However, this is only possible within the ADS' operational design domain (ODD). The Level 3 ADS recognises its ODD on its own and offers its activation to the in-vehicle human driver who was previously driving the vehicle. After the in-vehicle human driver has activated the Level 3 system, the ADS takes over the entire driving task and the person previously driving the vehicle switches into the so-called role of the user. As the user, the person in the driver's seat can turn their attention to other activities. The prerequisite is that the user remains receptive enough to be able to take over the entire driving task again when requested by the ADS. In this example, it can be assumed that the ADS recognises that its ODD (i.e. the conditions of the ODD are no longer met) will be left soon. In this case, the Level 3 ADS - based on UN Regulation 157 - requests the remote driving system to take over the entire driving task with a lead time of at least ten seconds. After taking over by deactivating the ADS, the remote driver (the person driving the vehicle is now outside the vehicle) takes over full control and responsibility for the vehicle motion (see remote fallback ready user according to SAE J3016).

Vehicle with the designation 3

The complete execution of the continuous driving task is carried out by a teleoperator (the person driving the vehicle is now outside the vehicle) using wireless technologies (wide area network connection (WWAN connection)). In the context of remote driving, the person driving the vehicle from outside the vehicle assumes full control and responsibility for the vehicle motion. The complete execution of the continuous driving task by the remote driver can be handed over to the person using the vehicle at any time with at least ten seconds lead time to take over the entire driving task. In this case, the user switches back to the role of the driver who is in charge of the driving task.

Nowadays, remote driving can be implemented using ready-made components (hardware and software). The acronyms COTS and MOTS denote different classifications, each of which has its own characteristics and usage scenarios. These are explained in more detail below:

- Commercial off-the-shelf (COTS)
  Commercial, customary products
- Modifiable off-the-shelf (MOTS)
  Modifiable products

COTS are commercial, off-the-shelf components. These components are ready to use immediately after installation and are designed so that they can be easily integrated into an existing system. Office programmes, operating systems or e-mail programmes are classic examples of COTS products. Components from enacted standards also fall into this classification in most cases. The attractiveness of COTS components lies primarily in their availability and high level of technological maturity, i.e. the components are tested and ready for full commercial use. They are also attractive due to their affordability (scalability, as mass production for a large customer base).

MOTS refers to a COTS component, whereby the source code for software, for example, is supplied in an accessible form. This allows the components to be extensively customised in order to adapt them to the use case of the new system. MOTS combines the advantages of commercial, off-the-shelf components with the flexibility to adapt the component to the individual requirements of the new system. Compared to developing a completely customised solution from scratch, this approach can save time, effort and resources.

Since it is planned to establish the appropriate technical equipment for remote driving, for example in motor vehicles already authorised with driver assistance systems in accordance with SAE Level 2 using commercial, off-the-shelf components, the focus of research should be on the interaction of these components in particular. The coherent interaction of the requirements for the person controlling the vehicle, the requirements for data processing/transmission and the requirements for the technology in the vehicle/workstation is of great importance.

4 Research questions by clusters

4.1 Cluster 1: Vehicle, area of operation and functional safety

Cluster lead: Prof. Dr.-Ing. Markus Maurer, Leon Johann Brettin

Contributors: Frank Diermeyer, Tobias Hesse, Torsten Marx, Gerd Riegelhuth, Nayel Fabian Salem

The chapter on vehicle, area of operation and functional safety is organised according to the presented use cases of remote assistance, continuous remote driving and event-based remote driving. In Table 4 all cluster-specific research questions are listed according to the content-related sub-chapters. In addition, the research questions are sorted by chapter according to their temporal prioritisation and therefore differ slightly in their order from the textual appearance.

Table 4: Cluster 1 research questions including assignment to the use case and prioritisation in terms of time

No.	Case A	Case B	Case C	Reference	Research question	Temporal prioritization
1	☑	☑	☑	General questions	What are requirements for teleoperation to ensure traffic flow is not impaired but improved?	m
2	☑	☑	☑	Safe operation	Which technical requirements on the vehicle side result from the safety qualification (ASIL vs. QM) for teleoperation?	s
3	☑	☑	☑	Safe operation	What are the effects of a communication link necessary for teleoperation on the concept of a teleoperated vehicle?	s
4	☑	☑	☑	Safe operation	Which existing safety standards from the automotive sector can be transferred to teleoperation?	s
5		☑		Safe operation	What are the minimum functional and sensory requirements for remote driving?	s

No.	Case A	Case B	Case C	Reference	Research question	Temporal prioritization
6		☑	☑	Safe operation	What technical requirements are necessary to achieve a minimal risk condition?	s
7	☑		☑	Safe operation	To what extent can scenario-based approaches for ensuring safety of automated and autonomous driving be transferred to teleoperation?	m
8	☑	☑	☑	Safe operation	What influence do weaknesses in the subsystems have on the control loop between teleoperation and the vehicle?	m
9		☑		Controllability	Is there an upper speed limit for reasons of road safety or to achieve a minimal risk condition?	s
10		☑	☑	Controllability	How can the override of remote driving be technically secured?	s
11	☑	☑	☑	Controllability	How does a data interface between vehicles and workstations need to be designed?	m
12	☑	☑	☑	Controllability	Are new approaches for hazard identification and risk assessment necessary for teleoperation?	l
13		☑	☑	Safe degradation	What strategies and technologies can be developed to ensure safe degradation?	m
14	☑	☑	☑	Security issues (Security)	What security mechanisms need to be implemented to minimise attacks on teleoperation systems?	s
15	☑	☑	☑	Security issues (Security)	How can attacks on a teleoperation system be classified and what effects can such attacks have on the entire journey, depending on those classifications?	m
16	☑		☑	Requirements	What requirements must be specified for an ADS of Level 4 or Level 5 so that technical communication between an ADS and teleoperation can take place?	s

No.	Case A	Case B	Case C	Reference	Research question	Temporal prioritiza-tion
17	☑		☑	Requirements	What types of events can trig-ger the need for requesting tel-eoperation?	m
18	☑			Requirements	What happens if an emergency situation arises in the surround-ing area during remote assis-tance?	l
19			☑	Requirements	How must event-based remote driving be adapted for use in disasters and special situations?	l

Legend: Case A: remote assistance, case B: continuous remote driving, case C: event-based remote driving; the temporal prioritization is labelled s=short-term, m=mid-term and l=long-term.

4.1.1 Introduction

Cluster 1 "Vehicle, area of operation and functional safety" can be divided into these three main points, as already mentioned in the name.

4.1.1.1 Vehicle

The vehicle serves as the basis for the transportation task and as the receiver of control commands in the teleoperation. As described in the introduction of the document, the vehicle is one of the subsystems of an overall teleoperation system that interact with each other. This part allows to receive commands from the workstation via the respective communication technology and to send sensor data from the vehicle back to the workstation. However, this exchange can also give rise to issues in this cluster that are at the boundaries of the vehicle subsystem, as they can be of crucial importance for the system itself. This subsystem is presented in this subsection.

In order to understand what such a system might look like, it can be helpful to categorise it architecturally. For this purpose, the views of the driving task, the vehicle system and the overall system are described briefly.

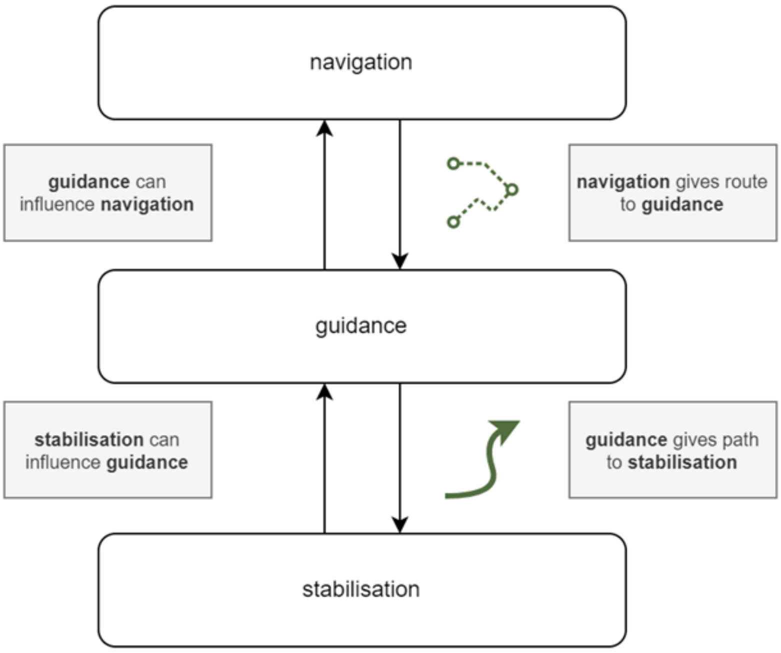

Figure 3: Categories of the driving task following Donges (1999).

Driving task

The driving task as such concerns both human drivers and a remote driver. According to Donges, a driving task can be divided into the categories of stabilisation, guidance and navigation. The following explanations are based on the descriptions following Donges (1999; Figure 3).

For a better understanding, navigation is discussed first: In order to be able to start a journey (or part of a journey), both a driver and a remote driver must know where to go and what a route to that destination looks like. Such route planning can either be done implicitly by the driver through planning the route in their head, or a system consisting of hardware and software components can be used for route planning. It is important to note that the route does not have to be fixed. Unforeseen events can lead to the route having to be re-planned during the journey. Compared to stabilisation and guidance, all of this planning requires a better understanding of the overall route and considerations that go beyond a short section of the route.

Once such a route has been selected, it can be divided into smaller sections that need to be driven. According to Donges, this sectioning, that is the dynamic driving task, takes place in the two other categories of guidance and stabilisation. In the case of guidance, it is determined how drivers should drive these sections. A path and a target speed that the vehicle should maintain are defined either mentally or mathematically. An example of such a path could be driving behind a truck, where drivers try to adjust the speed of the vehicle so that it keeps its distance from the truck while remaining in the lane in curves.

This generated trajectory is then executed in the stabilisation area. The aim here is to retain the generated or cognitive trajectory. Minimal adjustments are made automatically by the driver. Examples of this are slight corrections to the steering wheel or a slight adjustment of the accelerator pedal pressure in order to maintain the trajectory and speed specified in the guidance.

As can be seen in the Figure, the categories naturally also influence each other in the opposite direction: stabilisation can influence guidance and guidance can influence navigation. This creates a so-called control loop.

By understanding the driving task, it is possible to understand how and where the remote driving and remote assistance categories apply. For example, stabilisation must also be included in remote driving. This category is completely taken over by the ADS of Level 4 or Level 5 in the case of remote assistance.

Vehicle system

This refers to the vehicle guidance system with which the vehicle is equipped. This can also be categorised into different perspectives or views. Especially in the field of automated driving, concepts for architectural views are still the current state of research and can be found, for example, in Bagschik et al. (2018) and Kampmann et al. (2022). For a rough overview, the architecture of Ulbrich et al. (2017) is presented here, which is shown in Figure 4.

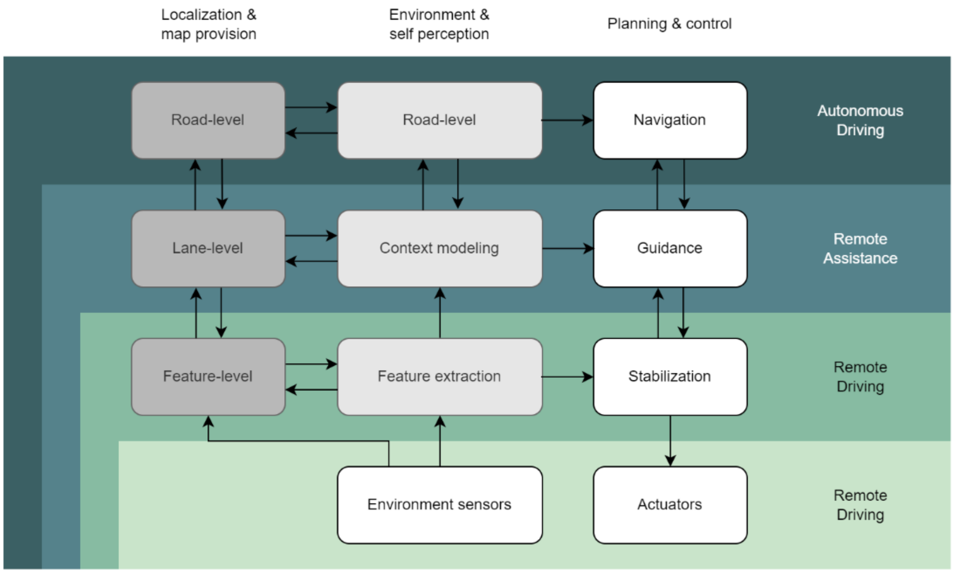

Figure 4: Highly simplified diagram of the architecture following Ulbrich et al. (2017), which is colour-coded with the teleoperation and automation modes as examples.

The figure shows the central concepts of Donges' driving task, which are shown on the right under the “Planning & control” realisation tab. To carry out a general journey, information is still required that is roughly made up of localisation and perception aspects. Depending on the level, this information can be combined and interpreted by the system. At the top level, for example, information relating to the entire journey is more relevant, while at the lowest level, information required to maintain the trajectory is more interesting.

The figure can also be used as an example to show where a teleoperation operating mode can begin. In remote driving, for example, it is sufficient for the person operating the vehicle to have access to the vehicle's actuators in order to send control commands and to have access to the environment and vehicle sensors in order to detect the surroundings.

However, if control commands are made for remote driving, which the vehicle shall follow, at least the stabilisation and the associated measured values for vehicle control, such as the steering angle and possibly the vehicle speed, must be implemented.

If the driving assistance system should provide trajectories or if a trajectory should be provided by waypoints for the vehicle by the operator, these are remote assistance modes. In this case, the vehicle is given trajectories by the automation system. Information from the guidance level is therefore also required to generate these trajectories.

If all the concepts in the diagram are used, it makes sense to classify operation in automated or autonomous mode at this point to complete the Figure.

4.1.1.1.1 Overall system (across clusters)

In general, the overall system can be described as the combination of the vehicle system with granted type approval, supplementary technical components in the vehicle, broadband radio connection and the teleoperators control station, as described in the introduction in the system diagram (see chapter 1.1). As the individual components of the overall system are mentioned in separate clusters in this document, this sub-item is only briefly discussed here. However, the interaction in the overall system is an important part of the system design and also has an influence on the defined area of operation, the operating environment and the safety of the vehicle during teleoperation.

4.1.1.2 Operational Design Domain (ODD) / Operating Environment

The ODD, see Introduction, Chap. 2.7 is according to SAE standard J3016 (2021; Chapter 3.21): “[the] conditions under which a given driving automation system or a feature” of such a system should function. A subset of the conditions specified in SAE Standard J3016 (2021) are “environmental, geographical and time of day restrictions and/or the requisite presence or absence of certain traffic or roadway characteristics.”

According to Irvine et al. (2021), the ODD limits the development area for such a function and makes it possible to have defined boundaries in which the capabilities and limitations of the vehicle are clear.

A well-known example of an ODD restriction is, for example, the type of drivable area. For example, if the vehicle is only allowed to operate on the highway, it can be assumed that there are no pedestrians on the road. Other assumptions can be that the average speed is usually just over 100 km/h and that there are very few vehicles on the roadside. All this information helps to limit the functionality of the system and narrow down the safety-critical aspects. In addition, developers of the detection function then do not have to focus on the detection of pedestrian crossings, for example (assuming that no service station is used) and do not have to develop an all-encompassing system, but can limit themselves to the tasks in this ODD, which is usually already a sufficiently challenging task.

The question of where and how teleoperation can be used always includes the ODD, as this defines the system's area of application. If the ODD is too restrictive, the roads and the speed that a teleoperated vehicle is allowed to travel may not be sufficient for the system to actually be used in road traffic.

4.1.1.3 Safety

The third focus of research in this cluster is on safety issues.

In the field of autonomous driving, safety is categorised differently than in general usage. In society, for example, a system is sometimes considered safe if it is free of risks. However, as the risk of dangerous events cannot be completely ruled out, safety is defined somewhat differently here: A system is safe if the system is free from unreasonable risks (according to ISO 26262). This means that an autonomous system can be described as safe if the risk is below a socially accepted threshold (ISO 26262; Maurer et al., 2015).

However, different accepted thresholds could apply to remote driving on public roads than to autonomous driving. The accidents that occur on conventional public roads seem to be accepted by society as an inherent risk of the transport system. The acceptance of this risk is, according to Salem et al. (2023), Grunwald (2016), Maurer (2018) and Nolte et al. (2018) the result of a trade-off between road safety and the need for mobility in society. These trade-offs have not yet taken place in the area of teleoperation, so it is a research question on its own to decide at what point teleoperation can be categorised as safe (see Cluster 5).

Specifically, the research questions relate to aspects of *safe operation* and the *controllability* and *safe degradation* of teleoperated vehicles, but also to issues of data and IT security. Safety is an issue that can be decisive for enabling, but also for banning this technology in road traffic in regular operation, precisely because of the potentially high social expectations in this area. Many of the research questions in this cluster shall create a more concrete problem descriptions and point out regulatory options in order to enable the safe operation of teleoperation.

4.1.2 Research questions on vehicle, area of operation and functional safety

4.1.2.1 Division into different modes

In the following, the research questions are divided into three categories: “remote assistance", "continuous remote driving" and "event-based remote driving". For a better understanding of the questions, it is assumed that no ADS of Level 4 or Level 5 is installed in the vehicle for continuous remote driving. As defined by SAE Standard J3016, the Automated Driving System (ADS, defined by SAE J3016) refers to the "hardware and software that are collectively capable of performing the entire DDT on a sustained basis, regardless of whether it is limited to a specific operational design domain (ODD); this term is used specifically to describe a Level 3, 4, or 5 driving automation system" (SAEJ3016, Chapter 3.2). In relation toFigure 4 of the introduction, remote driving without an ADS of Level 4 or Level 5 therefore only refers to the part of remote driving that can access the environment and vehicle sensors and actuators.

In the case of event-based remote driving and remote assistance, due to the event-based nature, it can be assumed that an ADS of Level 4 or Level 5 is installed. It can also be argued that event-based remote driving is possible with a system that does not include an ADS of Level 4 or Level 5, for example by means of an event that transfers the vehicle from driving with a person on site to teleoperation. However, as it can lead to a lack of understanding, this example can be regarded in the categorisation as continuous remote driving. This also corresponds to the definition in the introduction to the document as a whole, which assumes that an ADS of Level 4 or Level 5 must have been active during event-based remote driving.

4.1.2.2 Further information through tags

If there are similar questions for all categories “remote assistance", "continuous remote driving" and "event-based remote driving" the tag "#cross-category" was added to the research question to indicate that a similar question can be found in the other categories.

In addition, each question was assigned a categorisation in relation to the time at which this question could become relevant with the help of tags "#short-term", "#mid-term" and "#long-term".

4.1.2.3 Division into different focal points

The research questions are divided into the categories "General questions", "Safety questions", "Security questions" and "Requirements".

The "General questions" category deals with questions that focus on aspects that represent the benefits of teleoperation.

The "Safety questions" category deals with safety issues in the sense of hazards and risks that can arise from teleoperation.

The "Security questions" category deals with aspects of attacks on the overall teleoperation system.

The topic "Requirements" deals with requirements that are not yet covered by the previous categories and includes topics such as requirements for the ADS of Level 4 or Level 5, the sensor technology used and the types of triggering conditions.

4.1.3 Remote assistance

4.1.3.1 General questions

What are requirements for remote assistance to ensure traffic flow is not impaired but improved?

#mid-term

An autonomous vehicle that can no longer fulfil its mission by itself or in combination with remote assistance will enter a minimal risk condition, which in certain cases implies a safe stop. How this minimal risk state is realised can vary depending on the circumstances and therefore has different effects on the surrounding traffic situation, for example depending on location, speed, roads in or out of the city, etc. and can impair traffic flow or even pose a hazard to traffic. Remote assistance can be used to provide autonomous vehicles with additional information. In this context, the question arises as to what requirements must be specified for remote assistance so that traffic flow and road safety are not negatively influenced but improved (see also Cluster 2, Chapter 1.1.1.11; Cluster 5 Chapter 1.1.1.42).

4.1.3.2 Safety questions

This chapter deals with issues regarding safety. The categories of safe operation and controllability can serve as possible aspects to differentiate safety. In order to create an awareness of these categories, these aspects are presented below and have been used here for further categorisation.

Safety through safe operation means that safety protocols and safety measures are used during operation of the vehicle to minimise the risk of failure. This category also includes the monitoring of technical components and the use of safety mechanisms such as redundancy and self-awareness to ensure the safest operation possible.

Safety through controllability means being able to control the vehicle through sensors and actuators to a degree that can be expected by the remote assistance. A controllable overall system enables the remote assistance system to send accurate control recommendations to the vehicle even in unforeseen situations and avoid possible damage.

4.1.3.2.1 Safe operation

Which technical requirements on the vehicle side result from the safety qualification (ASIL vs. QM) for remote assistance?

#short-term #cross-category

Depending on how a system for remote assistance is designed, the question arises about the technical requirements for such a system. The question arises as to which technical properties the remote assistance system must exhibit depending on the safety qualification. What strategies can be used for a safety argumentation?

In the case of remote assistance, the requirements are based on the interaction between the ADS of Level 4 or Level 5 and remote assistance. This raises the question of whether the technical requirements for the communication link are a subset of the requirements on remote assistance due to the characteristics of the control capability.

If remote assistance is to be used as an ASIL-qualified system, more detailed research is needed into what use cases remote assistance can offer added value. In addition, the research question arises as to when remote assistance should be requested by the autonomous vehicle and how exactly the operating procedure should then be carried out (see also Cluster 2 Chapter 1.1.1.14; Cluster 5 Chapter 1.1.1.43).

To what extent can scenario-based approaches for ensuring safety of automated and autonomous driving be transferred to remote assistance?

#mid-term

For autonomous vehicles, it is possible to utilize scenarios for development, validation and testing (Bagschik et al., 2017; Schuldt, 2017). As remote assistance can be used in combination with autonomous vehicles, the scenario-based approach of autonomous driving could be transferred to such systems in order to ensure their safety. Future research should determine how exactly such a transfer would look like and how much of the existing research results and developed system of scenario-based approaches can be adopted (see also Cluster 2 Chapter 4.2.2; Cluster 3 Chapter 4.3.7).

What are the effects of a communication link necessary for remote assistance on the concept of a teleoperated vehicle?

#short-term #cross-category

The communication link is an important component in the design of the vehicle and thus for the remote assistance system. In view of its potentially safety-critical nature, it should be investigated whether the current safety standards in the automotive sector are sufficient to adequately address the new challenges radio communication is facing in the field of remote assistance. Current systems in the automotive sector are usually limited to the use of on-board electronics to provide safety-critical functionality. The role of a communication link for sending control recommendations for a vehicle is not explicitly considered in this context. Experience from other domains (e.g. Remote-controlled drones) may provide a starting point for further research.

Which existing safety standards from the automotive sector can be transferred to remote assistance?

#short-term #cross-category

The communication link plays a key role in remote assistance. In this context, the question arises as to which extent safety-critical functionality can be provided by it. In conventional EE systems in the automotive sector, for example, the ISO 26262 is used to qualify safety requirements. This raises an additional question of the extent to which existing safety standards can be applied to remote assistance and whether the communication link can therefore fulfil ASIL-qualified or comparable safety requirements.

What influence do weaknesses in the subsystems have on the control loop between remote assistance and the vehicle?

#mid-term #cross-category

With regard to the control loop, the question arises as to what extent the quality of the vehicles subsystems influences the safe usability of this control loop. For example, a reduced quality of a subsystem can affect the entire control loop. An example of this would be a poor connection to the workstation, which can lead to long delays in execution. However, other subsystems, such as fast computing components, may have a positive effect on the control loop as mitigating measures.

In addition, the question of how to organise regular checks of the subsystems in order to ensure the consistent quality of these systems must be asked.

4.1.3.2.2 Controllability

Are new approaches for hazard identification and risk assessment necessary for remote assistance?

#long-term #cross-category

The use of remote assistance can lead to scenarios in which a hazardous event potentially causes harm. Individual scenarios may have a low probability of occurrence but a high severity. These relevant scenarios must be identified for remote assistance. Such scenarios must be analysed as part of the safety argumentation to determine how the remote assistance system should react, how this reaction is or can be ensured and what technical mitigation mechanisms are available for the remote assistance.

With regard to the technical equipment, it should also be analysed whether and, if so, which vehicle-based safety systems (e.g. emergency brake assist etc.) must be available that can intervene in the control of the vehicle.

New interaction concepts could be devised due to a remote assistance's limited scope of action. To what extent could the use of remote assistance lead to a hazardous situation? The question also arises as to how the technical communication between the ADS of Level 4 or Level 5 and remote assistance must be designed if a dangerous situation arises.

How does a data interface between vehicles and workstations need to be designed?

#mid-term #cross-category

Given the current state of development of remote assistance systems, the possibility to collaborate on a guideline for a general data interface arises. Depending on the provider concept (centralised vs. decentralised), it may be necessary to be able to connect every remote assistance system to every vehicle. If necessary, how can such a data interface be implemented? Can scalability be increased by a common interface and thus improve traffic flow?

4.1.3.3 Security questions

In this chapter, questions are asked on the subject of security. These questions can be of great importance in the development of the overall teleoperation system. Manipulation of teleoperation subsystems can cause considerable damage, the risks of which must be minimised. Attacks on such systems are not limited to attacks aimed at taking over the system, but can also include jamming, for example, or a targeted attempt to disrupt the view of the remote assistant, who can potentially only gain an overview via a camera system. Furthermore, security also implicitly influences the acceptance of such systems, which may also be a factor that requires consideration of this issue, especially at this early stage of such technology.

How can attacks on a teleoperation system be classified and what effects can such attacks have on the entire journey, depending on those classifications?

#mid-term #cross-category

Categorising attacks on remote assistance makes it possible to understand the potential vulnerabilities and effects of such attack scenarios. Addressing this research question makes it possible to identify the potential risks of this technology and design mitigation mechanisms.

Depending on the type of attack on such a system, the impact on the journey can vary. A better understanding is needed to drive the development of this technology, which is why further research and security measures are required to minimise potential risks and improve the reliability of remote assistance systems in vehicles.

What security mechanisms need to be implemented to minimise attacks on remote assistance systems?

#short-term #cross-category

Firstly, the question arises as to what extent existing security concepts from related disciplines can be transferred to remote assistance. The development and implementation of security standards and measures that counteract the misuse of remote assistance systems and thus strengthen trust in such technology are relevant.

For example, *intrusion detection* can be examined as a required system or the specification of when a minimal risk manoeuvre must be performed by the vehicle, due to an attack. An example of an attack that can go beyond attacks at the network level could be the blinding of an operator's cameras to obstruct their view.

This aspect also includes research questions relating to the documentation and reporting of security incidents.

4.1.3.4 Requirements

This chapter deals with research questions on the subject of requirements that have not yet been addressed in the previous chapters. These questions concerning general requirements on the topics of automation, variants of teleoperation and human-machine interaction.

What requirements must be specified for an ADS of Level 4 or Level 5 so that technical communication between an ADS and teleoperation can take place?

#short-term

With remote assistance, there must be a technical communication interface between the ADS of Level 4 or Level 5 and the workstation in order to switch on the remote assistance in the event of an incident.

What requirements must be specified for an ADS of Level 4 or Level 5 so that technical communication between the automation and the remote assistance can take place?

This question becomes particularly critical when the vehicle leaves the ODD of the ADS with the help of remote assistance. With regard to safety and security, the question can also be raised as to the extent to which incorrect or malicious operation by the remote assistance can be recognised by the ADS.

What types of events can trigger the need for requesting remote assistance?

#mid-term

The need for support from a remote assistant is triggered by an event. First, research is needed to determine what exactly classifies an event, how events are specified and what types of events there are.

What happens if an emergency situation arises in the surrounding area during remote assistance?

#long-term #cross-category

If an emergency situation arises in the surroundings of the vehicle, situations can arise in which the vehicle, that receives steering recommendations from the remote assistance system, can be an obstacle to traffic. In such a situation, the research question can be posed as to how the vehicle must be moved so that it does not get in the way of emergency vehicles and what types of systems must be introduced to potentially violate public road traffic rules in such a case in order to ensure that the emergency situation is not obstructed by the teleoperated vehicle. The question can also be asked as to what must happen to such a vehicle in the event of a failure. In other words, what happens if the vehicle that should be teleoperated has to stop due to a failure and an emergency situation arises in which this vehicle blocks the route to the emergency site. In addition, the question arises as to how situations in which a teleoperated vehicle blocks relevant routes can be prevented.

4.1.4 Remote driving, continuous

4.1.4.1 General questions

What are requirements for continuous remote driving to ensure traffic flow is not impaired but improved?

#mid-term

In order to ensure that traffic flow and road safety are not impaired but rather improved by continuous remote driving, it should be investigated what requirements must be placed on continuous remote driving in this respect. Among other things, this includes whether continuous remote driving can be operated just as smoothly in traffic as manual or autonomous driving. The question also arises as to whether continuous remote driving can be implemented just as safely and to what extent requirements for manual and autonomous driving can be derived for remote driving. In addition, it must be investigated whether the use of continuous remote driving can in fact improve traffic flow and road safety.

1.1.1.1 Safety questions

This chapter deals with issues regarding safety. The categories of safe operation and controllability can serve as possible aspects to differentiate safety. In order to create an awareness of these categories, these aspects are presented below and have been used here for further categorisation.

Safety through safe operation means that safety protocols and safety measures are used during operation of the vehicle to minimise the risk of failure. This category also includes the monitoring of technical components and the use of safety mechanisms such as redundancy and self-awareness to ensure the safest operation possible.

Safety through controllability means being able to control the vehicle through sensors and actuators to a degree that can be expected by the remote driver. A controllable overall system enables the remote driving system to send accurate control recommendations to the vehicle even in unforeseen situations and avoid possible damage.

Safety through safe degradation means that the vehicle can still be transferred to a minimal risk condition, even though system components (e.g. sensors and actuators) cannot perform with their nominal performance.

4.1.4.1.1 Safe operation

Which technical requirements on the vehicle side result from the safety qualification (ASIL vs. QM) for continuous remote driving?

#short-term #cross-category

Depending on how a system for continuous remote driving is designed, the question arises about the technical requirements for such a system. The question arises as to which technical properties the continuous remote driving system must exhibit depending on the safety qualification. What strategies can be used for a safety argumentation? (See also Cluster 2 Chapter 1.1.1.14; Cluster 5 Chapter 1.1.1.43)

What are the minimum functional and sensory requirements for continuous remote driving?

#short-term

With regard to current prototype solutions for continuous remote driving in German road traffic, the research question arises as to what minimum functional requirements must be placed on such systems so that they can reliably participate in road traffic. The question relates to the minimum possible installation of certain sensors such as cameras or lidar and the associated installation of redundant systems in the vehicle. However, the question also relates to the requirements for speed and bandwidth that must be met in order for a vehicle to be driven remotely.

It should be investigated whether it is sufficient to operate a system for continuous remote driving (without ADS of Level 4 or Level 5) without lidar and what effects minimal equipment could have, for example, on the maximum possible driving speed.

What are the effects of a communication link necessary for continuous remote driving on the concept of a teleoperated vehicle?

#short-term #cross-category

The communication link is an important component in the design of the vehicle and thus for the continuous remote driving system. In view of its potentially safety-critical nature, it should be investigated whether the current safety standards in the automotive sector are sufficient to adequately address the new challenges radio communication is facing in the field of continuous remote driving. Current systems in the automotive sector are usually limited to the use of on-board electronics to provide safety-critical functionality. The role of a communication link for sending control information for a vehicle is not explicitly considered in this context. Experience from other domains (e.g. Remote-controlled drones) may provide a starting point for further research.

Which existing safety standards from the automotive sector can be transferred to continuous remote driving?

#short-term #cross-category

The communication link plays a key role in continuous remote driving. In this context, the question arises as to which extent safety-critical functionality can be provided by it. In conventional EE systems in the automotive sector, for example, the ISO 26262 is used to qualify safety requirements. This raises an additional question of the extent to which existing safety standards can be applied to continuous remote driving and whether the communication link can therefore fulfil ASIL-qualified or comparable safety requirements.

What technical requirements are necessary to achieve a minimal risk condition?

#short-term #cross-category

If the connection between the workstation and the remotely driven vehicle is interrupted, the question arises as to how the system inside the vehicle handles this situation in order to achieve minimal risk condition. Firstly, the question arises as to whether emergency braking is sufficient to simply slow the vehicle down in order to achieve a minimal risk condition. If this is not sufficient to achieve a minimal risk condition - especially on motorways - the question is to what extent the remote driving system must be automated/autonomous in order to enable a minimal risk stop. How can the need for a minimal risk condition be identified at an early stage in the overall remote driving system?

What influence do weaknesses in the subsystems have on the control loop between the remote driver and the vehicle?

#mid-term #cross-category

With regard to the control loop, the question arises as to what extent the quality of the vehicles subsystems influences the safe usability of this control loop. For example, a reduced quality of a subsystem can affect the entire control loop. An example of this would be a poor connection to the workstation, which can lead to long delays in execution. However, other subsystems, such as fast computing components, may have a positive effect on the control loop as mitigating measures.

In addition, the question of how to organise regular checks of the subsystems in order to ensure the consistent quality of these systems must be asked.

4.1.4.1.2 Controllability

Is there an upper speed limit for reasons of road safety or to achieve a minimal risk condition?

#short-term

The research question relates to the limitations in terms of latency, quality of the data connection, reliability of the control commands, reaction time and possible connection interruptions the operator faces when driving a vehicle remotely. The research question arises as to how high the maximum possible driving speed of such a vehicle may be in order to ensure that the vehicle can still reach a minimal risk condition. The speed may depend on the respective ODD. However, the research question may also lead to the conclusion that a maximum speed must be set regardless of the ODD. This question implies whether it is allowed to drive remotely at all if the maximum possible speed in a particular ODD is too low.

How can the override of continuous remote driving be technically secured?

#short-term

When a remote driver accesses a vehicle, it must also be ensured that the commands to the vehicle are safely received and executed. It must be ensured that the remote driver is authorised to control the vehicle remotely so that no unauthorised access can be gained. The technical implementation could, for example, be realised using steer-by-wire systems and/or mechanical encapsulation of the control devices in the vehicle (steering wheel, pedals etc.) if it is intended to operate with passengers inside the remotely driven vehicle.

Are new approaches for hazard identification and risk assessment necessary for continuous remote driving?

#long-term #cross-category

The use of continuous remote driving can lead to scenarios in which a hazardous event potentially causes harm. Individual scenarios may have a low probability of occurrence but a high severity. These relevant scenarios must be identified for continuous remote driving. Such scenarios must be analysed as part of the safety argumentation to determine how the continuous remote driving system should react, how this reaction is or can be ensured and what technical mitigation mechanisms are available for the remote driver.

With regard to the technical equipment, it should also be analysed whether and, if so, which vehicle-based safety systems (e.g. emergency brake assist etc.) must be available that can intervene in the control of the vehicle.

How does a data interface between vehicles and workstations need to be designed?

#mid-term #cross-category

Given the current state of development of remote continuous remote driving, the possibility to collaborate on a guideline for a general data interface arises. Depending on the provider concept (centralised vs. decentralised), it may be necessary to be able to connect every remote driving system to every vehicle. If necessary, how can such a data interface be implemented? Can scalability be increased by a common interface and thus improve traffic flow?

4.1.4.1.3 Safe degradation

What strategies and technologies can be developed to ensure safe degradation?

#mid-term #cross-category

A teleoperated vehicle can degrade for various reasons. The degradation of connection can be one of the main causes, but degradation can also be related to the vehicle's actuators or sensors. If such degradation occurs, the vehicle must be returned to a safe state. However, the question arises as to how a vehicle in teleoperated mode can recognise that it is in a degraded state and how a degraded system can achieve a minimal risk condition.

4.1.4.2 Security questions

In this chapter, questions are asked on the subject of security. These questions can be of great importance in the development of the overall teleoperation system. Manipulation of teleoperation subsystems can cause considerable damage, the risks of which must be minimised. Attacks on such systems are not limited to attacks aimed at taking over the system, but can also include jamming, for example, or a targeted attempt to disrupt the view of the remote driver, who can potentially only gain an overview via a camera system. Furthermore, security also implicitly influences the acceptance of such systems, which may also be a factor that requires consideration of this issue, especially at this early stage of such technology.

How can attacks on a teleoperation system be classified and what effects can such attacks have on the entire journey, depending on those classifications?

#mid-term #cross-category

Categorising attacks on continuous remote driving makes it possible to understand the potential vulnerabilities and effects of such attack scenarios. Addressing this research question makes it possible to identify the potential risks of this technology and design mitigation mechanisms.

Depending on the type of attack on such a system, the impact on the journey can vary. A better understanding is needed to drive the development of this technology, which is why further research and security measures are required to minimise potential risks and improve the reliability of continuous remote driving systems in vehicles.

What security mechanisms need to be implemented to minimise attacks on continuous remote driving systems?

#short-term #cross-category

Firstly, the question arises as to what extent existing security concepts from related disciplines can be transferred to continuous remote driving. The development and implementation of security standards and measures that counteract the misuse of continuous remote driving systems and thus strengthen trust in such technology are relevant.

For example, *intrusion detection* can be examined as a required system or the specification of when a minimal risk manoeuvre must be performed by the vehicle, due to an attack. An example of an attack that can go beyond attacks at the network level could be the blinding of an operator's cameras to obstruct their view.

This aspect also includes research questions relating to the documentation and reporting of security incidents.

4.1.5 Remote driving, event-based

4.1.5.1 General questions

What are requirements for event-based remote driving to ensure traffic flow is not impaired but improved?

#mid-term

An autonomous vehicle that can no longer fulfil its mission by itself or in combination with the remote driver will enter a state of minimal-risk, which in certain cases implies a safe stop. How this minimal risk state is realised can vary depending on the circumstances and therefore also has different effects on the surrounding traffic situation, for example depending on location, speed, roads in or out of town etc. and can represent an obstruction to traffic flow or even a hazard to traffic. Event-based remote driving can be used to move autonomous vehicles that are no longer able to fulfil their task independently. In this context, the question arises as to what requirements must be placed on event-based remote driving so that traffic flow and traffic safety are not negatively influenced or even improved (see also Cluster 2, Chapter 1.1.1.11; Cluster 5 Chapter 1.1.1.42).

4.1.5.2 Safety questions

This chapter deals with issues regarding safety. The categories of safe operation and controllability can serve as possible aspects to differentiate safety. In order to create an awareness of these categories, these aspects are presented below and have been used here for further categorisation.

Safety through safe operation means that safety protocols and safety measures are used during operation of the vehicle to minimise the risk of failure. This category also includes the monitoring of technical components and the use of safety mechanisms such as redundancy and self-awareness to ensure the safest operation possible.

Safety through controllability means being able to control the vehicle through sensors and actuators to a degree that can be expected by the remote driver. A controllable overall system enables the remote driving system to send accurate control recommendations to the vehicle even in unforeseen situations and avoid possible damage.

Safety through safe degradation means that the vehicle can still be transferred to a minimal risk condition, even though system components (e.g. sensors and actuators) cannot perform with their nominal performance

4.1.5.2.1 Safe operation

Which technical requirements on the vehicle side result from the safety qualification (ASIL vs. QM) for event-based remote driving?

#short-term #cross-category

Depending on how a system for continuous remote driving is designed, the question arises about the technical requirements for such a system. The question arises as to which technical properties the event-based remote driving system must exhibit depending on the safety qualification. What strategies can be used for a safety argumentation? (See also Cluster 2 Chapter 1.1.1.14; Cluster 5 Chapter 1.1.1.43)

In the case of event-based remote driving, research should investigate whether the functional limitations of the ADS of Level 4 or Level 5 can be resolved through reliable interaction with event-based remote driving. As a result, current safety requirements for autonomous driving could be bridged by the combination of autonomous driving and event-based remote driving. As with remote assistance, the research question arises, at which moment a minimal risk manoeuvre should be triggered and what type of precise operational sequence should then be carried out. In addition, this research question requires a closer look at the requirements for the communication link, as this generally has a greater influence on the dynamic driving task in remote driving due to the continuous transmission of commands.

If event-based remote driving is to be qualified with ASIL, it must be checked whether a fallback ready user can react quickly enough to serve as a fallback level, for example, or up to what lead time such a fallback level can be used reasonably. This raises the question of the controllability of such a system. In this context, it is necessary to examine how a takeover situation is to be organised, i.e. what technical requirements arise when the remote driver takes over vehicle motion control after the transfer to a minimal risk condition or during ongoing operation ("on-the-fly").

The extent to which event-based takeovers by the remote driver are possible when control is handed over by a human driver in the vehicle must also be investigated.

To what extent can scenario-based approaches for ensuring safety of automated and autonomous driving be transferred to event-based remote driving?

#mid-term

For autonomous vehicles, it is possible to utilize scenarios for development, validation and testing (Bagschik et al., 2017; Schuldt, 2017). As event-based remote driving can be used in combination with autonomous vehicles, the scenario-based approach of autonomous driving could be transferred to such systems in order to ensure their safety. Future research should determine how exactly such a transfer would look like and how much of the existing research results and developed system of scenario-based approaches can be adopted (see also Cluster 2 Chapter 4.2.2; Cluster 3 Chapter 4.3.7).

In the case of event-based remote driving, it can be investigated to what extent currently used approaches for automated and autonomous driving can be transferred to event-based remote driving or to what extent they need to be modified. In addition, new scenarios can be developed specifically for event-based remote driving (see also Cluster 2 Chapter 4.2.2; Cluster 3 Chapter 4.3.7).

What are the effects of a communication link necessary for event-based remote driving on the concept of a teleoperated vehicle?

#short-term #cross-category

The communication link is an important component in the design of the vehicle and thus for the event-based remote driving system. In view of its potentially safety-critical nature, it should be investigated whether the current safety standards in the automotive sector are sufficient to adequately address the new challenges radio communication is facing in the field of event-based remote driving. Current systems in the automotive sector are usually limited to the use of on-board electronics to provide safety-critical functionality. The role of a communication link for sending control recommendations for a vehicle is not explicitly considered in this context. Experience from other domains (e.g. Remote-controlled drones) may provide a starting point for further research.

Which existing safety standards from the automotive sector can be transferred to event-based remote driving?

#short-term #cross-category

The communication link plays a key role in event-based remote driving. In this context, the question arises as to which extent safety-critical functionality can be provided by it. In conventional EE systems in the automotive sector, for example, the ISO 26262 is used to qualify safety requirements. This raises an additional question of the extent to which existing safety standards can be applied to event-based remote driving and whether the communication link can therefore fulfil ASIL-qualified or comparable safety requirements.

What technical requirements are necessary to achieve a minimal risk condition?

#short-term #cross-category

If the connection between the workstation and the remotely driven vehicle is interrupted, the question arises as to how the system inside the vehicle handles this situation in order to achieve minimal risk condition. Firstly, the question arises as to whether emergency braking is sufficient to simply slow the vehicle down in order to achieve a minimal risk condition. If this is not sufficient to achieve a minimal risk condition - especially on motorways - the question is to what extent the remote driving system must be automated/autonomous in order to enable a minimal risk stop. How can the need for a minimal risk condition be identified at an early stage in the overall remote driving System?

What influence do weaknesses in the subsystems have on the control loop between the remote driver and the vehicle?

#mid-term #cross-category

With regard to the control loop, the question arises as to what extent the quality of the vehicles subsystems influences the safe usability of this control loop. For example, a reduced quality of a subsystem can affect the entire control loop. An example of this would be a poor connection to the workstation, which can lead to long delays in execution. However, other subsystems, such as fast computing components, may have a positive effect on the control loop as mitigating measures.

In addition, the question of how to organise regular checks of the subsystems in order to ensure the consistent quality of these systems must be asked.

4.1.5.2.2 Controllability

How can the override of remote event-based driving be technically secured?

#short-term

When a remote driver accesses a vehicle, it must also be ensured that the commands to the vehicle are safely received and executed. It must be ensured that the remote driver is authorised to control the vehicle remotely so that no unauthorised access can be gained. The technical implementation could, for example, be realised using steer-by-wire systems and/or mechanical encapsulation of the control devices in the vehicle (steering wheel, pedals etc.) if it is intended to operate with passengers inside the remotely driven vehicle.

Are new approaches for hazard identification and risk assessment necessary for event-based remote driving?

#long-term #cross-category

The use of event-based remote driving can lead to scenarios in which a hazardous event potentially causes harm. Individual scenarios may have a low probability of occurrence but a high severity. These relevant scenarios must be identified for event-based remote driving. Such scenarios must be analysed as part of the safety argumentation to determine how the event-based remote driving system should react, how this reaction is or can be ensured and what technical mitigation mechanisms are available for the remote driver.

With regard to the technical equipment, it should also be analysed whether and, if so, which vehicle-based safety systems (e.g. emergency brake assist etc.) must be available that can intervene in the control of the vehicle.

How does a data interface between vehicles and control stations need to be designed?

#mid-term #cross-category

Given the current state of development of remote event-based remote driving, the possibility to collaborate on a guideline for a general data interface arises. Depending on the provider concept (centralised vs. decentralised), it may be necessary to be able to connect every remote driving system to every vehicle. If necessary, how can such a data interface be implemented? Can scalability be increased by a common interface and thus improve traffic flow?

4.1.5.2.3 Safe degradation

What strategies and technologies can be developed to ensure safe degradation?

#mid-term #cross-category

A teleoperated vehicle can degrade for various reasons. The degradation of connection can be one of the main causes, but degradation can also be related to the vehicle's actuators or sensors. If such degradation occurs, the vehicle must be returned to a safe state. However, the question arises as to how a vehicle in teleoperated mode can recognise that it is in a degraded state and how a degraded system can achieve a minimal risk condition.

4.1.5.3 Security questions

In this chapter, questions are asked on the subject of security. These questions can be of great importance in the development of the overall teleoperation system. Manipulation of teleoperation subsystems can cause considerable damage, the risks of which must be minimised. Attacks on such systems are not limited to attacks aimed at taking over the system, but can also include jamming, for example, or a targeted attempt to disrupt the view of the remote driver, who can potentially only gain an overview via a camera system. Furthermore, security also implicitly influences the acceptance of such systems, which may also be a factor that requires consideration of this issue, especially at this early stage of such technology.

How can attacks on a teleoperation system be classified and what effects can such attacks have on the entire journey, depending on those classifications?

#mid-term #cross-category

Categorising attacks on event-based remote driving makes it possible to understand the potential vulnerabilities and effects of such attack scenarios. Addressing this research question makes it possible to identify the potential risks of this technology and design mitigation mechanisms.

Depending on the type of attack on such a system, the impact on the journey can vary. A better understanding is needed to drive the development of this technology, which is why further research and security measures are required to minimise potential risks and improve the reliability of event-based remote driving systems in vehicles.

What security mechanisms need to be implemented to minimise attacks on event-based remote driving systems?

#short-term #cross-category

Firstly, the question arises as to what extent existing security concepts from related disciplines can be transferred to continuous remote driving. The development and implementation of security standards and measures that counteract the misuse of continuous remote driving systems and thus strengthen trust in such technology are relevant.

For example, *intrusion detection* can be examined as a required system or the specification of when a minimal risk manoeuvre must be performed by the vehicle, due to an attack. An example of an attack that can go beyond attacks at the network level could be the blinding of an operator's cameras to obstruct their view.

This aspect also includes research questions relating to the documentation and reporting of security incidents.

4.1.5.4 Requirements

This chapter deals with research questions on the subject of requirements that have not yet been addressed in the previous chapters. These are general requirements questions on the topics of automation, variants of teleoperation and human-machine interaction.

What requirements must be specified for an ADS of Level 4 or Level 5 so that technical communication between an ADS and teleoperation can take place?

#short-term

In the case of event-based remote driving, there must be a technical computing and communication interface between the ADS of Level 4 or Level 5 and the workstation in order to initiate remote driving in the case of an event and to be able to transfer control of the vehicle. For example, the ADS of Level 4 or Level 5 and the remote driver access the same sensor system in the vehicle. It must be possible to safely transfer control to the workstation and vice versa. For example, the ADS of Level 4 or Level 5 must be able to minimise the risk of stopping if the teleoperation function loses the connection.

This raises the research question of what requirements must be specified for the ADS of Level 4 or Level 5 so that technical communication between automation and teleoperation can take place. This question becomes particularly critical when the vehicle leaves the ODD of the ADS of Level 4 or Level 5 with the help of teleoperation and enters a potential ODD of teleoperation. With regard to safety and security, the question can also be asked to what extent the systems must be encapsulated and to what extent an emergency separation between the vehicle and teleoperator must be implemented in the event of incorrect or malicious operation. This also includes the extent to which the system must be capable of minimising risk when stopping and how this can be implemented.

What types of events can trigger the need for a remote driver to take over the driving task?

#mid-term

In the case of event-based remote driving, access by the remote driver is triggered by an event. What exactly classifies an event, how events are specified and what types of events there are must first be investigated.

How must event-based remote driving be adapted for use in disasters and special situations?

#long-term

In crisis/disaster situations such as floods, chemical accidents, earthquakes, storms, forest fires etc., there is a risk that autonomous vehicles (e.g. those serving public transport) will fail just when they are needed the most because the ODD is systematically violated, for example due to a lack of visibility of the road surface in the event of flooding or sensory restrictions caused by smoke or soot. Event-based remote driving can be of help here if the systems are designed for these situations. Good local knowledge on the part of the remote driver can be very helpful in order to be able to orientate themselves even in poor visibility conditions. In such a situation, the vehicles should be able to be coordinated and dispatched by crisis response teams or an incident commander and be used for the coordinated transport of people and goods.

In general, the research question arises as to what is necessary for both autonomous and non-autonomous vehicles to be activated in crisis or other exceptional situations by means of event-based remote driving and used to transport people and goods.

With regard to communication, the question can be asked as to which communication interfaces must be supported (in the event of partial network failures, satellite communication or mobile ad hoc networks with selective satellite communication can be set up if necessary).

For the management of crisis situations, it is necessary to investigate how remotely driven vehicles can be managed by a central supply and dispatching system, how good the scalability of the available remote drivers is in certain geo-areas and whether a targeted voice connection to available remote drivers may be required. Furthermore, the design of a possibly required interface to the road operator must be considered in order to be informed about special occasions that could have an influence. This interface could also be used to provide up-to-date information/communication of, for example, a temporary cancellation of the release of an area of operation.

4.2 Cluster 2: Workstation, ergonomics and occupational health and safety

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The chapter on workstation, ergonomics and occupational health and safety is structured in terms of content on the basis of a system analysis of teleoperated systems and the subdivision and description in terms of evaluation, design and use. In Table 5 all cluster-specific research questions are listed based on the content-related subchapters. In addition, the research questions are sorted by chapter according to their temporal prioritisation and therefore differ slightly in their order from the textual appearance.

Table 5: Cluster 2 research questions including assignment to the use case and prioritisation in terms of time

No.	Case A	Case B	Case C	Reference	Research question	Temporal prioritization
1	☑	☑	☑	General system analysis	**General research area "System analysis and understanding"**: How can teleoperated systems, including people, organisations and environment, in particular the workstation, internal and external HMIs and control loops, be analysed and understood in a way that they are well designed, remain controllable and can be used effectively?	s
2	☑	☑	☑	General system analysis	Which system analysis methods are particularly suitable for which stakeholders?	s
3	☑	☑	☑	General system analysis	Which methods of system analysis can strengthen the common understanding of the system among all stakeholders involved?	s
4	☑	☑	☑	General system analysis	Which analysis methods can be transferred to teleoperation from other domains, e.g. aerospace, and in which manner?	m
5	☑	☑	☑	General system analysis	How can the ability to analyse system-of-systems, especially emergent effects, be sufficiently strengthened?	m

No.	Case A	Case B	Case C	Reference	Research question	Temporal prioritization
6	☑	☑	☑	Temporal dimensions of system analysis and synthesis	How can the agility of the socio-technical system be ensured, especially regarding analysis and development?	s
7	☑	☑	☑	Temporal dimensions of system analysis and synthesis	How is the system designed and used not only for the normal operation, but also for system limits and system failures?	s-m
8	☑	☑	☑	Temporal dimensions of system analysis and synthesis	In particular, how can the overall system's real-time responsiveness to disruptions or degradations of subsystems or partial systems be organized and coordinated in a way that the overall system can react reliably to such disruptions? Do we need a cross-manufacturer and transnational notification system comparable to NOTAMs used in aviation?	s-m
9	☑	☑	☑	Temporal dimensions of system analysis and synthesis	How can the resilience of the socio-technical system, i.e. the short-term stabilising and mid-term learning response to disruptive or dangerous events be ensured in the long/medium and short-term?	s-m-l
10	☑	☑	☑	Temporal dimensions of system analysis and synthesis	How can the ability to analyse system migration, in particular the temporal development of the mental models of all parties involved, be strengthened?	s-m-l
11	☑	☑	☑	Temporal dimensions of system analysis and synthesis	How can the socio-technical system be used in long-/mid- and short-term and what are the differences in terms of the duration of usage?	m-l
12	☑	☑	☑	Dimensions of evaluation and requirements	**General research area "Evaluation & requirements"**: How, i.e. by which criteria and methods, can requirements be specified and evaluated for the teleoperated system, in particular the workstation, internal and external HMIs and control loops, so that the socio-technical system is used safely, efficiently and ergonomically and is rated as good by the stakeholders?	s
13	☑	☑	☑	Dimensions of evaluation and requirements	Which stakeholders have which requirements for the overall system and how are they weighted holistically (e.g. performance, safety, transparency, acceptance, trust - see expanded devil's square/angel's diamond)?	s

No.	Case A	Case B	Case C	Reference	Research question	Temporal prioritization
14	☑	☑	☑	Dimensions of evaluation and requirements	Which evaluation criteria are relevant for the design of a control centre and workstation (display and usability concept, transitions, monitoring etc. of the teleoperator)?	s
15	☑	☑	☑	Dimensions of evaluation and requirements	What are the stakeholders' (users, passengers, drivers and teleoperators) intentions/motivations when using the socio-technical system and its components?	s
16	☑	☑	☑	Dimensions of evaluation and requirements	How can the requirements for basic ergonomic principles, such as usability, joy of use, transparency and controllability, be incorporated into the R&D process? How can they be measured? Which methods, already known from other domains, can be transferred?	s
17	☑	☑	☑	Dimensions of evaluation and requirements	How can (possibly mandatory) mitigation measures be evaluated in terms of road safety and what do they have to cover?	s
18	☑	☑	☑	Dimensions of evaluation and requirements	Which sets of requirements ("protocols") are needed for different ODDs (e.g. different evaluation criteria for use in the city and on the motorway)? Can sets of requirements be quantified across ODDs?	s
19	☑	☑	☑	Dimensions of evaluation and requirements	How does a human-machine interface create sufficient transparency for users in terms of processes associated with teleoperation?	s-m
20	☑	☑	☑	Dimensions of evaluation and requirements	How can the requirements be formulated and incorporated into the R&D process in such a way that they are applied as efficiently as possible during development, implementation and operation?	m
21	☑	☑	☑	Dimensions of evaluation and requirements	Can artificial intelligence, in particular, improve and speed up R&D processes, for example in the form of assistance functions for the teleoperator?	m
22	☑	☑	☑	Dimensions of evaluation and requirements	Which requirements and needs (e.g. internal/external HMIs, joy of use) must be met by the socio-technical system for the use by vehicle users (passengers or drivers) compared to the use by teleoperators and what impact does this have on acceptance?	m
23	☑	☑	☑	Dimensions of design	**General research area "Dimensions of design"**: How, i.e. by which system design and using which methods, can the teleoperated system, in	s

No.	Case A	Case B	Case C	Reference	Research question	Temporal prioritization
					particular the workstation, internal and external HMIs and control loops, be designed so that the socio-technical system can be used safely, efficiently and ergonomically and is rated as good by the stakeholders?	
24	☑	☑	☑	Dimensions of design	How should a workstation be designed (e.g. in terms of functionality, display and usability concept, control instruments, display of information and status) so that a teleoperator can provide remote assistance and remote driving safely and efficiently?	s
25		☑	☑	Dimensions of design	Which design is required in particular for transitions, i.e. handovers and takeovers of vehicle control?	s
26		☑	☑	Dimensions of design	What influence do motion cues and the noise representation have on driving experience, performance and workload? Are these modalities necessary for safe remote driving?	s
27	☑	☑	☑	Dimensions of design	Which aspects of occupational health and safety must be considered when designing the teleoperator workplace? Are the existing specifications for computer work spaces also applicable and relevant in this context?	s
28	☑	☑	☑	Dimensions of design	How must the control centre be designed for safe, secure and efficient teleoperation (operating concept, display, communication between the various operational roles)?	s
29	☑	☑	☑	Dimensions of design	How does teleoperation need to be organised operationally (e.g. allocation of tasks and distribution of roles, transitions between autonomous and manual operation including takeover requests and concept, procedure in the event of communication deterioration up to disconnection) so that it can be implemented safely and efficiently?	s
30	☑	☑	☑	Dimensions of design	How must the control loop of the overall teleoperation system be designed to enable safe, efficient and convenient use?	s
31	☑	☑	☑	Dimensions of design	How does the quality of the subsystems, such as the latency or bandwidth of data transmission, affect the safe usability of this control loop? To what extent and in which way should the teleoperator be informed about the quality?	s

No.	Case A	Case B	Case C	Reference	Research question	Temporal prioritization
32	☑	☑	☑	Dimensions of design	Which (mitigation) measures are necessary to ensure a minimal level of system safety?	s
33	☑	☑	☑	Dimensions of design	How is the operating concept organised, e.g. daily commissioning, handovers/takeovers (e.g. commissioning and monitoring)?	s
34	☑	☑	☑	Dimensions of design	Which options for support and compensation (e.g. predictive display that simulate the current latency in the visualisation of the environment) can facilitate remote driving or remote assistance for a teleoperator?	s
35	☑	☑	☑	Dimensions of design	How do different design aspects of the workstations, communication between the control centre and the vehicle (e.g. latency) as well as support and compensation systems influence the performance and safety of operations as well as the workload, situation awareness and telepresence of the teleoperator?	s
36	☑	☑	☑	Dimensions of design	How should the interaction between passengers and the teleoperator be designed so that subjective safety and trust are created and the teleoperation is accepted?	s
37	☑	☑	☑	Dimensions of design	What interaction and communication options (e.g. internal and external HMIs) are necessary (between teleoperator, service personnel, passengers, third parties, control centre) so that the safety and efficiency of teleoperated driving can be maintained even in special situations (e.g. unexpected events, accidents, breakdowns) and so that acceptance is not impaired?	s
38	☑	☑	☑	Dimensions of design	Are innovative screen concepts useful and how do they influence the teleoperator and teleoperation (e.g. influence of HMD on concentration and fatigue of the teleoperator)?	m
39	☑	☑	☑	Dimensions of design	Can augmented reality be used to provide the teleoperator with a nearly complete picture of the traffic situation?	m
40	☑	☑	☑	Dimensions of design	Is a spatial separation of the control centre and workstation safely possible and does this enable a decentralised setup of the workstation (example: Could workstations also be set up in a private environment/home office if the quality of connection is sufficient?)	m

No.	Case A	Case B	Case C	Reference	Research question	Temporal prioritization
41	☑	☑	☑	Dimensions of design	Can the integration of driver assistance systems (e.g. active lane keeping) and/or the use of approaches to artificial intelligence significantly improve system safety and how would this affect the workstations' and control centres' design?	m
42	☑	☑	☑	Dimensions of design	Which modes are useful, and which transitions should assistance and automation systems provide so that they are easily and correctly understood?	m
43	☑	☑	☑	Dimensions of design	Can active interaction or guidance by the teleoperator alter system trust in a targeted manner?	m
44	☑	☑	☑	Dimensions of design	With teleoperated systems: To what extent does the vehicle interior need to be monitored? To what extent can trust, system acceptance and safety monitoring be brought together with the desire for privacy?	m
45	☑	☑	☑	Dimensions of design	How must the system be designed so that people with different levels of experience (e.g. novices vs. heavy users) can use the system well in accordance with their different requirements?	m
46	☑	☑	☑	Dimensions of design	To what extent do teleoperated vehicles influence other road users in the context of mixed traffic (e.g. with regard to interaction behaviour) and what interactions are necessary?	m
47	☑	☑	☑	Dimensions of use	How reasonable is it to use information from (physiological) driver monitoring for the design of human-machine interfaces?	s
48	☑	☑	☑	Dimensions of use	How is the socio-technical system used by groups of users with different levels of experience (novices vs. heavy users)?	s
49	☑	☑	☑	Dimensions of use	What are expected challenges for the utilization of teleoperation?	s
50	☑	☑	☑	Dimensions of use	How can it be ensured that HMIs are used as intended and that misuse and abuse as safety-critical aspects are prevented?	s
51	☑	☑	☑	Dimensions of use	What types of misuse are conceivable and how can they be prevented?	s
52	☑	☑	☑	Dimensions of use	How can and how will the socio-technical system, in particular the workstation, internal and external HMIs and control loops, be used by users and operators?	m

No.	Case A	Case B	Case C	Reference	Research question	Temporal prioritization
53	☑	☑	☑	Dimensions of use	How can and how will the socio-technical system, in particular the workstation, internal and external HMI and control loops, be used by different groups of users?	m
54	☑	☑	☑	Dimensions of use	What information do the respective groups of users and roles in the overall teleoperation system provide and require depending on the respective use case?	m
55	☑	☑	☑	Dimensions of use	On which factors does the information provided or required in the use case depend?	m
56	☑	☑	☑	Dimensions of use	How should the required information be presented in the overall teleoperation system in order to create the most effective, efficient and manageable human-machine interface (HMI) possible between the respective groups of users and the teleoperated vehicle?	m
57	☑	☑	☑	Dimensions of use	How can and how is the socio-technical system, in particular the workstation, internal and external HMI and control loops, used in different areas of operation?	m
58	☑	☑	☑	Dimensions of use	How can the socio-technical system be used in logistics compared to passenger transportation?	m
59	☑	☑	☑	Dimensions of use	How can the socio-technical system be used in public transportation in comparison to individual transportation?	m
60	☑	☑	☑	Dimensions of use	How can the socio-technical system be used on private ground compared to public ground?	m
61	☑	☑	☑	Dimensions of use	How can and how will the socio-technical system, in particular the workstation, internal and external HMI and control loops, be used in comparison with remote driving and remote assistance?	m
62	☑	☑	☑	Dimensions of use	Do misuse cases result in new use cases or new types of utilisation?	m

Legend: Case A: remote assistance, Case B: Continuous remote driving, Case C: Event-based remote driving. The temporal prioritization is labelled s=short-term, m=mid-term and l=long-term.

4.2.1 Introduction: How do we design and operate teleoperated systems safely?

Cluster 2 "Workstation, Ergonomics and Occupational Safety" addresses the most important research questions relating to the safe and ergonomic design of teleoperation, with a central focus on the teleoperator and their working environment, and considers the questions of the design and testing of workstation, HMI inside and outside the vehicle, as well as their impact on system qualities such as performance, safety (e.g. in the form of controllability), usability and individual acceptance.

The following procedure was used to identify the research questions: Based on the socio-technical system model of teleoperated operation described in Chapter 1.1, the subsystems and their relationships crucial to this cluster are identified. Examples of subsystems are people, workstations and HMIs (Figure 5). Examples of relationships are control loops that describe the dynamic relationship between people, workstations, data links, vehicle systems, infrastructure and the environment. These subsystems and relationships open up an initial dimensions of design, which can be iteratively adapted and expanded. This initially results in the following general research areas:

General research area "System analysis and understanding": How can teleoperated systems, including people, organisation and environment, in particular the workstation, internal and external HMIs and control loops, be analysed and understood in a way that they are well designed, remain controllable and can be used effectively?

Based on an understanding of the system, systems can be designed, evaluated and requirements for these systems can be formulated. If initial evaluations and requirements are already established prior to the design stage, chances increase for better systems, as in reality, systems are often designed or changed without sufficient requirements and evaluation standard:

General **research area "Evaluation & requirements**": How, i.e. by which criteria and methods, can requirements be specified and evaluated for the teleoperated system, in particular the workstation, internal and external HMIs and control loops, so that the socio-technical system is used safely, efficiently and ergonomically and is rated as good by the stakeholders?"

Social acceptance and requirements are an important part of the "Evaluation & requirements" research area. The societal perspective, such as the requirements imposed by the local authorities or cities that are potential providers, are analysed in cluster 5 (chapter 4.5) in more detail. The requirements that potential investors place on such a system are also analysed in greater depth in cluster 5. HMIs are important interfaces between a teleoperated system and society, that is other road users and passengers. Both the external HMI for communication in complex traffic scenarios and the internal communication for the support of passengers are addressed in cluster 5.

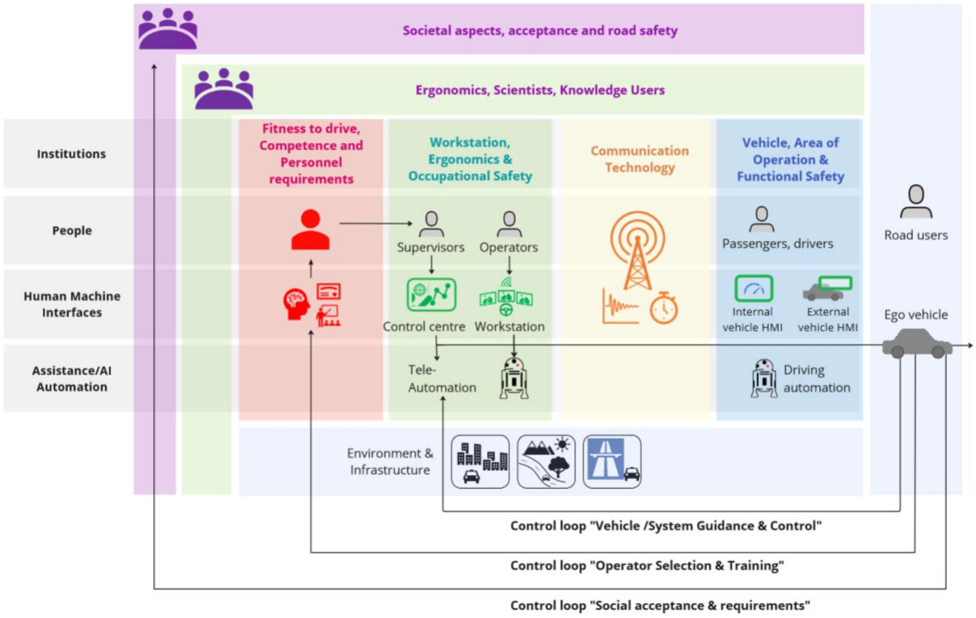

Figure 5: System diagram of teleoperation, with a focus on ergonomics & occupational safety (derived from Flemisch et al., 2021; Herzberger et al., 2022; BASt 2023)

General research area "Dimensions of design": General research area "Design": How, i.e. by which system design and using which methods, can the teleoperated system, in particular the workstation, internal and external HMIs and control loops, be designed so that the socio-technical system can be used safely, efficiently and ergonomically and is rated as good by the stakeholders? The issue of data connectivity is addressed technically in cluster 3 (chapter 0), but has a strong ergonomic impact on cluster 2, as the quality of the data connection (e.g. latency and resolution) interacts with the ergonomic quality of the workstations and HMIs to a large extent. The question of the requirements for the teleoperators operating the system (e.g. as a remote driver or remote assistance) is dealt with in cluster 4 (driving suitability, qualification and personnel requirements; chapter 4.4).

The design and evaluation become accessible once the socio-technical system is in use. This complex of questions can be structured by describing use situations and use cases that span dimensions of use. The following general research question can be formulated:

General research question "System use": "How can and how will the socio-technical system, in particular the workstation, internal and external HMIs and control loops, be used by users and operators?" - This research question can be further structured with the remote assistance and remote driving use cases described above and the selected edge cases identified.

Design, evaluation and utilisation already indicate that temporal factors can play an important role, which can be formulated as a general research question.

4.2.2 General system analysis

The consideration of teleoperated systems including organisation(s), people and the environment is complex. The analysis of existing and future teleoperated transportation systems is, on the one hand, an important starting point for a good understanding and action by as many stakeholders as possible, and on the other hand is anything but trivial due to the greater complexity and higher number of participants and stakeholders compared to non-teleoperated, non-automated individual vehicles. The analysis attempts to make the system as a whole comprehensible, for example by describing individual components and their relationships. It is faced by the opposite approach of synthesis that assembles and changes individual components, hopefully based on a good understanding. Examples of analyses of transportation systems are system analyses of individual vehicles on roads, of traffic flows in a transportation infrastructure, or of the relationship of transportation systems to metasystems such as society and the environment. Examples of the synthesis of transportation systems are the design, development and construction of vehicles, road networks or intelligent transport networks.

1.1.1.2 State of the art in science and technology

On the one hand, the current state of science and technology of teleoperated systems is based on the analysis of complex systems, which started with the cybernetics and systems science of the 1960s and continued with the more technically orientated systems engineering (Haberfellner et al., 2021) and its sister discipline Human Systems Integration / Human Factors Integration, which already integrates people, technology and organisation (e.g. O Rippy, 2021) providing far-reaching foundations. Furthermore, there is an extensive pool of scientific communities of industrial engineering (Schlick et al., 2010) human factors and ergonomics. While the actual implementation and operation in the road transportation domain is at an early stage, it has been well-established for decades in other domains such as aerospace and for more than a decade in military aviation and seafaring, despite the fact that not all issues have been solved here. Especially the training and application of existing system techniques, particularly system analysis, is still in need of development in many domains. Furthermore, gaps in the methodology have already been identified in systemically well-developed domains, for example a gap in system-of-systems understanding, in which new combinations of systems constantly produce new emergent effects that cannot practically be predicted by the individual systems. Another gap is the common understanding of the system by all stakeholders, which is currently, for example, emerging in research on mental models of teams (z.B. Casakin & Badke-Schaub, 2013) but is far from practical implementation.

1.1.1.3 Assumptions and their consequences

We assume, i.e. we have good reason to hope, that

1) for the time being, there is **no major gap in the theory** of system analysis, i.e. that existing system and analysis methods can be transferred from other domains to teleoperated transportation systems in a way that, with the right speed and care, sufficiently safe and usable systems can be designed, developed, implemented and operated.

2) the **transfer and application** of the analysis methods to teleoperated systems are **not trivial**, but pose research questions themselves, especially with regard to an interdisciplinary stable basic understanding of transport systems,

3) existing "smaller" but important gaps such as "system-of-systems", mental models and migration can be closed in good time with sufficient research before lacks of analysis and understanding skills lead to problems.

As a consequence, the following open research questions arise.

1.1.1.4 Open research questions

Which analysis methods can be transferred to teleoperation from other domains, e.g. aerospace, and in which manner?

#mid-term

Which system analysis methods are particularly suitable for which stakeholders?

#short-term

Which methods of system analysis can strengthen the common understanding of the system among all stakeholders involved?

#short-term

How can the ability to analyse system-of-systems, especially emergent effects, be sufficiently strengthened?

#mid-term

1.1.1.5 Temporal dimensions of system analysis and synthesis

How can the agility of the socio-technical system be ensured, especially regarding analysis and development?

#short-term

When considering the need for research, it is not only the initial analysis, development and introduction of the system that plays a role, but also the ongoing development, application and quality assurance. It therefore makes sense to describe the need for research not only for the "here and now", but also in terms of temporal dynamics, as all systems are subject to constant and continuous technical and social change, which requires ongoing maintenance and adaptation of all subsystems. Over time, new or unexpected challenges with regard to ergonomics and design could become apparent in the long-term use of workstations or HMIs. Simultaneously, with the continuous use of the systems, new processes will be established and mechanisms that were initially implemented, such as training instructions, may become redundant. As a result, the overall system should be able to proactively respond to changes and react flexibly to new requirements. At the same time, the aim of this report is to promote continuous development that builds on an already secure operation. The agility of the system is therefore a prerequisite (Bendel, 1993). With regard to performance and safety, a variety of new issues can also arise over time as the system is used, or obstacles can arise if, for example, the needs of society, the environment and users change.

How is the system designed and used not only for the normal operation, but also for system limits and system failures?

#short-term #mid-term

The agility of the system implies that the system as a whole must be designed not only for use in its normal state, but also for system limits and system failures. As the design for limits and failures, in particular, is directly relevant for the safety, this must be considered at very short notice, right from the start.

How can the resilience of the socio-technical system, i.e. the short-term stabilising and mid-term learning response to disruptive or dangerous events be ensured in the long/medium and short-term?

#short-term #mid-term #long-term

New insights into occupational health and safety can be gained which make system adaptation necessary. These temporal aspects should be considered at an early stage in order to identify the relevant research requirements at the right time. This includes focussing on system resilience during development. With regard to short-term failures or disruptions, the socio-technical system of teleoperation must therefore be able to maintain the essential processes and not fail completely. A system that is resilient in the long-term is expected to be able to realise new system states that represent an improvement compared to the initial state (Scharte & Thoma, 2016).

In particular, how can the overall system's real-time responsiveness to disruptions or degradations of subsystems or partial systems be organized and coordinated in a way that the overall system can react reliably to such disruptions? Do we need a cross-manufacturer and transnational notification system comparable to NOTAMs used in aviation?

#short-term #mid-term

An important contribution to resilience lies in the real-time response of the overall system to critical events in subsystems and partial systems. One example of this is automated driving, which has been sped up even further by competitors such as Tesla Inc. and is dynamically stabilised, for example, by online monitoring of all safety-relevant activities with overnight updates. The key to this dynamic stabilisation is continuous feedback on the system status to relevant stakeholders, which enables a prompt response to critical events. One example of this is the NOTAMS system established in aviation; time-critical information about critical conditions or events at airports are distributed to all users of airborne traffic practically in real time. Such time-critical information systems are largely missing in the transport sector.

How can the ability to analyse system migration, in particular the temporal development of the mental models of all parties involved, be strengthened?

#mid-term #long-term

The temporal development of complex systems, including humans and their interfaces to technology/HMI, as described in the example of human-system migration, is still mainly unexplored (e.g. Obrenović, 2011; Flemisch et al., 2011). It would be fatal if we understood and promoted the technical development of teleoperated systems, in this case HMI, but neglected the associated development of mental models, for example of users and other road users, such as vulnerable road users, and thus caused serious accidents.

How can the socio-technical system be used in long-/mid- and short-term and what are the differences in terms of the duration of usage?

#short-term #mid-term #long-term

A further research question arises from the challenge of describing the need for research in the short, medium and long-term. The main aim should be to design and maintain the teleoperated system through short, medium and long-term quality assurance measures in terms of monitoring, review and updating so that the socio-technical system is used safely, efficiently and ergonomically and is regarded as good by the stakeholders.

4.2.3 Dimensions of evaluation and requirements

After analysing and even before designing the system, the most important question in terms of requirements and system evaluation is**: What constitutes a good system** - in this case a teleoperated system with its workstations and HMIs? Evaluation standards and evaluation entities, for example stakeholders such as users or approvers, open up dimensions of requirements and evaluation. What appears to be a trivial question with an objective answer at first glance turns out, on closer inspection, to be a complex interplay of subjective and objective evaluation standards as well as different stakeholders who may have different requirements and evaluations. Systemic challenges and areas of tension are involved:

- **Subjective and objective:** While part of the research and development community strives for the highest possible objectivity of requirements and evaluation criteria, it is 1) epistemologically evident that unambiguous objectivity is an unattainable ideal, and 2) it is now widely recognised that the subjective assessment of stakeholders, for example on the perceived quality of system use, is also justified. In addition, 3) Human Systems Integration provides methods that can objectify subjective assessments.
- **Quantitative and qualitative:** Here, too, part of the research and development community, in imitation of 19th century physics, strives for the most precise quantifiability of facts; at the same time, it is now common knowledge in human systems integration that, in particular, complex issues with people cannot be quantified adequately, and that qualitative descriptions are relevant as well and should ideally be balanced with quantitative methods (z.B. als Döring & Bortz, 2016).

- **Data, information, knowledge and action:** What at first glance appears to be a simple correlation of observation and evaluation "This is a good/not so good system", becomes a comparably complex network of correlations in complex systems, in which data is generated, which is condensed into information and knowledge, from which stakeholders derive actions and finally act- hopefully correctly and decisively (see Figure 6). Weick (1995), for example describes these chains as "sensemaking", whereby an increasing gap between knowledge and action is perceived (Mandl & Gerstenmaier, 2000).

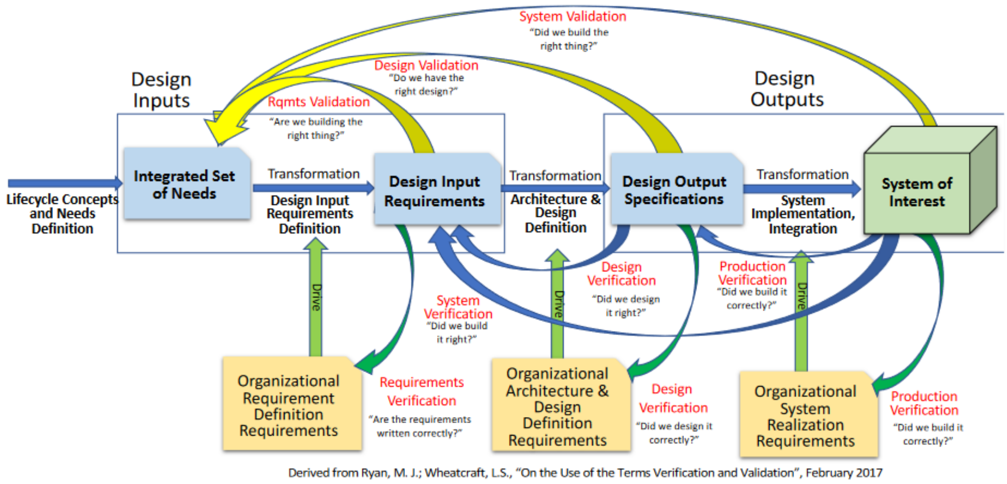

Figure 6: Extract from the Incose Guide for requirements (INCOSE, 2022).

1.1.1.6 State of the art in science and technology:

Requirements analysis, especially of user requirements, has been the subject of research for several decades, for example under the guiding principle of user-centred system design (e.g. Lindgaard et al., 2006based on Norman, 1986). Particularly in systems engineering, there are a number of guidelines, for example the "Needs and Requirements Manual" from INCOSE (Ryan et al., 2015) or the VDI Guideline 3780 on Technology assessment, basic principles and terms (VDI, 2000) which can also be applied to human-technology systems.

There is a large number of concepts and documents relating to ergonomic requirements, only a small selection of which can be described here:

- System safety: Functional safety, "Safety Integrity Levels" from ISO 26262
- Usability: Nielsen (1994), Brooke (1996), , as described in e.g. User centred system design: Shneiderman (1998), Endsley and Jones (2012), Norman (2013)
- *Situation* Awareness: Endsley (1995), Baumann and Krems (2007), Endsley (2021), Baumann et al. (2022)
- Trust: Calibrated Trust: Lee and See (2004), Hoff and Bashir (2015), Kraus et al. (2020)
- Workload: Wickens (2002), Parasuraman et al. (2008)

- Transparency: Walch et al. (2016), Hoc (2000), Chen et al. (2020), Zang and Jeon (2022)
- Controllability: Meaningful human control (e.g. Flemisch et al., 2023)

The variety of ergonomic requirements demonstrates that they cannot all be fulfilled equally. Due to this particular challenge, the balancing handling of conflicting objectives has found its way into project management, for example based on the so-called "magic triangle" of time, costs and functions, the "devil's square" with the additional dimension of quality (Sneed, 1987) and, with the inclusion of sustainability, the "angel diamond" (Figure 7).

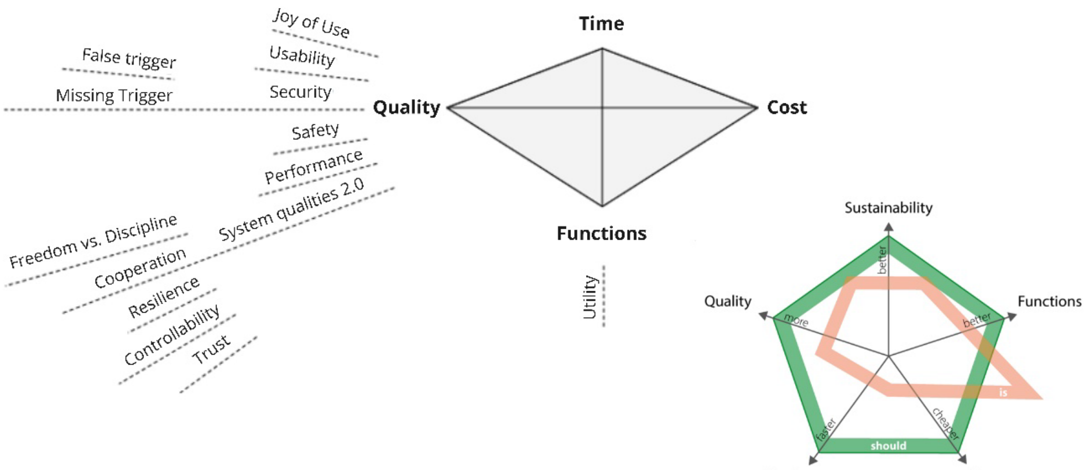

Figure 7: Left: Expanded devil's square of system requirements (Flemisch et al., 2019), based on Sneed (1987). Right: "Angel’s diamond" with the additional dimension of sustainability for the system analysis of complex systems (Flemisch et al., 2023).

The particular challenge of conflicting objectives in the system analysis and design has also led to process paradigms such as balanced analysis through a series of DFG and EU projects, in which a combination of methods is used to achieve the best possible coverage of the various requirements (Figure 8).

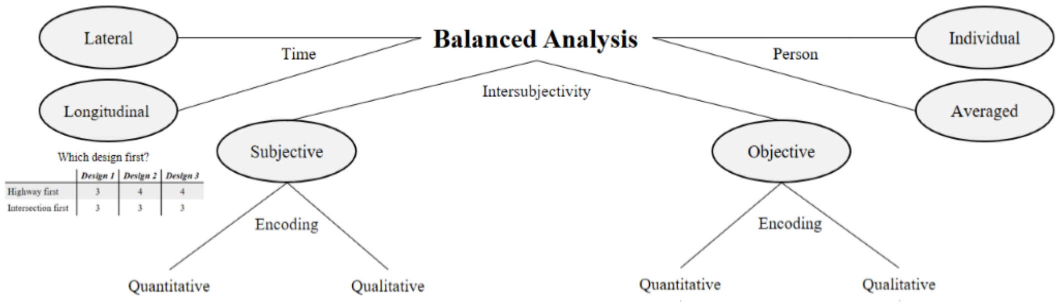

Figure 8: Balanced Analysis of Systems (Usai et al., 2023; Flemisch et al., 2021; based on Döring & Bortz, 2016).

1.1.1.7 Assumptions and their consequences:

1. Similar to system analysis, we estimate that there is sufficient theory on qualities and requirements to initially develop, implement and operate teleoperated systems, but that
2. the practical application of theory, especially to complex transportation systems such as teleoperated systems, and in particular to ergonomics and occupational health and safety, is still far from its actual potential, so that **dangerous gaps are** already emerging. As other domains such as aviation have already shown that putting theory into practice takes time and money, even with the best of intentions, the rapid introduction of teleoperation could lead to strong negative effects in individual and public acceptance which will be difficult to recover. A current example from the automotive sector are the safety problems with so-called autopilots from an US manufacturer, which are being watched with great concern and actively combated by European OEMs.
3. In addition to identifying gaps, as in this report, regular monitoring of the need for fundamental and applied research will be necessary.

1.1.1.8 Open research questions:

Which stakeholders have which requirements for the overall system and how are they weighted holistically (e.g. performance, safety, transparency, acceptance, trust - see extended devil's square/ angel's diamond)?

#short-term

This fundamental question is anything but trivial, especially the common understanding of the minimum requirements of the respective other group of stakeholders, for example legal requirements (e.g. authorisation capability), which are often insufficiently understood by the more technically oriented stakeholders.

Which evaluation criteria are relevant for the design of a control centre and workstation (display and usability concept, transitions, monitoring etc. of the teleoperator)?

#short-term

How can the requirements be formulated and incorporated into the R&D process in such a way that they are applied as efficiently as possible during development, implementation and operation?

#mid-term

What are the stakeholders' (users, passengers, drivers and teleoperators) intentions/motivations when using the socio-technical system and its components?

#short-term

Can artificial intelligence, in particular, improve and speed up R&D processes, for example in the form of assistance functions for the tele-operator?

#mid-term

How can the requirements for basic ergonomic principles, such as usability, joy of use, transparency and controllability, be incorporated into the R&D process? How can they be measured? Which methods, already known from other domains, can be transferred?

#short-term

How can (possibly mandatory) mitigation measures be evaluated in terms of road safety and what do they have to cover?

#short-term

Which requirements and needs (e.g. internal/external HMIs, joy of use) must be met by the socio-technical system for the use by vehicle users (passengers or drivers) compared to the use by teleoperators and what impact does this have on acceptance?

#mid-term

How does a human-machine interface create sufficient transparency for users in terms of processes associated with teleoperation?

#short-term #mid-term

Which sets of requirements ("protocols") are needed for different ODDs (e.g. different evaluation criteria for use in the city and on the motorway)? Can sets of requirements be quantified across ODDs? An example of this would be a quantification where 60/100 points can be driven on the motorway and 90/100 on rural roads)?

#short-term

4.2.4 Dimensions of design

System synthesis and design can be seen as a logical continuation of system analysis, whereby understanding and design do not follow each other in a cascading manner, but are often interlinked: Starting from a sufficient basic understanding of the system, designing and testing the effects can significantly increase the ability to analyse and thus increase the understanding of the system. Emergent effects can often not be determined in advance, but only appear through new combinations of subsystems and relationships.

The degrees of freedom to design, develop, implement etc. can be described as dimensions of design that cannot be randomly combined, but can be combined in surprisingly diverse ways. The dimensions represent different design options, which are initially listed without evaluation or concrete application. This should prevent potential solutions from being unintentionally ignored. Various system combinations can be explored within the dimensions of design, and evaluated and documented with the help of the dimensions of evaluation.

1.1.1.9 State of the art in science and technology

The question of design concerns various subsystems of the overall teleoperation system (including the people involved, the technical components and the organisational conditions) as well as the control loops in between. The relevant subsystems have already been described in chapter 2 and are summarised again here for the sake of clarity:

- **Teleoperator:** Person who, depending on the design of the system, permanently or temporarily takes over the driving task and drives a vehicle (remote driver), or supports an ADS of Level 4 or Level 5 in the event of failures (remote assistance) and may also be responsible for other tasks (e.g. communication with passengers).
- **Workstation:** The workplace of the teleoperator, which is equipped with the appropriate controls for the task, such as a steering wheel, pedals and screens for viewing the surroundings. From here, a vehicle can be driven remotely or remote assistance is provided.
- **Control centre:** The operations centre for the vehicle fleet. The control centre is where the overview, assignment of tasks, scheduling, organisation of maintenance and service calls take place. The control centre does not include any operating elements that allow direct control or assistance of a vehicle. Instead, driving orders can be assigned to the respective workstations and the teleoperators can be monitored or supported.
- **Teleoperated vehicle**: The vehicle to be driven or assisted, which might be located in a separate environment to the control centre and the workstation. Depending on the application, it offers interaction possibilities between the teleoperator and the passengers and the surrounding traffic. It includes systems for data acquisition and connectivity to the control station via the control centre.

Other subsystems whose implementation and quality are also relevant for safe, efficient and ergonomic teleoperation include the traffic environment (e.g. infrastructure, road users) and the communication interfaces. Some of these are also subject to design options (e.g. road-side units, information for road users).

The question of design therefore concerns the following central interaction elements:

- HMI of the workstation
- HMI of the control centre

The ergonomic design depends to a large extent on the implemented teleoperation concept (Majstorovic et al., 2022) and the respective (driving) tasks of the teleoperator.

1.1.1.9.1 Workstation

The design of the workstations for remote drivers often resembles static driving simulators with an immobile support structure that holds a seat and serves to fix the pedals and steering wheel (Chucholowski, 2016; Gnatzig, 2015 , 2015; Hofbauer et al., 2020; see Figure 9). The views of the real vehicle are displayed on a horizontally arranged row of commercially available computer monitors, whereby some design approaches rely on an additional screens to display further information (e.g. navigation information, information about the vehicle and the vehicle status, the communication network, the customer or the transported goods). The picture-in-picture method is used, so that additional views, such as the rear-view mirrors or the speedometer, are superimposed on the view to the front. The screen size varies and so do the perspectives and details that can be displayed. This is also influenced by the position of the cameras. In one system, for example, the cameras are positioned on the front edge of the roof of a car and thus offer a higher angle of view than another system in which the cameras are positioned inside the vehicle and thus provide a classic perspective of a person driving.

In the case of remote assistance, the selection or input of trajectories and/or waypoints usually takes place via input instruments such as a keyboard, touch display or mouse at an office-like workstation, displaying the traffic environment on several screens (cf. Buchholz et al., 2020; Kettwich, Schrank, & Oehl, 2021; Schrank et al., 2024).

Description categories of workstations therefore include visual display (e.g. medium, visual range, recording means), sound display (e.g. means of visual/sound display, localizability of sound sources, recording devices), driving position (e.g. mock-up, primary and secondary control elements) and operating concept (e.g. user interface, input instruments, displayed information, functionality). The possible monitoring of the teleoperator (e.g. with regard to attention) and the continuous documentation of relevant driving and operating data, the communication link with its functionalities as well as the possible teleoperation modes and possible assistance (systems) for the remote driver are further aspects.

The basic requirements for teleoperation are sufficient driving performance and safety levels (comparable to driving a vehicle with a person present in the vehicle). This poses, for example, the following challenges:

- Altered sensory perception (e.g. on-screen display of the traffic situation, display with latency, lack of proprioceptive information, different field of vision; Chen et al., 2007; Lu et al., 2019; Neumeier et al., 2019; Tang Chen, 2015).
- Additional tasks (login, takeover/return of vehicle control, remote communication with operating personnel or passengers, technical inspection and departure tests, modified communication with other road users)
- Establishing appropriate situation awareness before supporting or controlling the teleoperated vehicle, i.e. the mental representation of the current driving situation for the remote driver (according to Endsley, 1988), situation awareness consists of the three levels of perception, understanding and anticipation of the situation (see also Hosseini & Lienkamp, 2016; Tang Chen, 2015).

- Telepresence (cognitive and emotional) despite physical absence (e.g. latencies can reduce the perception of the virtual environment as an actual traffic situation as well as the experience of presence), perspective-taking regarding comfort and safety as well as the prevention of cyber-sickness (cf. Sheridan, 1992; Huang & Alessi, 1999)
- Maintaining the attention and vigilance of the remote driver and preventing distraction as well as excessive workload (especially if the remote driver serves as a fallback level for an ADS; cf. Lu et al., 2019; Neumeier et al., 2019)

Due to the rapid development in the field of teleoperation, some providers are already carrying out initial trials with prototypical systems on public roads.

Figure 9: Workstation at the final event of the UNICARagil project. (Picture: BASt: Lena Plum)

1.1.1.9.2 Control centre

The teleoperator is integrated spatially, organisationally and in terms of personnel into a control centre and an overall teleoperations system. Kettwich, Schrank, Avsar, and Oehl (2021) distinguish between different roles that employees in control centres can take on in this context (in addition to the teleoperator, for example, coordinators who monitor operations or perform service functions for the technical infrastructure and the operated vehicles). Finally, other areas of responsibility and roles arise from the higher-level, organisational structures (e.g. employees for the teleoperator personnel selection and training or other employees in the control centre; Cummings et al., 2021).

1.1.1.9.3 Other domains

In other domains, teleoperation is already being used militarily or commercially. In addition to the teleoperated control of drones, for example, heavy transportation trucks and other machines have been used in mines for a decade with the aim of achieving greater safety in the field of application. However, the most significant difference is often the area of use and utilisation. In the application "mine", this is a confined area in which the network connection, other traffic and the environment can be controlled very precisely. The workstation consists of a combination of traditional computer screens and the control elements that are also used in the real vehicles. Thanks to a standardised control unit, different vehicles can be operated from one workstation. Operation is supported by a high degree of automation, which is also available in traditionally operated machines.

1.1.1.10 Assumptions and their consequences

In principle, the technology needed to set up safe, secure and efficient teleoperation should be available. Nevertheless, further relevant developments are conceivable in the future:

Visualisation of the driving environment: New technologies can bring about a significant change, particularly in the area of displaying camera views. For example, head-mounted displays (HMDs) might replace the screens of a workstation and at the same time offer even more extensive views. In combination with various camera systems, the visualisation of the driving environment has a major influence on the usability and safe operability of workstations. Technical solutions in the field of virtual or augmented reality could help to provide the teleoperator with an image of the traffic situation that is as comprehensive as possible; this makes it easier for the teleoperator to immerse in the situation or makes it possible to provide additional information which makes it easier to deal with the challenges (according to Dix et al., 2021). Negative effects on the workload or the well-being of the teleoperator (cybersickness) should be avoided.

Artificial intelligence: The possible uses and implications of artificial intelligence methods in teleoperation are currently also open.

Concepts for operation and control centre: The future design of teleoperation control centres is currently still in the conceptual phase. Accordingly, their exact function and role are still being worked out. It can be assumed that control centres are not necessarily physical entities, but rather digital platforms that mediate driving requests and free teleoperators and thus acts as a contact interface for users and drivers. Various functions, such as an overview of the vehicles and teleoperators registered in the system, a booking system and a safety monitoring should be implemented accordingly.

Interaction with users: In the case of teleoperating a vehicle with people on board (public passenger transport or people present in the vehicle with an ADS), passengers usually favour information about their booked journey and - depending on their preference and level of experience - a communication link to the teleoperator accompanying the journey. In an emergency situation, a direct connection is required that enables both parties to communicate with each other in order to exchange safety-related instructions or information. In current systems, there is often a direct voice connection established via the telecommunications network. During teleoperation or in the event of faults and incidents, an HMI on/in the vehicle is therefore necessary in order to communicate with passengers, service technicians or emergency services. Especially in the introduction phase of such systems, the possibility of communicating with passengers and other road users is necessary in order to communicate vehicle behaviour transparently.

Automation and support systems: The rapid development of driver assistance and automation functions also played a significant role in the design of workstations in the context of teleoperation. For vehicles that only have SAE Level 2 assistance systems, a workstation must include the steering wheel and pedals, as the driving task is still actively and permanently performed here (remote driving). Should the development of the functions lead to vehicles with an ADS of a higher automation levels (L3 upwards) being teleoperated, the automation installed in the vehicles can be used. In this case, a workstation could be reduced to an input unit that does not take over any active driving tasks, but only assists the automation with decisions (remote assistance). Furthermore, support and assistance systems (e.g. lane departure warning or adaptive cruise control) could significantly reduce the workload of a remote driver and achieve a higher level of safety.

Occupational health and safety: The workstations should enable people to work in a humane manner. To achieve this, the four criteria of "feasibility", "harmlessness", "freedom from impairment" and "personal development" must be met (criteria according to Hacker, 1986). In addition, a risk assessment should be planned or carried out in the context of occupational health and safety (cf. § 5 ArbSchG).

1.1.1.11 Open research questions

- Workstation design

How should a workstation be designed (e.g. in terms of functionality, display and usability concept, control instruments, display of information and status) so that a teleoperator can provide remote assistance and remote driving safely and efficiently?

#short-term

Which design is required in particular for transitions, i.e. handovers and takeovers of vehicle control?

#short-term

What influence do motion cues and the noise representation have on driving experience, performance and workload? Are these modalities necessary for safe remote driving?

#short-term

Which aspects of occupational health and safety must be considered when designing the teleoperator workplace? Are the existing specifications for computer work spaces also applicable and relevant in this context? What does the premise of "humane working" mean in this context?

#short-term

Are innovative screen concepts useful and how do they influence the teleoperator and teleoperation (e.g. influence of HMD on concentration and fatigue of the teleoperator)?

#mid-term

Can augmented reality be used to provide the teleoperator with a nearly complete picture of the traffic situation?

#mid-term

- Control centre design:

How must the control centre be designed for safe, secure and efficient teleoperation (operating concept, display, communication between the various operational roles)?

#short-term

Is a spatial separation of the control centre and workstation safely possible and does this enable a decentralised setup of the workstation (example: Could workstations also be set up in a private environment/home office if the quality of connection is sufficient?)

#mid-term

How does teleoperation need to be organised operationally (e.g. allocation of tasks and distribution of roles, transitions between autonomous and manual operation including takeover requests and concept, procedure in the event of communication deterioration up to disconnection) so that it can be implemented safely and efficiently?

#short-term

- Control loop design:

How must the control loop of the overall teleoperation system be designed to enable safe, efficient and convenient use?

#short-term

How does the quality of the subsystems, such as the latency or bandwidth of data transmission, affect the safe usability of this control loop? To what extent and in which way should the teleoperator be informed about the quality?

#short-term

Which (mitigation) measures are necessary to ensure a minimum level of system safety?

#short-term

How is the operating concept organised, e.g. daily commissioning, handovers/takeovers (e.g. commissioning and monitoring)?

#short-term

- Design of assistance and automation systems:

Which options for support and compensation (e.g. predictive display that simulate the current latency in the visualisation of the environment) can facilitate remote driving or remote assistance for a teleoperator?

#short-term

How do different design aspects of the workstations, communication between the control centre and the vehicle (e.g. latency) as well as support and compensation systems influence the performance and safety of operations as well as the workload, situation awareness and telepresence of the teleoperator?

#short-term

Can the integration of driver assistance systems (e.g. active lane keeping) and/or the use of approaches to artificial intelligence significantly improve system safety and how would this affect the workstations' and control centres' design?

#mid-term

Which modes are useful, and which transitions should assistance and automation systems provide so that they are easily and correctly understood?

#mid-term

- Shaping the interaction:

How should the interaction between passengers and the teleoperator be designed so that subjective safety and trust are created and the teleoperation is accepted?

#short-term

Can active interaction or guidance by the teleoperator alter system trust in a targeted manner?

#mid-term

With teleoperated systems: To what extent does the vehicle interior need to be monitored? To what extent can trust, system acceptance and safety monitoring be brought together with the desire for privacy?

#mid-term

How must the system be designed so that people with different levels of experience (e.g. novices vs. heavy users) can use the system well in accordance with their different requirements?

#mid-term

What interaction and communication options (e.g. internal and external HMIs) are necessary (between teleoperator, service personnel, passengers, third parties, control centre) so that the safety and efficiency of teleoperated driving can be maintained even in special situations (e.g. unexpected events, accidents, breakdowns) and so that acceptance is not impaired?

#short-term

To what extent do teleoperated vehicles influence other road users in the context of mixed traffic (e.g. with regard to interaction behaviour) and what interactions are necessary?

#mid-term

4.2.5 Dimensions of use

As described in the introduction, this subchapter identifies research questions on the use of teleoperation. The general key question is "How can and how will the socio-technical system, in particular the workstation, internal and external HMI and control loops, be used by users and operators?". The main focus therefore lies on the type of use of the socio-technical system and the resulting consequences for control loops.

The dimensions of use describe a multidimensional space that opens up the dimensions of users (groups of users), places of use (areas of operation) and opportunities for use (use cases). To this end, specific research questions on the use cases of remote assistance and remote driving are derived based on the current state of science and technology.

1.1.1.12 State of the art in science and technology:

The Technology Acceptance Model 3 (TAM3; Venkatesh & Bala, 2008) is an important basis to research the conditions of use and the resulting behaviour of users of technical systems. The model originates from the field of work and organisational technology. It was originally developed to describe the individual acceptance and use of information technologies in the workplace and to predict correlations before the introduction of new technologies. In addition, the model is used in non-work-related contexts to research user acceptance and behaviour. With regard to the teleoperator as a profession, the TAM could be used here in its entirety. The TAM3 is the third extension of the original model by Davis (1989). The TAM describes two basic components that determine whether a technology is used: perceived usefulness and perceived ease of use. It is explained that the influence of external variables on behavioural intention is mediated by perceived ease of use and perceived usefulness. The behavioural intention then directly leads to the use behaviour. External influencing factors can be, for example, system characteristics or certain facilitating conditions. The extended TAM3 also includes so-called anchor and adjustment variables, which can be seen as an extension or refinement of the external variables described above. These include individual characteristics of the user, such as computer self-efficacy and perceived enjoyment of use. The influence of other variables is mediated by perceived usefulness, which includes the image of a technology. The experience of users, the voluntariness of use and the influence of subjective norms are also considered in the TAM3. Overall, the TAM and its extensions demonstrate the complexity of user behaviour and illustrate the diversity of factors influencing the acceptance and actual proper use of a new technology. Although the TAM originates from a different context, the components of the model provide many reference points for research on the conditions of use and the possible resulting user behaviour.

However, when considering the socio-technical system, not only end users are of interest, but also employees and operators within the control centre. Kettwich, Schrank, Avsar, and Oehl (2021) specified requirements for employees in control centres and differentiated between central and peripheral roles. The *central* roles, which are directly necessary for operations, include remote coordinator, remote driving operator and remote system operator. The remote coordinator views incoming messages from the monitored vehicle and delegates these to other employees, such as remote driving operators. These provide the support service for the monitored vehicle. The remote system operator is responsible for the configuration and maintenance of the remote operation system. There are also *peripheral* roles that are not immediately critical for operations but ensure smooth operations in the long-term. An example of a peripheral role is the service technician, who deals with malfunctions in the interaction between the monitored vehicle and the control centre that do not fundamentally hinder ongoing operations. This category also includes dispatchers, those who provide data on passengers and employees who repair and clean the vehicles and maintain the safety of passengers.

Regarding the areas of operation of the socio-technical system, research results show that even short delays in the transmission of data from the vehicle to the remote driver led to deviations from lanes or difficulties in maintaining consistent speeds, especially at higher speeds (Musicant et al., 2023). These deviations from the lane would possibly not be expected with short delays and slower speeds. In addition, traffic flows, development and other characteristics of the traffic environment could prevail. Such and other research results indicate that different areas of operation, for example in urban/rural or motorway traffic or a combination of these, pose different challenges for the use of the socio-technical system, which must be investigated and overcome. To date, extensive collections of scenarios have already been established, which illustrate the specific cases in which teleoperation might be required or utilised (Kettwich et al., 2022) and which need to be taken into account.

Among other things, research projects on remote assistance for autonomous L4 shuttles have already developed and trialled prototype HMIs for use in public transportation (Kettwich, Schrank, & Oehl, 2021). Since the socio-technical system is to be used for various applications, current research results must be extended to other use cases, such as continuous and event-based remote driving, and their transferability must be tested.

1.1.1.13 Assumptions and their consequences:

There are already sufficient models for investigating the behaviour and acceptance of users. It therefore remains to be seen, how the use of teleoperated systems will continue to develop and how it will be implemented in real use. In addition, the description of various roles within the teleoperation system already appears to be at an advanced stage. This implies that future research into the interactions of these groups of users will be facilitated. So far, little research has been conducted regarding the possibilities and combinations that are possible for areas of operation of the socio-technical system. Even if some prototypes (see Vay model e.g. Wittler, 2021) are already on the market, it is unclear to what extent these can be combined or expanded. Subsequently, it remains to be seen how the actual use and frequency of use of these areas of operation will ultimately turn out. With regard to existing concepts for HMIs and use cases in certain areas of operation, it can be assumed that research must continue to consider the extent to which the use of the concepts can be transferred to reality and other areas, as well as whether ongoing use can be ensured or how this will develop.

1.1.1.14 Open research questions:

A distinction can be made between direct users and indirect users as **groups of users** of the socio-technical teleoperation system. Direct users are primarily the occupants of the vehicle to be controlled, including potential drivers and any passengers as well as all employees of the control centre, including teleoperators. Indirect users also include operators and providers (e.g. transportation companies) as well as all interfaces within and outside the operator, such as public transport control centres, traffic control centres for traffic management, emergency services, maintenance and cleaning services. For different groups of users, the general research question is: "How can and how will the socio-technical system, in particular the workstation, internal and external HMI and control loops, be used by different groups of users?".

What information do the respective groups of users and roles in the overall teleoperation system provide and require depending on the respective use case?

#mid-term

On which factors does the information provided or required in the use case depend?

#mid-term

How should the required information be presented in the overall teleoperation system in order to create the most effective, efficient and manageable human-machine interface (HMI) possible between the respective groups of users and the teleoperated vehicle?

#mid-term

How reasonable is it to use information from (physiological) driver monitoring for the design of human-machine interfaces?

#short-term

How is the socio-technical system used by groups of users with different levels of experience (novices vs. heavy users)?

#short-term

All groups of users have individual requirements and needs that should be considered and covered by the socio-technical system. For example, people in the driver's seat (of a multimode vehicle) may require different information from the display of an internal HMI compared to, for example, passengers travelling in a L4 shuttle, where there is no possibility of being able to take over control of the vehicle. Whether and how HMIs and the structure of the workstation can and should be used for communication between the teleoperator and passengers also plays a role here. Usage could differ in terms of the level of expertise/experience and motivation that the individual users bring in for the interaction with the socio-technical system and their specific intentions. Different levels of expertise could therefore place requirements on the design of HMIs, control rooms or control loops. Ultimately, the success of use also depends on whether and how the components of the socio-technical system are accepted.

The areas of use refer to the authorised **areas of operation** of teleoperated systems. Different environments such as urban, rural and motorway traffic can be considered here, as well as areas of operation of variable size, for which the research question arises: "How can and how is the socio-technical system, in particular the workstation, internal and external HMI and control loops, used in different areas of operation?".

What are expected challenges for the utilization of teleoperation?

#short-term

How can the socio-technical system be used in logistics compared to passenger transportation?

#mid-term

How can the socio-technical system be used in public transportation in comparison to individual transportation?

#mid-term

How can the socio-technical system be used on private ground compared to public ground?

#mid-term

The definition of areas of operation for teleoperation results in different requirements for control loops, workstations and HMIs, depending on the challenges that arise for the teleoperator and also the vehicle passengers. For example, there could be differences between private and public spaces, which are based on laws and regulations on the one hand and also give rise to special utilisation options on the other. In the private space, for example, different information could be relevant for occupants and teleoperators, which would change the context of use. Likewise, the socio-technical system could lead to different circumstances of use if it is used in logistics or passenger transport. As the presence or absence of passengers places different demands on the teleoperator, and tasks are added or removed, this results in different usage requirements and possibilities for the socio-technical system. Differences in the use can also be expected between passenger transportation and private transportation, partly because the intentions of use can differ here. The question arises as to which combinations of possible uses, but also challenges, arise when a system has to be designed to meet the requirements of urban/rural and motorway traffic in terms of HMIs and workstation.

The utilisation opportunities, i.e. **use cases**, concern differences between remote assistance and remote driving (continuous and event-based). The general research question for the use cases is: " How can and how will the socio-technical system, in particular the workstation, internal and external HMI and control loops, be used for remote driving in comparison with remote assistance?".

The focus here primarily lies on times of utilisation. On the one hand, this concerns the challenges and requirements of long-term/mid-term and short-term utilisation of the socio-technical system. On the other hand, specific points in time of use must be considered, as the circumstances and conditions that have led to the use of teleoperation, for example, can place different demands on the entire system, including the workstation, external and internal HMIs. In this context, it is relevant, what exactly the system is used for in detail.

The combination of all three **dimensions of use** results in a scope for action that has a direct influence on the use of the socio-technical system, whereby the duration, frequency, long-term nature, purpose and correctness of use, among other things, describe how the system is used. The type of use in turn has an impact on safety and other design aspects of the socio-technical system. For the entire dimensions of use, i.e. the interaction between the groups of users, areas of operation and use cases, it is necessary to consider the intended use of the socio-technical system with regard to all components. This includes researching cases of misuse and abuse, which could result in safety-critical conditions if, for example, the workstation or HMIs are used incorrectly, for the wrong purpose or not at all. Disuse and misuse should initially be prevented in order to ensure safe use in accordance with the intended purpose (see also Cluster 1, chapter 4.1.3.3, chapter 1.1.1.1, chapter 4.1.5.3). Analysing such cases could also provide indications of novel use cases and types of use that could contribute to expanding and improving the use of the socio-technical system.

How can it be ensured that HMIs are used as intended and that misuse and abuse as safety-critical aspects are prevented?

#short-term

What types of misuse are conceivable and how can they be prevented?

#short-term

Do misuse cases result in new use cases/ new types of use?

#mid-term

4.2.6 Conclusion on Cluster 2

The order of system analysis, system design and evaluation, which at first glance seems obvious, reveals a complex field of tension between understanding, evaluating and acting on the part of different stakeholders with further observation.

This requires bridging methods between the design, evaluation and utilisation areas. Bridging methods should bring together these different ways of thinking and acting of the various stakeholders in such a way that good systems can be created, stabilised and further developed. This is only likely to be successful, if this constructive approach is combined with a critical perspective that understands the antithesis that systems can also be bad, i.e. unsafe or unsuitable for use, not as defeatism, but as an indispensable part of a research and development society that is capable of functioning and acting as a whole.

The review of existing concepts and methods encourages us on the one hand to conclude that a large part of the theory of such complex socio-technical systems is already available, but that smaller gaps, for example in the understanding of systems of systems, should on the other hand be closed. Major gaps exist in the application of existing theory to teleoperated systems, for example by translating from other domains such as aviation or defence into the context of teleoperation. These gaps should be closed as soon as possible in order to minimise risks. In addition, especially in the case of reasonably successful initial implementations of teleoperated systems, medium and long-term accompanying research comparable to aviation should be set up in order to be able to react to technological, organisational or social developments or to the situation changing continuously or, much more likely, in catastrophic spurts due to climate change.

4.3 Cluster 3: Communication technology

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The chapter on communication technology is subdivided into locations of deployment, use cases, metrics of communication technology, measures to improve the metrics and their consequences. In the following table, all cluster-specific research questions are listed according to the content sub-chapters. In addition, the research questions are sorted by chapter according to their temporal prioritisation and therefore deviate slightly from the order in which they appear in the text.

Table 6: Research questions from cluster 3 including assignment to the use case and prioritisation in terms of time

No.	Case A	Case B	Case C	Reference	Research question	Temporal prioritization
1		☑	☑	4.3.7 Research questions for cluster 3	How are the classic metrics such as data rate/latency/jitter related to the quality of experience for teleoperator and/or users?	s
2		☑	☑	4.3.7 Research questions for cluster 3	How much latency/jitter is tolerable for a complete cross product of remote driving and remote assistance on motorways, dual carriageways and urban roads?	s
3		☑	☑	4.3.7 Research questions for cluster 3	How can techniques for determining the maximum tolerable latency/jitter be developed and validated?	s
4	☑	☑	☑	4.3.7 Research questions for cluster 3	How can remote driving/Remote assistance be modelled and simulated for computer simulations?	s
5	☑	☑	☑	4.3.7 Research questions for cluster 3	Can the concept of ODDs be extended to the requirements for the available communication services?	s
6	☑	☑	☑	4.3.7 Research questions for cluster 3	What quality assurance measures can be used to continuously monitor the performance of the networks used for teleoperation and make them available to the teleoperation system operators?	s
7	☑	☑	☑	4.3.7 Research questions for cluster 3	How can coverage gaps in existing technologies (e.g. 3GPP) be closed without compromising performance?	m

No.	Case A	Case B	Case C	Reference	Research question	Temporal prioritiza-tion
8	☑	☑	☑	4.3.7 Research questions for clus-ter 3	Can multi-link approaches contrib-ute to the stabilisation of network connectivity?	m
9	☑	☑	☑	4.3.7 Research questions for clus-ter 3	How can the three possible dimen-sions of handovers (remote driv-ing/ remote assistance, horizontal from base to base, vertical across technologies) be utilised?	m
10		☑	☑	4.3.7 Research questions for clus-ter 3	Does the tolerable latency/jitter depend on the accuracy/resolution of the transmitted image? Can this accuracy/resolution be adjusted to compensate for latency/jitter?	m
11		☑	☑	4.3.7 Research questions for clus-ter 3	Does the tolerable latency/jitter depend on the microscopic driving situation - and if so, can we predict this?	m
12		☑	☑	4.3.7 Research questions for clus-ter 3	How can latency/jitter be reduced and/or stabilised by reserving net-work capacities?	m
13		☑	☑	4.3.7 Research questions for clus-ter 3	How can latency or jitter be re-duced or stabilised using additional infrastructure elements?	m
14	☑	☑	☑	4.3.7 Research questions for clus-ter 3	How can Quality of Experience be predicted?	m
15	☑	☑	☑	4.3.7 Research questions for clus-ter 3	How can communication data be safely and securely recorded and stored (in a black box for accident research)?	l
16	☑	☑	☑	4.3.7 Research questions for clus-ter 3	How can the goals of performance and security be harmonised with privacy protection goals?	l

Legend: Case A: remote assistance, Case B: Continuous remote driving, Case C: Event-based remote driving. The temporal prioritization is labelled s=short-term, m=mid-term and l=long-term.

4.3.1 Introduction

Communication is a central aspect of teleoperation, as it is essential for the transmission of data and control signals between the vehicle and the teleoperator or workstation. To ensure the safety and reliability of a teleoperation system, a number of aspects of communication must be considered: Locations of deployment, use cases, metrics and measures to improve these. These aspects will be briefly examined below and research questions on communication technologies will be derived from them.

4.3.2 Locations of deployment

It is important where or in which environment the teleoperation is carried out in order to be able to determine the communication-specific requirements of a teleoperation system. There are three broad classes of teleoperation locations. They are described in more detail below and summarised in Table 7 briefly summarised.

Table 7: Operational environments and boundary conditions of teleoperation

	Motorways	City roads	Rural roads
Road infrastructure	☑ good	☑ good	◍ challenging
Communication infrastructure	☑ good	☑ good	◍ often incomplete
Road layout	☑ simple	◍ Complex	◍ Complex
Visual obstructions	☑ Few	◍ many	◍ many
Radio obstacles	☑ Few	◍ many	◍ many
Driving situations	☑ simple	◍ Complex	◍ Complex
Traffic flow	◍ fast	☑ Slow	◍ fast

1.1.1.15 Motorway

Motorways are essentially characterised by fast traffic, good infrastructural development (both in terms of road surface and markings as well as available communication infrastructure), intersection-free traffic, straight road layout, defined access roads and few adjacent buildings, simple visual and communication relationships as well as clear driving situations. In specific individual cases, however, there may be spontaneous lane closures, one-day roadworks or similar, and the communication infrastructure is not always available.

However, at the recommended speed of 130 km/h on German motorways, a distance of almost 36 metres is covered in one second, which means that high latency times etc. have a correspondingly strong effect here. The comparatively low density of radio obstructions along the motorway may also cause a sharp increase in interference, from which radio connections suffer.

1.1.1.16 City roads

In terms of communication requirements, urban areas are the opposite of motorways in many respects: traffic flows comparatively slowly, the road layout is winding and buildings make visibility and communication relationships difficult. However, they are very similar to motorways in two key aspects: the infrastructure development in terms of road surface and markings as well as the available communication infrastructure is rarely restricted.

Urban areas thus present particular challenges and opportunities for teleoperation, as they tend to be more complex and dynamic environments with a high density of pedestrians, vehicles and buildings. Navigation in urban areas requires sophisticated sensors and advanced algorithms to navigate the complex city streets in often dense traffic.

In contrast to a motorway, there are many more aspects that influence wireless communication. These include, in particular, buildings and other obstacles such as parked vehicles, trees or other obstructions.

Direct communication between two road users is not necessarily given. Accordingly, other communication techniques and protocols are required here. The presence of other road users next to a motor vehicle also requires the ability to react particularly quickly and flexibly.

1.1.1.17 Rural roads

In terms of their communication requirements, rural roads are not, as might be assumed, the middle ground between urban roads and motorways.

Rather, rural roads represent a third profile alongside urban roads and motorways, with their very own requirements.

Rural roads are characterised by complex road layouts (albeit less complex than urban roads), many visual and radio obstacles and complex driving situations, such as overtaking manoeuvres with severely restricted sensor conditions and/or undefined access routes. Speeds are also higher than on urban roads, but infrastructure deployment and road condition are often inadequate (both in terms of road surface and markings as well as the available communication infrastructure).

In rural areas, mobile broadband cells with a larger coverage area are often used, in which a larger number of network participants have to share the available communication resources. This leads to a reduction in the expected data rate per user, which in some cases increases communication latency due to buffering effects. Packet loss can also increase the expected jitter, which can have a major impact on the quality and safety of teleoperation.

In rural areas in particular, however, autonomous driving functions supported by remote assistance can enable the realisation of autonomous on-demand transport, possibly also in smaller vehicles, and with the aim of creating seamless mobility chains at an early stage.

4.3.3 Use cases

Similar to the influence of the deployment location of the teleoperation on the requirements with regard to communication, the planned purpose of the teleoperation also specifies very different requirements. Some examples of teleoperation use cases are shown in Table 8 and are briefly discussed below.

Table 8: Exemplary use cases of teleoperation

	Transport of	Route	Comfort	Speed	Plannability	Place of use
Taxis	People	free	important	important	unimportant	City/rural
Shuttles	People	fixed	unimportant	unimportant	important	City/rural
Local goods transport	Goods	free	unimportant	unimportant	unimportant	City/rural
Long-distance goods transport	Goods	fixed	unimportant	unimportant	unimportant	Motorway
Test drives	nothing	fixed	unimportant	unimportant	unimportant	City
Remote Hailing	nothing	free	unimportant	important	unimportant	City
Remote Parking	nothing	free	unimportant	unimportant	unimportant	City
Agriculture	Goods	fixed	unimportant	unimportant	unimportant	Rural
Road maintenance service	nothing	fixed	unimportant	important	important	City, rural, motorway

1.1.1.18 Taxis

Taxis (here: teleoperated taxis) are primarily used for passenger transport in the city. They do not follow fixed routes. Convenience, flexibility and short journey times are the primary requirements of users of this service.

1.1.1.19 Shuttles

Shuttles are similar to taxis, but transport passengers on predefined routes. The ability to plan the duration of the journey plays a greater role here than short journey times.

1.1.1.20 Local goods transport

Local goods transport, particularly last-mile delivery transport, is similar to shuttles, but is used to transport goods instead of people and therefore has even lower requirements in terms of journey times - but in the case of multimodal supply chains, predictability is a requirement.

1.1.1.21 Long-distance goods transport

Long-distance goods transport probably has the lowest requirements in terms of comfort, journey time and plannability due to the long distances, but it does have the highest requirements in terms of reliability of the overall system.

1.1.1.22 Intra-company traffic

Intra-company traffic places lower demands on comfort and journey time, but very high demands on reliability.

1.1.1.23 Test drives

Test drives of new vehicle classes - for example for the homologation of autonomous vehicles - are even less demanding. Here, only trained operating personnel, who would otherwise have to sit in the vehicle as accompanying drivers, are moved to the workstation.

1.1.1.24 Remote hailing and parking

Remote hailing and parking extends traditional individual passenger transport to include the option of not having to park the vehicle where one's journey begins or ends. Instead, the vehicle is driven (here: by a remote driver) from a potentially more distant large car park to or from the starting point or destination. Accordingly, only few requirements are placed on comfort during remote driving (as this takes place without people in the vehicle), but aspects such as a high degree of plannability are very much required.

1.1.1.25 Agriculture

Remote driving systems can also be used in agriculture to automate tasks such as planting, irrigation and harvesting as well as harvest transport, increase efficiency and reduce the need for manual labour. Their requirement profile largely corresponds to that of long-distance goods transport, but in many places such systems have to be able to cope with sub-optimal operating conditions in terms of not only sensing, but also network coverage.

1.1.1.26 Road maintenance service

Autonomous driving and remote driving systems can also be used in road maintenance, preferably on motorways. This is particularly useful where people need to be protected from moving traffic when carrying out road maintenance or road operation work and where vehicles used for roadworks safety may be travelling without a person in the vehicle.

4.3.4 Metrics of communication technology

The requirements of teleoperation for communication can be expressed via the usual parameters of data rate, goodput, latency, jitter, signal strength, signal to noise and interference ratio (SNIR) and quality of experience (QoE). These parameters are briefly explained below and their influence on teleoperation is discussed.

1.1.1.27 Data rate and goodput

Data rate refers to the speed rate at which digital information can be transmitted from and to the vehicle. It essentially depends on the transmission technology used and the bandwidth utilised. However, the data rate in no way indicates how quickly information can actually be exchanged. The digital data exchanged not only contains user data, i.e. the actual information to be transmitted, but often also additional monitoring and control data. The transmission technology used also means that part of the data rate cannot be used to transmit information. In addition, interference on the radio channel can often lead to packet loss and makes it necessary to repeat transmissions. The term "goodput" therefore refers to the speed at which user data is actually successfully transmitted between the source and destination, i.e. the speed at which information is actually sent, as opposed to the data rate. Goodput is often significantly lower than the data rate, sometimes by an order of magnitude in poor conditions - a lower data rate often achieves a higher goodput, especially in sub-optimal conditions.

When estimating achievable performance, it is therefore essential not to blindly rely on the technically possible ("gross") data rate of the technology used, but to determine the actual achievable goodput for each specific situation and location.

The achievable goodput plays a central role in communication with teleoperated vehicles. Assuming that video and sensor data from the vehicle should be available at the teleoperator with a certain update rate, the goodput directly specifies how extensive this data can be - for example, how high the resolution of the video image can be. Conversely, based on a fixed resolution of the video image, the goodput directly specifies how often new images are available to the remote driver. If the goodput is too low, this would immediately mean that the image is either blurred or not displayed smoothly.

1.1.1.28 Latency and AoI (Age of Information)

Latency is the time that elapses before information reaches its destination from the source. It is determined by numerous factors. However, it is not only the distance between source and destination that is decisive here - electromagnetic waves do not propagate faster than the speed of light in air and in cables (for typical cable connections in the range of milliseconds per hundred kilometres). The processing technology used also often only leads to short delays. In the case of shared network capacity on the transmission link, but also in the processing technology, multiple utilisation often leads to considerable additional delays.

Similar to the data rate, latency plays a central role in communication with teleoperated vehicles. After all, it determines the delay with which information about what is happening on the vehicle is made available to a teleoperator and the delay with which the vehicle can react to commands from the teleoperator. If the latency is too high, this would directly mean that the remote driver bases decisions on outdated information (e.g. the distance to a pedestrian) or that the vehicle executes control commands (e.g. a braking command) with too much delay.

The "Age of Information" (AoI) metric is closely related to latency, but does not focus on the immediate delay of individual data packets, but on the age of information itself. It also reflects effects such as the fact that several fractions of information that only make sense together must first be transmitted - and in the case of lost fractions, all of them must first be repeated - before new information is available at the destination. Conversely, the (albeit rapid) transmission of outdated or redundant information does not contribute to a reduction in AoI. This metric therefore reflects application effects more directly.

1.1.1.29 Jitter

Strictly speaking, jitter refers to a variety of measures that quantify the extent of fluctuations in the latency of a transmission path. Often, however, the difference between the latencies of two consecutive transmissions is simply specified as jitter (IETF RFC 4689; Poretsky, S. et al., 2006). Jitter is essentially caused by the temporal change in the factors that influence latency (see there); poor network coverage, packet loss and overloading in particular therefore cause extreme jitter.

Jitter plays a central role in communication with teleoperated vehicles, as many algorithms can compensate for latencies - even high latencies - relatively easily, but not for unforeseen increases. However, without further knowledge, high jitter means precisely such unforeseen increases in latency.

1.1.1.30 Signal strength and Signal to Noise and Interference Ratio (SNIR)

Signal strength refers to the power level of a wireless signal measured at a specific point in space. It is usually measured in decibel milliwatts (dBm). However, it is not the absolute signal strength that is directly decisive for the quality of remote driving, but rather the ratio of the power level of the wanted signal and the levels of interference signals and noise, which is referred to as the "Signal to Noise and Interference Ratio" (SNIR). It should be noted here that with poor channel separation, the wanted signal of one vehicle can simultaneously act as an interference signal for all other vehicles. Simply increasing the transmission power at the transmitter or increasing the density of the infrastructure increases the signal strength of a single receiver, but reduces the SNIR of all other participants.

Signal strength, and therefore SNIR, is an important metric for wireless communication as it can have a significant impact on the quality and reliability of wireless communication. A strong signal strength ensures that wireless devices can communicate with a high data rate and a low error rate, while a weak signal strength can cause poor communication quality, packet loss and the associated high latency or high jitter.

1.1.1.31 QoE (Quality of Experience)

Unlike the "physically" directly measurable parameters of goodput, latency/AoI, jitter and SNIR, the term Quality of Experience (QoE) refers to a satisfaction parameter specific to the application and the user that is only indirectly derived from the aforementioned parameters.

Frequently, their determination requires the performance of field tests with test persons - sometimes also with the aim of determining an application-specific relationship between the aforementioned variables and the QoE in the sense of a "conversion formula".

The QoE in terms of user satisfaction, especially for new applications such as teleoperation, cannot therefore be derived a priori from network metrics, but requires preliminary analyses.

4.3.5 Measures to improve metrics

The theoretically available data rate can be increased by using advanced wireless technologies, but this often requires a proportional increase in infrastructure density or additional capacity in the core network.

Latency (and therefore jitter) can be reduced with measures to maintain the quality of service (QoS), which can prioritise more important data streams in networks with shared resources. This includes, for example, prioritised processing of network elements, overload detection, dedicated capacities only for important data streams (e.g. 5G network slicing). What all of these have in common, however, is that such capacities must of course be available, i.e. the network is expanded more than is immediately necessary. In addition, latency can be reduced by making packet errors less likely. This can be achieved with the help of forward error correction (FEC) measures, but a FEC procedure also triggers increased resource requirements as redundant information is inserted into the useful signal. The needs-based use of FEC is therefore always a compromise between the expected packet error rate and the overhead caused by the redundancy information.

The signal strength can be improved directly by reducing the distance between the transmitter and the teleoperated vehicle, for example by densifying the infrastructure or using mesh networking technologies in WLAN or 6G. The use of new communication methods, such as intelligent reflecting surfaces, can also improve signal strength.

All these measures together then ensure an improvement in the quality of experience (QoE).

4.3.6 Consequences

The main consequences of the assumptions discussed regarding locations, use cases, metrics and measures to improve these are as follows:

The specific locations, such as motorway, city and rural roads, have a substantially different requirement profile; the rural roads probably have the most challenging profile.

Different applications - from taxis to works transport to agriculture - add an additional dimension of very heterogeneous requirements.

Classic metrics can help in the evaluation of communication technologies, but with numerous limitations: for example, there are considerable differences between theory and practice of possible transmission speeds and latencies as well as their variability. Furthermore, little is known about the specific relationship between metrics and quality of service.

Numerous measures can improve the suitability of communication technologies, but case-by-case analyses that cover the specific location and the specific use cases of teleoperation are necessary.

4.3.7 Research questions for cluster 3

How are the classic metrics such as data rate/latency/jitter related to the quality of experience for teleoperator and/or users?

#short-term

While in other areas the correlations between classic metrics and the resulting Quality of Experience (QoE) have been well researched, this is not yet the case for teleoperation.

A clear distinction must be made between the QoE for passengers in the vehicle and the QoE for teleoperators.

How much latency/jitter is tolerable for a complete cross product of remote driving and remote assistance on motorways, dual carriageways and urban roads?

#short-term

It is likely that the tolerable latency or tolerable jitter is different for different driving situations. The extent of the differences is not yet known. For motorway driving (high speed, long distance, but few obstacles and simple geometry) and urban driving (low speed and short distance, but many obstacles and complex geometry), the tolerable latency/jitter is likely to be different than for rural road driving (high speed and long distance, but many obstacles and complex geometry). The tolerance threshold for latency/jitter must be researched both with regard to the QoE of the teleoperators and with regard to the safety of the vehicle being operated.

How can techniques for determining the maximum tolerable latency/jitter be developed and validated?

#short-term

As the human factor must also be taken into account in teleoperation, an empirical evaluation is required to determine the maximum tolerable latency/jitter in the communication system (Schüler et al., 2022). Under certain circumstances, the human brain can deal with certain misinformation (caused by delayed arrival of data packets) to a certain extent or even extrapolate this information to a certain extent. An interdisciplinary approach to this research question is desirable.

How can remote driving/Remote assistance be modelled and simulated for computer simulations?

#short-term

The simulation of aspects of autonomous driving as well as aspects of communication between or among vehicles has already been very well researched. However, the behaviour of the holistic system consisting of teleoperator, radio link and teleoperated vehicle has so far only been mapped in isolated simulation environments. The cornerstone of future research here would be open simulation tools for the holistic system with generally available input data and models of vehicle dynamics, traffic, control systems and human-machine interface(s). Standardised scenario databases are also required for researching particularly typical but also particularly unusual driving situations.

Can the concept of ODDs be extended to the requirements for the available communication services?

#short-term

The concept of ODDs, which is well established in the field of autonomous driving, is to be expanded to include teleoperation, i.e. the use of teleoperation may be used to bridge sections of the route that do not fulfil the ODD requirements. However, in order to implement teleoperation, especially the criterion of adequate availability of mobile services must be fulfilled. In this respect, it must be questioned whether it might be sensible to define specific operating environments in which teleoperation is possible, taking into account the above-mentioned quality parameters of the networks. The quantitative requirements to be placed on teleoperation in terms of data throughput, latency, jitter, etc. are an unresolved research question. Monitoring the quality profiles of the networks defined in this way leads to the following research question.

What quality assurance measures can be used to continuously monitor the performance of the networks used for teleoperation and make them available to the teleoperation system operators?

#short-term

The networks used for teleoperation are subject to constant further development or change, for example due to expansion measures, technological evolution etc.). Spot measurements of mobile network quality for a route to be travelled are therefore not sufficient to qualify a route section for teleoperation in terms of mobile network quality. Rather, a continuous and comprehensive recording of the condition of the networks is necessary. The concept "Data-Driven Digital Mobile Network Twin Enabling Mission-Critical Vehicular Applications" developed in the VIZIT project funded by the BMDV (Schippers et al., 2023) provides an example of the implementation of a complete process for determining traffic areas in which the mobile networks available there are able to fulfil the performance indicators required for safe teleoperation, such as minimum data rate and maximum latency. The process presented and tested as an example initially involves the systematic passive and active recording of performance indicators of the available mobile radio networks using regularly travelling vehicles (in this case a fleet of waste disposal vehicles). The research question derived from this is whether and how such an approach could be used for teleoperation. This raises questions about the methods of data collection and the nationwide scaling of a corresponding system.

How can coverage gaps in existing technologies (e.g. 3GPP) be closed without compromising on performance?

#mid-term

Mobile broadband is not a continuous service by nature, but a service that is subject to gaps in coverage. This is particularly true in rural areas, where gaps in coverage are common, especially for technologies with high data throughput. These gaps in coverage can be closed by using alternative technologies. Possible approaches here include mesh networks that also connect vehicles to each other (for which the trade-off between less packet loss and higher jitter as well as higher network load must be researched in particular), the inclusion of satellite communication or multi-technology approaches (Hardes & Sommer, 2023).

Can multi-link approaches contribute to the stabilisation of network connectivity?

#mid-term

Maintaining multiple redundant wireless connections using either the same technology or a different communication technology could help with short outages and load shifting. In the field of teleoperation of robotic systems, current research work (Gebauer et al., 2023) show the fundamental feasibility of multilink protocols, even in heterogeneous radio environments. However, there is still a considerable need for further research to implement this for the increased requirements of teleoperation in road traffic.

How can the three possible dimensions of handovers (remote driving/remote assistance, horizontal from base to base, vertical across technologies) be utilised?

#mid-term

While the combination of horizontal and vertical handovers has been well researched in the past, teleoperation adds an additional dimension: the change of the vehicle from complete remote control to a mere support of autonomous capabilities of the vehicle itself.

Does the tolerable latency/jitter depend on the accuracy/resolution of the transmitted image? Can this accuracy/resolution be adjusted to compensate for latency/jitter?

#mid-term

It is likely that the teleoperator will be more heavily loaded if both the latency/jitter is high and the accuracy/resolution of the remote image is low, a potential solution to this could be to adjust the accuracy/resolution of the remote image - either reducing it to reduce the network load to improve latency/jitter, or increasing it to reduce the mental load.

Does the tolerable latency/jitter depend on the microscopic driving situation - and if so, can we predict this?

#mid-term

In addition to macroscopic driving situations (e.g. motorway, rural road, city), it is likely that microscopic driving situations (e.g. tailgating, overtaking, complex turning manoeuvres) will have different tolerable latency/jitter, although the extent of these differences remains to be explored. If the tolerable latency/jitter actually depends on the microscopic driving situation, the question arises whether such a situation can be predicted so that measures can be taken to either shift resources from one driving situation to another or to allocate more resources specifically to deal with such microscopic driving situations.

How can latency/jitter be reduced and/or stabilised by reserving network capacities?

#mid-term

Many networks offer the option of reserving certain network capacities for specific applications, for example via prioritisation using QoS classes or, in future, via 5G network slicing. With the targeted development of communication protocols, reservation schemes for channel access and network capacity can be realised. This can also be realised to a certain extent in ad-hoc based networks and does not exclusively require cellular communication systems (e.g. 5G). Initial research results (Overbeck et al., 2022) prove the feasibility of network slicing, but there is still a considerable need for research in order to implement the concept of network slicing efficiently across the board for teleoperation.

How can latency or jitter be reduced or stabilised using additional infrastructure elements?

#mid-term

Direct improvements to the communication link, such as procedures for modulation, coding and FEC, are already well researched. The influence of additional infrastructure elements on the QoE of teleoperation, on the other hand, is much less well researched. Such infrastructure elements could be edge clouds, for example, which take on prediction and buffering tasks.

How can Quality of Experience be predicted?

#mid-term

Knowing the QoE on a specific road section in advance would allow proactive adaptation of the remote control/support, for example by reducing the maximum speed or switching from one type to the other. It should be noted that the specific solutions depend on the use case and application and a combination of these solutions may be required. Therefore, the most important metrics (e.g. goodput, latency, jitter) must be determined and their influence on the QoE analysed. In particular, however, it must also be determined to what extent the behaviour of the metrics (and thus the QoE) can be predicted on known and unknown routes in order to be able to make statements about the reliability of the teleoperation on this route. In preliminary work (including the BMDV-funded VIZIT; (Schippers et al., 2023)), initial results were presented on methods for predicting data throughput and latency based on passively measured network quality indicators. Even if the initial results are promising, there is still a need for extensive research in order to be able to realise the predictions specifically for the requirements of teleoperation with a high degree of reliability.

How can communication data be safely and securely recorded and stored (in a black box for accident research)?

#long-term

Safety-critical systems are often equipped with a black box for the purposes of accident research or evidence, which continuously records the behaviour of important components and protects them from changes. With teleoperation, the aspect of off-board communication has now become an integral part of the safety-critical system. This immediately raises the question of how important metrics of the radio channel (e.g. goodput, latency, jitter) can be determined reliably and protected against manipulation for recording. The question of whether statements can be made about the cause of degradation of individual metrics goes even further.

How can the goals of performance and security be harmonised with privacy protection goals?

#long-term

If considered too late in the system design process, privacy protection objectives - such as the non-traceability of movements by unauthorised persons (Sommer, 2021) - often directly conflict with high performance or high security. Great progress has been made on this topic in the area of direct vehicle-to-vehicle communication. However, little research has been conducted into the transferability of these solutions to the field of teleoperation.

4.4 Cluster 4: Fitness to drive, competence and personnel requirements

Cluster lead: Prof.- Dr. Wolfgang Fastenmeier

Contributors: Nicole Gräcmann, Manuela Huetten, Viktor Oubaid

The chapter on fitness to drive, competence and personnel requirements is structured in terms of content based on the tasks and requirements analysis as the basis for determining the suitability and qualification requirements for teleoperation, the driving task, the question of what are crucial driving tasks, the model of information processing and the final presentation of open research questions on this topic. In Table 9 all cluster-specific research questions are listed according to the content-related subchapters. In addition, the research questions are sorted by chapter according to their temporal prioritisation and therefore differ slightly in their order from the textual appearance.

Table 9: Research questions from cluster 4 including assignment to the use case and prioritisation in terms of time

No.	Case A	Case B	Case C	Reference	Research question	Temporal prioritization
1	☑	☑	☑	Tasks and requirements analysis	Fundamental: What do driving task and driving related requirement analyses for teleoperators look like, at least selectively?	s
2	☑	☑	☑	Tasks and requirements analysis	Fundamental: Which job-related characteristics can be derived from a tasks and requirements analysis with regard to teleoperators' qualifications and fitness to drive?	s
3	☑	☑	☑	Tasks and requirements analysis	How can teleoperators' job profiles and "roles" be defined and determined?	s
4	☑	☑	☑	Tasks and requirements analysis	What are the requirements for any necessary verification of their suitability, competence and reliability (e.g. medical and/or medical-psychological suitability certificate, police clearance certificate, certificate from the register of driver fitness)?	s

No.	Case A	Case B	Case C	Reference	Research question	Temporal prioritization
5	☑	☑	☑	Tasks and requirements analysis	What is the appropriate period of time for periodical inspection of suitability/competence of the teleoperator?	s
6	☑	☑	☑	Tasks and requirements analysis	What are the requirements in terms of qualifications (driving licence, driving experience)?	s
7	☑	☑	☑	Tasks and requirements analysis	What type/form of training is required (e.g. in relation to knowledge of autonomous driving or taking over vehicle control)?	s
8	☑	☑	☑	Tasks and requirements analysis	What type/form of ongoing training is required?	s
9	☑	☑	☑	Tasks and requirements analysis	What mental models does the teleoperator develop about system functions? How can these be shaped?	s
10	☑	☑	☑	Tasks and requirements analysis	What type/form of test is required (e.g. driving test or similar)?	s
11		☑	☑	Tasks and requirements analysis	Are the physical and mental suitability requirements defined for the German Group 2 licences preliminarily sufficient for remote driving?	s
12	☑	☑	☑	Tasks and requirements analysis	How do the requirements differ between remote assistance and remote driving?	s
13	☑	☑	☑	Tasks and requirements analysis	How do the tasks and requirements of a teleoperator differ from those of a driver in a vehicle?	s
14	☑	☑	☑	Tasks and requirements analysis	Which personal characteristics and their necessary intensity can be identified for each role on the basis of empirical requirement profiles?	s
15	☑	☑	☑	Tasks and requirements analysis	Which diagnostic methods can be used to assess people along the requirement profiles?	s

No.	Case A	Case B	Case C	Reference	Research question	Temporal prioritization
16	☑	☑	☑	Tasks and requirements analysis	What threshold values can be recommended for each personal characteristic so that a viable forecast of future fulfilment of the requirements can be guaranteed?	s
17	☑	☑	☑	Tasks and requirements analysis	When do the requirements for professional driver training apply or when should they apply (and if necessary, including which specifics)?	s
18	☑	☑	☑	Tasks and requirements analysis	Do the requirements for the teleoperator differ depending on the vehicle class, in particular with regard to authorisation? Are the requirements for teleoperation the same for buses, trucks and cars (possibly also cars with and without passenger transport), particularly with regard to qualification?	m-l
19	☑	☑	☑	Behaviour	Is it necessary to monitor ("supervise") the teleoperator and, if so, what possibilities are there to recognise both the physical and psychological "initial condition" and the situational/present condition of the teleoperator and, if necessary, to intervene from outside?	s
20	☑	☑	☑	Behaviour	How can it be ensured that attention is consciously focussed on the information relevant to the situation at hand, and that attention is maintained during the teleoperation activity?	s
21		☑	☑	Behaviour	Are remote drivers more prone to errors than in-vehicle drivers?	s
22		☑	☑	Behaviour	Do remote drivers react just as reliably as a driver in the vehicle? Which safety-enhancing factors of personality are required?	s
23		☑	☑	Behaviour	How do teleoperators communicate with vulnerable, non-motorised road users?	s

No.	Case A	Case B	Case C	Reference	Research question	Temporal prioritization
24	☑	☑	☑	Latency influence	What are the effects of latencies on teleoperators' performance?	s
25	☑	☑	☑	Latency influence	Do latencies alter teleoperators' adequate hazard perception?	s
26		☑	☑	Latency influence	At which latencies does kinetosis/ pseudokinetosis occur for the teleoperator?	s
27	☑	☑	☑	Spatial separation	Does spatial separation of a teleoperator from the vehicle site and the driving task lead to reduced orientation?	m
28	☑	☑	☑	Spatial separation	Does spatial separation of a teleoperator from the driving task or from the vehicle site lead to reduced speed and distance estimation?	m
29	☑	☑	☑	Spatial separation	Does spatial separation of a teleoperator from the driving task or the vehicle site lead to a reduced understanding of the traffic environment?	m
30	☑	☑	☑	Spatial separation	Does the spatial separation of the teleoperator from the driving task or from the vehicle lead to out-of-the-loop phenomena?	m
31	☑	☑	☑	Situational awareness	Is a reduced situational awareness of the teleoperator to be expected? Is this accompanied by delayed reaction?	m
32		☑	☑	Task shift	Which tasks of the drivers are automated, which new tasks remain with teleoperators and which new tasks emerge?	m
33	☑	☑	☑	Task shift	What is the complexity of teleoperators' tasks and what possible incorrect actions may result from the complexity of teleoperators' remaining/new tasks?	m
34	☑	☑	☑	Special challenges	Does mixed or hybrid traffic lead to increased requirements for teleoperators?	m

No.	Case A	Case B	Case C	Reference	Research question	Temporal prioritiza-tion
					What are the consequences if teleoperators' compliant behaviour meets irregular or informally enforced driving behaviour?	
35	☑	☑	☑	Special challenges	What psychophysical performance limits of teleoperators must be considered (e.g. with regard to shift working)?	m

Legend: Case A: remote assistance, Case B: Continuous remote driving, Case C: Event-based remote driving. The temporal prioritization is labelled s=short-term, m=mid-term and l=long-term.

4.4.1 Introduction

In this report, the SAE standard J3016 is used as the basis for defining teleoperation. Two basic operating modes are derived from this, as described in chapter 1 of this document:

- Remote assistance (SAE J3016)
- Remote driving (SAE J3016) with the two forms "event-based remote driving" and "continuous remote driving".

It can be assumed that remote assistance on the one hand and remote driving on the other will differ in terms of tasks, requirements and possible critical areas. In this chapter, the focus is on remote driving as a use case that has so far only been insufficiently described. In contrast, legal requirements already exist for remote assistance. In the following text, differences between the two operating modes of remote assistance and remote driving are pointed out where necessary.

4.4.2 Tasks and requirements analysis

The aim of this analysis is firstly to create a basis for determining the suitability and qualification requirements for teleoperation. To date, the specific field of activity of teleoperation, with presumably different areas of responsibility or "roles", has been insufficiently described. It leaves open which responsibilities are assigned to a teleoperator, which specific tasks are to be taken on and thus also the complexity of tasks a teleoperator will be confronted with. Although the remote driver is not sitting in the vehicle, they can still perform vehicle guidance tasks; although remote assistants are not sitting in the vehicle, they can provide decision-relevant information to the autonomous vehicle. There are therefore two approaches to the tasks and requirements analysis for teleoperation:

- Driving task-related
- Workplace-related

Driving a motor vehicle is an activity that is understood as work in transport and labour sciences. This applies equally to professional drivers and all other motor vehicle drivers who drive in road traffic. Both driving behaviour and work behaviour can be regarded as performance under specific situational conditions. Terms such as work tasks, requirements, working environment, available work equipment are just as valid for driving a motor vehicle as for any other job. This therefore also includes remote driving.

1.1.1.32 The driving task

Traffic takes place in a complex system comprising routing, traffic situation, road users and vehicles. From a behavioural science perspective, the *human task as a driver in road traffic,* in short, the "driving task", must be modelled in the context of the safe transport of people. It should be analysed in smaller units, which we refer to as the human-machine system (MMS) "driver-vehicle-road". In this context, the hierarchical 3-level model of driving motor vehicles is highly valued in the transport sciences (Figure 10).

Navigation, guidance and stabilisation in a hierarchical structure form the typical requirements of the driving task, which are contrasted with organisation, coordination and

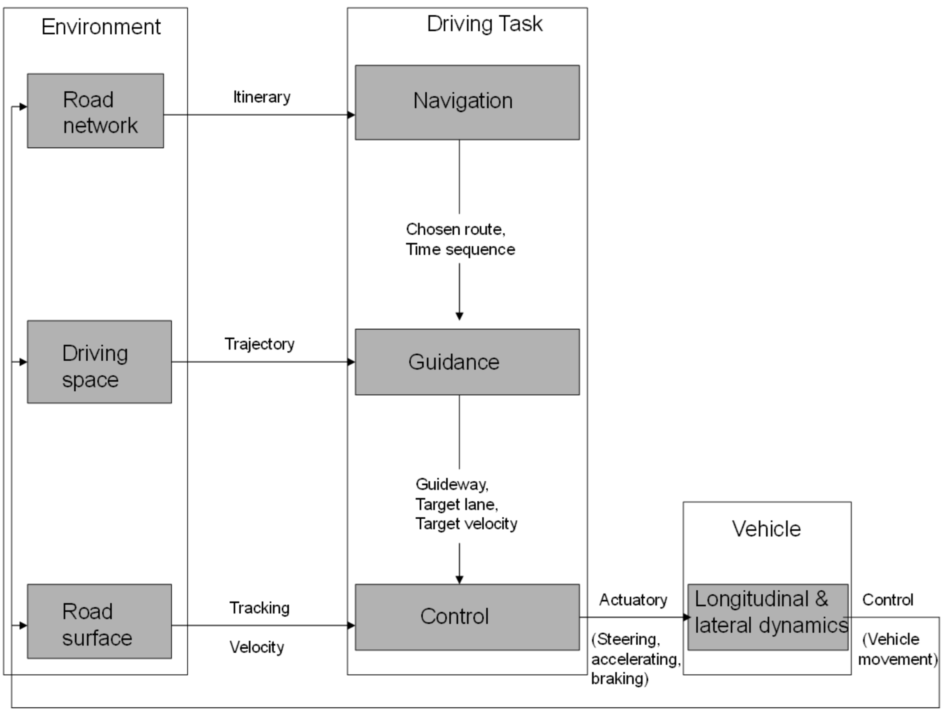

Figure 10: Hierarchical 3-level model of the driving task (based on Allen et al., 1971, or Alexander & Lunenfeld, 1979; this figure by Gstalter, 1988).

control on the management side of vehicle guidance. Formulated abstractly on the basis of this heuristic 3-level model: Drivers choose a route from the transport network and try to reach their destination on this route. They therefore perform a navigation task at this level. At the guidance level, they orientate themselves in the narrower driving space. They select manoeuvres that correspond to the higher navigation level and carry out these manoeuvres (for example: the driver turns left at the next junction). To implement these manoeuvres in practice, the target lane and target speed must be selected with sufficient accuracy and transmitted to the vehicle as control variables using suitable skill-based operations (steering, pedal control). This part of vehicle control is referred to as stabilisation.

Each of these three driving task levels has different time horizons and also different priorities, for example for the presentation of information, which must be satisfied in order to fulfil the driving task. Problems at one level may have an influence on decisions at the next higher level, for example, difficulties in keeping in lane influence decision-making processes when overtaking, or heavy traffic leads to a different choice of route to reach the destination. The same applies vice versa: Decisions at a higher task level influence the levels below. For example, if there is time pressure to reach a certain destination, this means attempting more overtaking manoeuvres; at the same time, higher demands are placed on steering behaviour during such manoeuvres.

The driving task places *demands on* the driver. Mental and psychomotor skills are required to master the respective driving tasks. Requirements are *target values* that can be met within a certain range, but which must not be undercut in order to maintain an appropriate safety standard. The interrelationship between the driving task and the performance capabilities of *suitable and qualified* drivers results in behaviour *that meets the requirements* (description in these sections based on Fastenmeier (1995) and Fastenmeier et al. (2023).

Suitability and qualification include aspects of traffic medicine, traffic psychology and pedagogy/didactics. Anyone who fulfils the necessary mental, character and physical requirements is fit to drive a motor vehicle. This means that physical and mental abilities (e.g. with regard to vision or certain attention functions) that are indispensable for driving fitness must be defined in each case. Abilities include theoretical and practical components, such as those taught in driver training, but which are also developed and enhanced through experience. This includes knowledge of the relevant regulations, technical knowledge and the operation and control of the vehicle under various conditions.

1.1.1.33 What driving tasks are there?

The current presentation refers to Fastenmeier et al. (2023). If the 3-level model of the driving task is assumed, then the navigation and stabilisation tasks can be combined into a *"basic driving task"*: These subtasks have to be mastered in all situations of a journey and can therefore be regarded as a continuous task that is "over-formed" in every given situation respectively, i.e. they have to be specified according to the situation in each section of the trip.

Brief characteristics of the basic driving task:

- Navigation level: Reaching a defined destination in the traffic network and translation into suitable lane guidance, including lane selection and possible lane changes.
- Stabilisation level: Detection and adherence to target lane and target speed (incl. horizontal and vertical course).

Other permanent tasks:

- Checking the vehicle status, reacting to vehicle displays/messages if needed
- Checking own condition (e.g. fatigue)
- Control of selective attention:
    - for visual control of the driving corridor including oncoming traffic;

- Search for possible dangers;
- Monitoring the rear traffic area;
- Control of traffic regulation;
- Observe and comply with regulations;
- Ignore distractors.

All other driving tasks belong to the *situational level* (guidance or manoeuvre level), i.e. the characteristics of the traffic situations are decisive for their description. In a similar way to McKnight and Adams (1970a) and McKnight and Adams (1970b), it is differentiated between tasks in longitudinal traffic ("tasks related to traffic conditions") and tasks in junctions ("tasks related to roadway characteristics"). In *longitudinal traffic* (intersection-free traffic), these situational characteristics are primarily the other vehicles, i.e. their temporal-spatial constellation around the vehicle under consideration. In the traffic at *junctions,* the situation is different; here the respective task is determined more by situational characteristics of the traffic facilities and the type of traffic control (as well as other parameters of the operating sequence) than by the current vehicle constellation.

There are other driving tasks that, for various reasons, do not fit into the separation of longitudinal traffic vs. intersections. These are either "special situations" or tasks that can optionally be considered or modelled together with the tasks in longitudinal traffic or in intersections. It is necessary to check which of these other driving tasks are relevant for teleoperation.

List 1: Driving tasks with crossing traffic outside intersections

- Level crossings
- Pedestrian crossings
- Small junctions, driveways, country lanes

List 2: Travelling on special route sections

- Bridges
- Tunnels
- Car parks
- Ferries, trains
- Tollbooth, border controls
- Steep gradients, steep inclines
- Construction sites
- Lane narrowing, zipper merge

List 3: Special situations

- Emergency vehicle
- Accidents
- Sudden obstacles
- Breakdowns

- Turning
- Reversing
- Parking and pulling out of a parking space

List 4: Driving under poor visibility conditions and road conditions

- Night rides
- Travelling in dense fog
- Hard-packed snow
- Black ice
- Driving in heavy rain

4.4.3 Model of information processing

A tasks and requirements analysis requires a model for information processing that plays a role for drivers when mastering the driving task. Without such a model, the selection of requirement groups would be arbitrary and could not be checked for completeness (Figure 11).

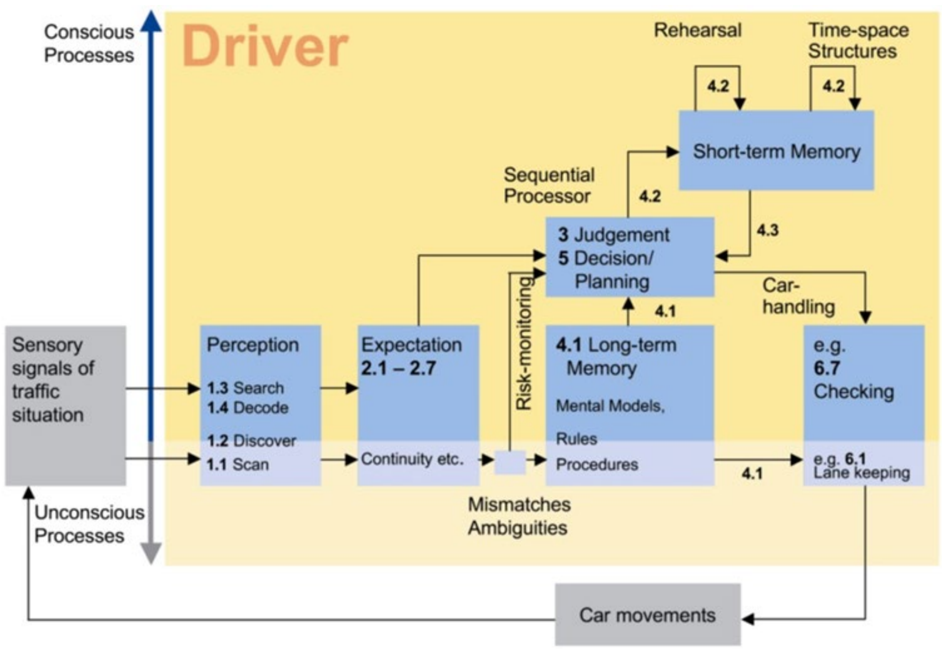

Figure 11: Information processing model for deriving requirements from the driving task from Fastenmeier and Gstalter (2003) and Fastenmeier and Gstalter (2007) modified after Rasmussen (1986); the numbers in the boxes refer to the respective chapters of a tasks and requirements analysis with SAFe (Fastenmeier & Gstalter, 2003, 2007).

The basic starting model of human information processing is a model by Rasmussen (1986). The model has proven to be heuristically fruitful in various fields of application in engineering psychology. For the purpose of requirements analysis, on the one hand, it provides the desired groups of psychological requirements that structure the individual chapters of the requirements analysis. On the other hand, it clarifies the relationships between these structures, from which requirements for the driving activity can also be derived. The consistent separation of controlled (conscious) and automated processing is also very important for this application context and should be considered for each individual requirement.

The model has been modified in two respects. Firstly, structures that lead to longer-term changes and do not fit so well with the situational analysis have been removed. Instead, a feedback loop was introduced to show how the driving behaviour, too, creates the situation to be mastered, which is then fed back into the model as an input variable. This considers the fact that it is a system consisting of the driver, the vehicle and its environment.

In contrast to other models of information processing that have found their way into engineering psychology (e.g. Wickens et al., 2022), but in line with current theoretical and empirical findings, the model presented assumes two distinct processing systems. The system of conscious, controlled information processing is characterised by a sequentially operating processor of limited capacity, which determines information processing primarily in situations that require logical thinking, symbol processing, decisions and judgement. This system controls and monitors the second subsystem depicted at the bottom of the model. This automated system is designed as a distributed system working in parallel. It performs on the basis of perceptual content and an "internal world model" (as described by Rasmussen, 1986, in this version located in long-term memory), it performs a continuous dynamic simulation of the environment and its own situation within it. In interaction with various coordination functions of the motor system, which is regarded as an integral part of the distributed processor, this enables movements and actions to be coordinated with the environment. While the processes taking place in this system are not themselves conscious, the processing results can be monitored and controlled to a certain extent by the first system. All groups of driving task-related requirements can be assigned to this model.

4.4.4 Research questions on Cluster 4

1.1.1.34 Tasks and requirements analysis

Fundamental: What do driving task and driving related requirements analyses for teleoperators look like, at least selectively? Which job-related qualifications and suitability characteristics can be determined from the tasks and requirements analyses in relation to the teleoperator's activities? How can teleoperators' job profiles and "roles" be defined and determined?

#short-term

The job profiles of the teleoperator must be made subject to a job-related (e.g. workstation related) tasks and requirements analysis, from which requirement-related qualifications/suitability characteristics and, subsequently, training and support measures can be derived in a comprehensible manner. Established work analysis procedures can be used for this purpose.

Driving task-related tasks and requirements analyses should be carried out at least selectively for areas that are to be classified as critical. The implementation could be carried out either with the help of or based on existing procedures (e.g. SAFe; Fastenmeier & Gstalter, 2007). Alternatively, a workplace-related work analysis procedure adapted to transport or a procedure specially developed for teleoperator would also be conceivable.

What are the requirements for any necessary verification of their suitability, competence and reliability (e.g. medical and/or medical-psychological suitability certificate, police clearance certificate, certificate from the register of driver fitness)? What is the appropriate period of time for periodical inspection of suitability/competence of the teleoperator?

#short-term

What are the requirements in terms of qualifications (driving licence, driving experience)?

#short-term

What type/form of training is required (e.g. in relation to knowledge of autonomous driving or taking over vehicle control)? What type/form of ongoing training is required? What mental models does the teleoperator develop about system functions? How can these be shaped?

#short-term

Training and qualification measures appear to make sense both at the beginning of the activity as teleoperator and periodically, for example training in the area of autonomous driving (for remote assistance) or training in takeover procedures (for remote drivers).

What type/form of test is required (e.g. driving test or similar)?

#short-term

The supplementary use of work and driving tests to check suitability appear to make sense.

To which field of activity is the teleoperator’s field of activity comparable (German driving licence group 2, professional drivers, air traffic controllers, drone pilots, train drivers, etc...) in order to have an initial indication of suitability requirements? Are such comparisons useful at all? How do the tasks and the requirements differ between remote assistance and remote driving?

#short-term

A transfer from the area of train drivers is rather out of the question, as rail-bound transport is associated with low degrees of freedom and low situational variance. A similar argument could be made for airline pilots. At first glance, air traffic controllers and drone pilots seem more obvious. But here, too, there are considerable differences to (any kind of) vehicle guidance in road traffic: the teleoperator has a significantly higher situational variance due to participation in or involvement in public road traffic, has shorter distances to other road users, has shorter time intervals for decision-making and action and may lack a human communication and cooperation partner on site.

For the time being, therefore, it seems sensible to focus on vehicle driving: assuming the performance requirements for obtaining a German Group 2 driving licence for remote drivers.

If an applicant is seeking the initial issue or renewal of a driving licence to transport passengers, special requirements must be met with regard to resilience, orientation, concentration, attention and reaction. In addition to these requirements for psychofunctional performance, the aspects of health constitution and personal reliability must also be taken into account.

In requirements analyses in safety-critical fields of work (aviation, medicine, etc.), rule orientation (= willingness to work according to rules and within structures) repeatedly proves to be a very important personality trait (Oubaid & Graefe zu Baringdorf, 2014; Oubaid, 2019; Oubaid & Anheuser, 2020).

Rule orientation is therefore of great importance for operators/participants in transport systems, as the (technical) design of the work situation already defines the scope for human behaviour. Effective and efficient human behaviour can therefore only take place within this setting. Human behaviour, for its part, is largely determined by the development of personality traits and performance capabilities. It is therefore extremely important to identify people with the "matching" personality traits and performance potential.

As the requirements analyses were created for other areas of activity, there is a need for research into the topic of teleoperation. The relevant regulations use the term "character reliability", which must be translated into psychological characteristics and psychodiagnostic measurements, so that ultimately such measurement results can be used to determine whether character reliability is given in individual cases.

The need for research here consists of at least the following sub-questions:

How do the tasks and requirements of a teleoperator differ from those of a driver in a vehicle?

Which personal characteristics and their necessary intensity can be identified for each role on the basis of empirical requirement profiles?

Which diagnostic methods can be used to assess people along the requirement profiles?

What threshold values can be recommended for each personal characteristic so that a viable prediction of future probation and fulfilment of the requirements can be guaranteed?

When do the requirements for professional driver training apply or when should they apply (and if necessary, including which specifics)?

#short-term

1.1.1.35 Behaviour

Is it necessary to monitor ("supervise") the teleoperator and, if so, what possibilities are there to recognise both the physical and mental "initial condition" and the situational/present condition of the teleoperator and, if necessary, to intervene from outside?

#short-term

How can it be ensured that attention is consciously focussed on the information relevant to the situation at hand and that attention is maintained during the activity?

#short-term

Can a match be achieved between the remote driver and the driver in a vehicle? This concerns the following sub-questions:

#short-term

Are remote drivers more prone to errors than in-vehicle drivers?

Do remote drivers react just as reliably as a driver in the vehicle? Which safety-enhancing factors of personality are required?

How do teleoperators communicate with vulnerable, non-motorised road users?

1.1.1.36 Latency influence

What are the effects of latencies on teleoperators' performance? Do latencies alter teleoperators' adequate hazard perception? At which latencies does kinetosis/pseudokinetosis occur for the teleoperator?

#short-term

The spatial separation of the teleoperator from the driving task or the vehicle site in combination with technical communication, which tends to be prone to errors, can lead to more difficult or reduced information reception as well as latency between action and feedback for the teleoperator. For example, the extent to which the technical solutions available to date can adequately simulate the dynamic process of human hazard perception and hazard avoidance at all distance levels, visual axes of drivers and the associated fixation processes has not yet been proven (Dix et al., 2021). The reduced information that can be provided to a teleoperator in many aspects also involves the risk of a lack of embodiment, i.e. teleoperators will not be able to feel the meaning of their actions, similar to a computer game (Mutzenich et al., 2021). This can be accompanied by a reduced sense of responsibility, but above all can lead to misunderstandings due to misjudgement of the meaning of singular pieces of information. For example, the perception of movement is made significantly more difficult by the limitation to visual information captured by cameras combined with abstract parameters such as speed information. A lack of feedback on acoustic information from the environment can also lead to relevant information being overlooked - similar to drivers in vehicles listening to music that is too loud (Dix et al., 2021). Another problem, which is primarily associated with latency influences, is kinetosis (mismatch between vestibular organ and visual impression) and contradictions in sensory perception (e.g. visual impression of movement without actual movement/pseudokinetosis), also known as motion sickness or cybersickness in this context.

1.1.1.37 Spatial separation

Does spatial separation from the driving task or from the vehicle site lead to reduced orientation, reduced speed and distance estimation, reduced understanding of the traffic environment and out-of-the-loop phenomena?

#mid-term

Separation from the task can lead to out-of-the-loop phenomena. On the one hand, this applies to event-based remote driving, but may also apply to remote assistance. While drivers in the vehicle are continuously receiving and processing information about the traffic situation, the teleoperator may suddenly be confronted with a problem. This takes place with a selective supply of information, which differs quantitatively, qualitatively and in its temporal-dynamic development from active drivers.

Teleoperators will presumably orientate themselves on relatively abstract parameters and must infer missing information and events. This makes teleoperators' information processing error-prone (Dix et al., 2021). Misjudgements by the teleoperator can, for example, concern driving speed. Drivers' assessment of other vehicles' speed in oncoming traffic varies considerably. In general, low speeds tend to be underestimated, in the medium range (50-100 km/h depending on the literature) speed is underestimated or relatively correctly assessed, higher speeds tend to be overestimated. Depending on whether the observer is estimating the distance from inside a car or from a workstation, the estimates can differ considerably (e.g. Bubb, 1977; Klebelsberg, 1982). Such potentially incorrect use of information, i.e. orientation errors or misjudgements (e.g. of distance or speed), must be regarded as safety-critical.

Spatial separation from the actual driving task or the vehicle during teleoperation: understanding and interpretation of objective conditions of a driving task follow the stages of human information processing shown above and depend largely on current perception, feedback during behavioural execution and the experiences and expectations of the teleoperator. Incorrect, undifferentiated and incomplete representations of action regulation impair the understanding of the human-machine-environment system.

1.1.1.38 Situational awareness

Is a reduced situational awareness of the teleoperator to be expected? Is this accompanied by delayed reaction?

#mid-term

Studies on situational awareness in takeover situations by drivers in automated vehicles show a significant overall delay in reaction (e.g. Vollrath & Krems, 2011) - this is likely to be significantly exacerbated in the case of remote assistance and event-based remote driving.

1.1.1.39 Task shift

Task shift: Which tasks of the drivers are automated, which new tasks remain with teleoperators and which new tasks emerge? What is the complexity of teleoperators' tasks and what possible incorrect actions may result from the complexity of teleoperators' remaining/new tasks?

#mid-term

The findings on the so-called "ironies of automation" (Bainbridge, 1983) should be taken into account here: The technically feasible, usually "easier" tasks are automated, leaving parts of the task with high complexity that no longer have to be performed by drivers in the vehicle, but from now on by teleoperators. Possible errors resulting from the shift in tasks must be compensated for by the employment of teleoperators, who in turn are exposed to new sources of error.

Stress/load: Vigilance problem: An activated teleoperator copes better with an additional demand than a less busy, underloaded teleoperator (e.g. Fastenmeier, 2021). Capacity losses due to underload can lead to overload scenarios if performance is suddenly requested during remote assistance or event-based remote driving. There is a risk that the work situation of a teleoperator will exhibit precisely these characteristics: For example, underload conditions in quiet times combined with peaks in which several vehicles have to be dispatched at the same time and problems have to be solved with different prioritisation.

1.1.1.40 Special challenges

Does mixed and hybrid traffic lead to increased requirements for the teleoperator? What are the consequences if teleoperators' compliant behaviour meets irregular or informally enforced driving behaviour?

#mid-term

What psychophysical performance limits of teleoperators must be considered (e.g. with regard to shift work)?

#mid-term

Shift work and possible stress: The activities of the teleoperator are likely to be carried out professionally and in shifts (both during the day and at night). Shift work challenges the circadian rhythm and can lead to fatigue and reduced performance (e.g. Reinberg & Ashkenazi, 2008). Impairments in performance increase the likelihood of performance fluctuations, incorrect actions, reduced psychomotor alertness and lack of concentration, among others. These performance criteria in particular are of fundamental importance for reliable task processing in teleoperators' field of activity. The psychophysical performance limits of teleoperators must also be determined for this purpose.

4.5 Cluster 5: Societal aspects, acceptance and road safety

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The chapter on social aspects, acceptance and road safety is organised according to the state of science and research questions on social aspects, acceptance and road safety. All cluster-specific research questions are listed in Table 10 representing the sub-chapters. In addition, the research questions are sorted by chapter according to their temporal prioritisation and therefore deviate slightly from the order in which they appear in the text.

Table 10: Research questions from cluster 5 including assignment to the use case and prioritisation in terms of time

No.	Case A	Case B	Case C	Reference	Research question	Temporal prioritization
1	☑	☑	☑	Determinants of individual acceptance of teleoperation in general	What requirements for the design of communication between individuals and teleoperated vehicles result from the analysis of the acceptance conditions?	s
2			☑	Determinants of individual acceptance of teleoperation in general	Is acceptance altered by remote drivers' takeover of vehicle motion control if this influences traffic flow?	s
3	☑	☑	☑	Determinants of individual acceptance of teleoperation in general	What factors influence the individual acceptance of remote assistance and remote driving in general?	s-m
4	☑		☑	Determinants of individual acceptance of teleoperation in general	Does the option of teleoperation by a human teleoperator increase the acceptance of autonomous systems?	s-m
5		☑	☑	Determinants of individual acceptance of teleoperation in general	How does the use of remote driving in mixed traffic influence its acceptance, in this case especially in view of the greater complexity of a road user's interaction with a mixture of different technologies (teleoperation, in-vehicle human driver, driving automation system)?	m
6	☑	☑	☑	Determinants of perceived safety and perceived risk and their implications	What factors influence users' perceived safety/security?	s

No.	Case A	Case B	Case C	Reference	Research question	Temporal prioritization
7	☑	☑	☑	Determinants of perceived safety and perceived risk and their implications	What factors influence the perceived safety of other road users?	s
8		☑	☑	Determinants of perceived safety and perceived risk and their implications	How does trust in a remote driver differ from trust in an ADS of Level 4 or Level 5?	m
9	☑	☑	☑	Potential (also far-reaching) social impacts and their analysis	What is the societal added value of teleoperation?	s
10	☑	☑	☑	Potential (also far-reaching) social effects and their analysis	What opportunities arise from teleoperation for change in professions and in terms of shortage of skilled labour?	s
11	☑	☑	☑	Potential (also far-reaching) social effects and their analysis	What costs and risks can be expected with the introduction and use of teleoperation?	s
12	☑	☑	☑	Potential (also far-reaching) social effects and their analysis	Which methods are suitable for analysing the potential impact of technology on society? Which (new) methods for effects analysis are needed?	s-m
13		☑	☑	Potential (also far-reaching) social effects and their analysis	What opportunities does remote driving offer for the establishment of new forms of mobility, e.g. in rural areas?	s-m
14	☑	☑	☑	Thematic and strategic objectives and focal points of a social dialogue and its design	Which narrative is best suited as preparation for a successful introduction of the technology?	s
15	☑	☑	☑	Thematic and strategic goals and focal points of a social dialogue and its design	What is the best way to convey an image of a teleoperator and what role does it play in the acceptance of the technology?	s-m
16	☑	☑	☑	Thematic and strategic goals and focal points of a social dialogue and its design	What should a social dialogue on teleoperation look like?	s-m
17	☑	☑	☑	Introduction strategies, obstacles and factors promoting market penetration (diffusion) of the technology	What introduction strategies are conceivable and what obstacles and favourable factors can be identified for the market penetration (diffusion) of the technology?	m
18	☑	☑	☑	Introduction strategies, obstacles and factors promoting market penetration (diffusion) of the technology	What does a cost-benefit analysis look like for society?	m
19	☑	☑	☑	Introduction strategies, obstacles and factors	To what extent is teleoperation a strategy for compensating for (and acknowledging; temporary)	l

No.	Case A	Case B	Case C	Reference	Research question	Temporal prioritization
				promoting market penetration (diffusion) of the technology	technical shortcomings of autonomous driving? To what extent can it be an enabler of new business models for car sharing?	
20	☑	☑	☑	Introduction strategies, obstacles and factors promoting market penetration (diffusion) of the technology	To what extent does the market penetration process of teleoperation differ from that of autonomous driving or the combination of the two?	l
21			☑	Introduction strategies, obstacles and factors promoting market penetration (diffusion) of the technology	How can a decision be made in high-risk situations as to whether execution of the driving task by a remote driver or by an ADS (of Level 4 /Level 5) poses less of a risk to passengers?	l

Legend: Case A: remote assistance, Case B: Continuous remote driving, Case C: Event-based remote driving. The temporal prioritization is labelled s=short-term, m=mid-term and l=long-term.

4.5.1 Introduction

The introduction of any technology brings opportunities for society, but also bears risks. Furthermore, especially in the initial phase of introducing technology into the immediate lives of citizens, reservations are to be expected among some of the potential users and in the society as a whole. This also applies to teleoperation.

Analysing the societal aspects of a technology in terms of its potential to solve societal challenges, the factors for its (far-reaching) adoption or diffusion as well as the reflection on and discussion of the potential impact of the technology on society is a central component of modern innovation activities by those involved in scientific, economic and political innovation. Studies in this area make a significant contribution to ensuring safe development and operation in line with social needs, can accelerate the market penetration process and identify innovation conflicts at an early stage and - assuming appropriate action - reduce or eliminate difficulties.

The considered societal aspects are diverse.

Firstly, in addition to the technical or objective risk and safety of the technology, the safety of teleoperation as *subjectively* perceived by potential users and other parts of civil society is crucial for the technology's acceptance in society. In this context, the question arises as to conditions under which the technology will be perceived or evaluated as *safe enough*, what tolerances are to be expected, and what implications do findings about society's requirements on safety of the technology, on the development of the technology and on communication about the performance and limits of the technology in society have.

Secondly, the question arises as to what added value for potential individual users and for society is to be expected from the technology and what role this plays in facilitating social acceptance of the technology. Teleoperation has the potential to make road transport overall safer, to offer a solution to problems such as a shortage of professional drivers or to be a basis for more ecologically sustainable mobility alternatives in the transport sector. At the same time - when we focus on the issue of shortage of professional drivers - it is to be expected that only a small group of users will benefit directly from the use of the technology during the introductory phase. In order for the technology to be accepted by the society as a whole, it may be necessary to gain insights into problems of society as a whole and societal needs of individuals and societal groups who are directly or indirectly affected by the technology without directly benefiting from the technology (e.g. other road users).

Thirdly, teleoperation potentially creates new job profiles. Linked to this are the topics of job profiles' and work design, workplace design and societal requirements and expectations in relation to these.

Fourthly, and beyond the aspects mentioned above, the question arises as to what framework conditions need to be created to enable the introduction and successful market penetration of the technology and to unfold its potential.

Beyond all aspects, the question arises as to what parallels there are with SAE Level 4 driving automation and what differences and similarities can be identified between the two technological developments regarding research into social implications and factors that affect the acceptance conditions.

Fifthly, there is the explicit question of what measurable influence teleoperation will have on road safety and how it will "get along" with other types of vehicle motion control (human, driving automation system) in mixed traffic. This also includes questions about the best possible introduction strategies for teleoperated driving. In general, a toolbox needs to be developed that makes the effects before and after the new technology's introduction measurable and allows to draw conclusions. For example, simulation environments and validated behavioural models of drivers must be created, without which it will not be possible to make a prospective statement on the impact on road safety. Furthermore, although accident and traffic data collected in a timely manner are still necessary and useful, they come too late for implementation strategies etc. In general, there are synergies with all facets of automated and connected driving, and the question of where teleoperation fits in/can be found in already established processes.

Against this background, various research topics are formulated in this cluster, including the societal requirements and effects of the presented use cases.

4.5.2 State of knowledge

"Acceptance" (of technology) is a term frequently used in scientific and public debate, but unfortunately often defined in different ways or given different, more intuitively constructed meanings. Probably the most widespread interpretation is to understand acceptance as the (positive) attitude of individuals towards a technology or as the willingness of individuals to use a technology (special case: to purchase).

In certain constellations, such a perspective also provides useful insights and is comparatively easy to analyse empirically. However, for a systematic analysis of adoption or diffusion processes in socio-technical systems (STS) - and the mobility system can be regarded as such - it quickly reaches its limits. For example, it has long been known that attitudes towards a technology or *ex ante* stated willingness to use a technology can only to a limited extent serve as predictors of actual technology use (Bhattacherjee & Sanford, 2009; e.g.: despite a positive attitude, a technology is not used because it is de facto unavailable to the person due to economic or spatio-temporal conditions; despite a rather sceptical attitude, a technology is nevertheless used because individual non-use would be associated with the risk of social exclusion). Technology-related attitudes are not only directed at a technology itself, they are also repeatedly linked to ideas about the role and relevance of this technology in "imaginaries" of socio-technical futures and their individual evaluation (Fleischer et al., 2022). Furthermore, in contrast to simple consumer goods, the possibility of shaping diffusion conditions for technical innovations in STS is generally not in the hands of one or a few innovation parties. Rather, it requires the coordinated co-operation of parties from different societal spheres. This coordination itself is challenging and - due to the roles involved – laden with controversy (Meyer, 2016). It is further complicated by the fact that these parties have their own, different but nevertheless specific ideas of what might be acceptable for their interaction partners.

A further challenge arises from the expectation of being able to take assumed technology acceptance (in the sense of the above-mentioned understanding of the term) into account as early as the design and development phase of new technologies. Prospective anticipatory approaches should be used to find out whether and in what "form" a technology would actually be accepted in order to derive a design framework or a kind of requirement specification for developers. The fulfilment of such expectations faces far-reaching methodological and conceptual difficulties (including high complexity (see above) as well as a lack of predictability or extrapolability of acceptance behaviour, situational and temporal instability of technology acceptance, impossibility of consistent aggregation of preference structures (Gloede, 1987; Grunwald, 2005). In the course of the so-called "procedural turn", parts of research and development practice (Simonis, 1999) turned to more participation-orientated procedures. Nevertheless, even today there is still the regular hope that technology-related controversies and conflicts (a second interpretation of technology acceptance, here in the sense of its absence) can be avoided or pacified in this way. Corresponding research can provide valuable information for technology development, policy-making and regulatory design - but it is no guarantee of rapid, uncontroversial and resistance-free adoption and diffusion processes.

With these fundamental considerations in mind, the aim of this chapter is to present general research topics in relation to societal aspects, acceptance and (above all perceived and expected) road safety in teleoperation and to develop specific questions on the respective research topic.

4.5.3 Research questions of cluster 5

Societal issues relating to the development, introduction and use of the technology are discussed across all use cases. Application-specific assumptions and their implications are addressed at the relevant passages.

1.1.1.41 Determinants of individual acceptance of teleoperation in general

If teleoperation is considered from the user's point of view, the investigations focus on which factors (benefits and barriers) influence the willingness to use the technology and to what extent they do so.

What factors influence individual acceptance of teleoperation in general?

#short and mid-term

Acceptance research generally considers a total of three groups of factors that influence the willingness of potential users to utilise a technology: Individual characteristics (e.g. socio-demographics, individual experiences with similar technology, risk attitudes etc.), technology-related characteristics (e.g. perceived benefits such as efficiency, convenience etc., barriers to acceptance such as perceived risk or high complexity of the technology etc.) and context-specific characteristics. The latter include, for example, the geographical context in which the technology is used, the specific area of application of a technology (e.g. motorway travel or type of mobility service (individual vehicle use, sharing, collective transport)) or normative ideas about a "good" transport and mobility system.

It is necessary to analyse which specific acceptance conditions and influencing factors can be identified for remote assistance and remote driving and to what extent these differ between the three application scenarios.

Does the option of teleoperation by a human teleoperator increase the acceptance of autonomous systems?

#short and mid-term

Previous studies in the field of acceptance research into autonomous driving have focussed on potential users' perception of the technology and its characteristics. In the case of remote assistance, the possibility or necessity of a human being exerting influence brings with it an additional level of consideration: it is not only a question of analysing trust in the technology, but also trust in another person or in the reliability of the cooperation between human and machine, which is not under the user's control. The question that arises here is to what extent the possibility of human remote assistance in autonomous driving influences acceptance of the system.

Similarly, for event-based remote driving, the question can be asked as to how the acceptance of the autonomous system changes if there is a human fallback level that can take over the entire vehicle motion control. Do people trust a human more than a machine? Does the result also apply in critical cases? To what extent are human errors more likely to be forgiven than those of a machine (see also the topic of risk perception and safety)? At this point, the question also arises as to what distribution between autonomous driving (or entire driving executed task by the ADS) and remote driving is desirable or acceptable for users and society. Is it possible to derive a minimum requirement (e.g. at least 60% by ADS)?

How does the use of remote driving in mixed traffic influence its acceptance, in this case especially in view of the greater complexity of a road user's interaction with a mixture of different technologies (teleoperation, in-vehicle human driver, driving automation system) in this case?

#mid-term

Assuming that different application scenarios of teleoperation and autonomous driving are introduced on the road, it is to be expected that there will be mixed traffic over a longer period of time. This poses challenges in terms of communication between the different road users, especially if it is assumed that they will have different driving behaviours and types of communication with other road users. Assuming that the complexity of interaction between road users increases, the following questions arise:

How will teleoperation change communication behaviour and traffic patterns?

How complex can/should the interaction and the mental model for interacting with different other road users be? To what extent will this complexity have a negative impact on the acceptance of the technology? (see also topic *impact*).

What requirements for the design of communication between individuals and teleoperated vehicles result from the analysis of the acceptance conditions?

#short-term

It can be expected that the complexity of the interaction between different road users will increase due to the growing number of types of vehicles (e.g. teleoperated, ADS-driven etc.). At the same time, communication between the user and the teleoperated vehicle (incl. teleoperator) as well as non-teleoperation-using road users in the vicinity of the vehicle with the vehicle and the teleoperator must also be redesigned. Successful communication between road users is, on the one hand, an important condition for safe mixed traffic and, on the other hand, an important condition for the acceptance of the technology. This raises the following research questions:

- What communication needs arise between individuals (persons using teleoperation or other road users) and a teleoperated vehicle? What form and type of communication (audio, video, chatbot for general questions etc.) is necessary, suitable and/or desired? These questions relate to both internal and external human-machine interfaces.
- What constitutes high quality communication between road users and teleoperated vehicles and how can this be ensured?
- To what extent should or must teleoperated vehicles be labelled? Would the labelling concern the vehicle itself and/or also the respective area of operation? What forms of labelling would be suitable?
- To what extent should the communication interfaces between road users (inside and outside the vehicle) and the remote assistant/remote driver be created? How should these be designed?

Is acceptance altered by remote drivers' takeover of vehicle motion control if this influences the traffic flow?

#short-term

Under certain circumstances, remote driving can change previously known and "practised" patterns of traffic flow. For example, the following situation could occur in the course of a safer takeover by the remote driver: The system of a teleoperable vehicle has to hand over to the remote driver and reduces its speed ("on-the-fly") to increase safety and stops at the roadside. The remote driver then takes over and continues driving the vehicle. In this context, the question arises as to what extent the vehicle's behaviour influences users' and other road users' acceptance of the technology, and also what discrepancies arise between expected and actual behaviour of vehicles.

This also raises the question of what additional waiting times and changed speeds will be accepted by the environment and users. A comparison can be made with movement planning in ADS-driven vehicles, in which, according to Nolte et al. (2018) one difficulty is to design vehicles' movement in such a way that it is safe for the travellers/passengers, but at the same time not too irritating.

1.1.1.42 Determinants of perceived safety and perceived risk and their implications

Perceived risk is an important factor influencing acceptance of new technology by users in general. The objectively measured or proven risk or safety of the technology can differ greatly from the safety perception of the technology's users or the perceived risk. Due to the importance of the topic of safety, it is reasonable and necessary to consider the relationship between functional and perceived safety separately and in a more differentiated manner.

What factors influence users' perceived safety/security?

#short-term

Initial hypotheses regarding potential factors that influence the perceived safety and perceived risk of technology can be derived from findings in the field of risk perception research. For example, the perceived controllability of the risk plays an important role: if people have the impression that they can control the outcome of a situation in which a risk arises (e.g. when driving manually), they rate the risk as lower (e.g. Slovic, 1988; Ropeik, 2002). In addition, numerous examples of socio-demographic effects (such as those related to age or education) have been proven in technology acceptance research, which can also be plausibly assumed for teleoperation, but which nevertheless require case-specific empirical evidence in order to be considered reliable. Questions in this area are therefore:

- How do people or certain groups of people assess the risk or safety/security of teleoperation?
- What factors influence the risk perception of people who interact with such vehicles as non-users in their everyday traffic?
- What implications for the design of teleoperation can be derived from the findings on factors influencing risk perception?

What factors influence the perceived safety of other road users?

#short-term

Risk perception in society has also been analysed extensively in the literature. In addition to the factors that determine technology users' individual risk perception, future studies should also analyse the determinants of risk perception and the evaluation of technology in society as a whole.

How does trust in a remote driver differ from trust in an ADS of Level 4 or Level 5?

#mid-term

Previous studies on automated driving have shown that trust in the technology is an important factor influencing acceptance of the technology. The questions related to this topic are:

- To what extent does trust in the technology differ from trust in the remote driver as a human fallback level (or in the overall teleoperation system consisting of the communication system in the vehicle and the remote driver)?
- To what extent are potentially very rare accidents involving teleoperated vehicles accepted?

1.1.1.43 Potential (also far-reaching) social impacts and their analysis

What is the societal added value of teleoperation?

#short-term

To what extent, for example, does enabling new services, creating new jobs and convenience play a role?

What opportunities arise from teleoperation for change in professions and in terms of shortage of skilled labour?

#short-term

- What new job profiles are being created by the introduction of technology? ("Home office" for professional drivers? Will gaming experience be more attractive than it is today? Are new technical professions emerging at technical services or similar employers?). New questions about testing procedures may also arise.
- What new job profiles are emerging?
- To what extent can teleoperation make the job of a truck driver more attractive?

What costs and risks can be expected with the introduction and use of teleoperation?

#short-term

- How expensive will the infrastructure for teleoperators be? Who bears the costs?
- How high is the risk of misuse of teleoperated vehicles?

Which methods are suitable for analysing the potential impact of technology on society? Which (new) analysis methods for effects analysis are needed?

#short and mid-term

- Are there prospective tools for estimating the impact on road safety and for deriving appropriate implementation strategies? Can existing instruments be used or is there a need for case-specific adaptation?
- How can the impact of teleoperation on road safety be measured?

- How can simulated environments and behavioural models of drivers be used to make prospective assessments?
- Which KPIs must be met to release the next implementation level?
- How must the existing in-depth accident data analysis (e.g. GIDAS) be adapted in order to be able to retrospectively measure the road safety effects of teleoperation (Courier, express and parcel)?

What opportunities does remote driving offer for the establishment of new forms of mobility, e.g. in rural areas?

#short and mid-term

- To what extent can a broad diffusion of teleoperated vehicles or the transport services based on them be expected to change the mobility behaviour of other road users?
- For example, to what extent would non-motorised road users feel less safe if there were more vehicles without occupants (remotely driven vehicles) on the roads?
- Would remote driving also have an influence on existing and new forms of goods transport, for example in the area of so-called CEP services or for city logistics?

1.1.1.44 The thematic and strategic objectives and priorities of a social dialogue and its design

Since the 1980s, dialogue-based or participatory processes involving citizens and stakeholders have increasingly become an established instrument in policy advice and innovation support for - at least anticipated - controversial technologies. Above all, they serve to include different values, interests and perspectives, but also additional bodies of knowledge, and thus have a legitimising and epistemological function (Grunwald, 2019). Transparency, connectivity and - ideally - the integration of different considerations and evaluations can contribute to the social legitimisation of results and the decisions based on them, and can also make results more epistemologically robust by drawing on the knowledge of local and/or non-scientific stakeholders (Grunwald & Saretzki, 2020). The organisation of a social dialogue could also be considered for a broad introduction of teleoperation. Similar to the context of automated and connected driving, its task would be, among other things, to develop a common vision for the use of the technology, or to identify and negotiate conditions for its use that are acceptable to all, while taking different demands into account.

Which narrative is best suited as preparation for a successful introduction of the technology?

#short-term

To date, the following narrative has prevailed for automated driving as a new technology in the transport sector: The potential to increase safety, comfort and efficiency in transport are main drivers behind the technology's introduction. Teleoperation therefore raises the following questions:

- What stories or convincing narratives about the introduction of remote assistance and remote driving currently exist and which can favour a successful introduction of the technology? What is the introduction narrative? What resonance does it have among the population?
- What is the easiest way to communicate the differences and similarities between the application scenarios?
- How can the link to autonomous driving be established? Should the technology be seen as a substitute, supplement or parallel development? Is there a need to differentiate between vehicles operated by an ADS of Level 4 or Level 5, or by teleoperation (especially vehicles without drivers and passengers)?
- What is the easiest way to communicate the topic of ODD to society?
- What can realistic expectation management or communication management for teleoperation look like? (Assumption: "People notice when they are presented with overly optimistic forecasts.")
- To what extent does it help with the acceptance of the technology if the lack of drivers is integrated into the debate as an argument? (e.g. "We need truck drivers and certain application scenarios can be a solution to the shortage of drivers.")

What is the best way to convey an image of a teleoperator and what role does it play in the acceptance of the technology?

#short and mid-term

- To what extent is it conducive to acceptance to create transparency about the work and tasks of a teleoperator?
- How can the new job profiles of a remote assistant or remote driver be positioned in society? To what extent can this promote acceptance and market penetration? To what extent can this contribute to the recruitment of skilled labour in this area?

What should a societal dialogue on teleoperation look like?

#short and mid-term

- How can a common vision for teleoperation be developed by societal dialogue?
- What are the differences, similarities and overlaps between the societal dialogue on autonomous driving and the dialogue on teleoperation?
- What implications for public communication (specialist public and general public) result from the analyses of the conditions of acceptance of the technology?
- How can a joint learning process be shaped by communication and dialogue?

1.1.1.45 *Introduction strategies, obstacles and factors promoting market penetration (diffusion) of the technology*

This subject area bundles open questions on implementation strategies for the various application scenarios and questions related to the implementation process.

What introduction strategies are conceivable and what obstacles and favourable factors can be identified for the market penetration (diffusion) of the technology?

#mid-term

To what extent does the market penetration process of teleoperation differ from that of autonomous driving or the combination of the two?

#long-term

- How are the questions related to the "private car" and "Mobility as a Service" (MaaS) application scenario?

To what extent is teleoperation a strategy for compensating for (and acknowledging; at least temporarily) the technical shortcomings of autonomous driving? To what extent can it be an enabler of new business models for car sharing?

#long-term

- Should teleoperation be seen as a bridging technology? Are we integrating an "immature" solution into another "immature" solution? Where are difficulties added, where are difficulties subtracted?
- What knowledge do we have a priori and what do we need to learn in the process of development and implementation?
- How much experimentation and social learning about teleoperation (and autonomous driving) does society want and allow?
- Is there a chronological order for the introduction of different teleoperation use cases?
- To what extent does a gradual introduction of the technology make sense in order not to jeopardise road safety?
- To what extent would a maximum penetration rate need to be introduced (if, for example, the ODD can only tolerate 5% of vehicles operated by remote driving). This is not only relevant from a technical point of view, but also from a societal perspective.

What does a cost-benefit analysis look like for society?

#mid-term

- To what extent would society (and in particular affected residents and other road users) be content to accept the potential risks of teleoperation if only a few social stakeholders or a small proportion of the population can benefit directly from the technology at the start of its introduction (e.g. in the context of delivery services, users of on-demand mobility services)?

- How can a society be prepared to deal with risk? What is an acceptable risk? How can an acceptable risk be visualised? (A comparison can be made here with airline pilots and flight systems, where data on accident rates over the years is available and changes resulting from improvements of the system can be visualised).

How can a decision be made in high-risk situations as to whether execution of the driving task by a remote driver or by an ADS (of Level 4/ Level 5) poses less of a risk to passengers?

#long-term

Assuming that event-based remote driving is intended to complement the ODD of the Level 4 or Level 5 ADS, and that a remote driver performs the driving task when the ADS (of Level 4 or Level 5) is no longer able to perform it, situations may arise in which there is an inherent risk in which harm to passengers cannot be ruled out. This can be illustrated by the defect of a sensor, as a result of which the remote driver can still move the vehicle, but the Level 4 / Level 5 ADS cannot perform the driving task. First, the question arises as to whether, in such a case, moving the vehicle with the help of the remote driver represents a lower risk than the vehicle remaining stationary. Second, the question arises as to whether the requirements for vehicle movement by a remote driver are also met if a sensor is defective. More abstractly, the question arises as to how risks between teleoperation and ADS (of Level 4 / Level 5) are to be compared.

4.5.4 Conclusion on Cluster 5

Overall, it should be noted that the introduction of teleoperation, as with the introduction of any new technology, raises a number of questions with regard to its societal added value and risks.

Many of the questions have already been addressed in the context of automated and connected driving (e.g. on acceptance conditions and the design of a social dialogue to resolve conflicting goals in the development and introduction of the technology). At the same time, the complexity of teleoperation is increased by the additional (human) instance in vehicle operation or support (namely the teleoperator). In particular, the question arises as to how individuals and society deal with potential errors caused by humans "from a distance" (in teleoperation) compared to errors caused by an ADS (in autonomous driving). In addition, a number of questions arise in relation to society's demands on teleoperation as a system and teleoperators as an important part of this system.

It should also be noted that although there are parallels in the research topics of remote assistance or remote driving and autonomous and connected driving, the state of knowledge is much more pronounced in the context of autonomous driving than in the area of teleoperation due to a significantly higher number of studies.

5 Cross-cluster research questions

Compilation by: Dr. Alexander Frey

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Each cluster on its own and in combination with others has an influence on road safety. The (predicted) road safety, in turn, is a kind of quality criterion for the holistic system evaluation, which runs like a common thread through all clusters. Ultimately, the holistic system should be kept "in balance". The idea of this chapter is therefore to show cluster connections on the basis of selected research questions. Where previously the focus was on each cluster with its specific topics, the aim here is to provide space for topics and research questions in order to identify connections, dependencies, stabilising and destabilising factors for the system as a whole. The following cross-cluster research questions are sorted according to their research priority in the same way as those raised above. In addition, the clusters affected in terms of content and the meaningful applicability to the previously defined use cases of teleoperation (assisted (A), continuous remote driving (B), event-based remote driving (C)) are indicated. Table 11 lists all cross-cluster research questions.

Table 11: Cross-cluster research questions including prioritisation in terms of time

Nr.	Case A	Case B	Case C	Research question	Temporal pri-oriti-zation
1		☑	☑	What are the requirements for transmitting data from the vehicle to the teleoperator for better support?	k
2		☑	☑	What are the human effects of increased latency and jitter, changes in latency, and/or reduced fidelity?	k
3	☑	☑	☑	What data can be transferred in the "overall teleoperation system"?	k
4	☑	☑	☑	What data does the teleoperator need and in which quality? What gradation, what prioritisation is there? Does this depend on the use case or the speed?	k
5	☑	☑	☑	What are the effects of latency etc. on the teleoperator? How high is the mental workload?	k
6	☑	☑	☑	What are the requirements for teleoperator monitoring in the workstation?	k
7		☑	☑	How to deal with an emergency of the teleoperator (e.g. heart attack)?	k

Nr.	Case A	Case B	Case C	Research question	Temporal pri-oriti-zation
8		☑	☑	How must the minimal-risk manoeuvre be desig-ned?	k
9	☑	☑	☑	What framework conditions need to be considered when analysing tasks and requirements for tele-operators?	k
10		☑	☑	What is the basis for the decision to define an area of operation for remote driving?	k
11	☑	☑	☑	To what extent is it necessary to communicate the workplace of teleoperators and other relevant wor-king conditions (e.g. safety standards and responsi-bilities) to society?	k
12	☑	☑	☑	Do remotely assisted and remotely driven vehicles have to be labelled and, if so, what should the ve-hicle labelling look like?	k
13	☑	☑	☑	Which role does teleoperation play in the gradual market launch of autonomous vehicles?	m
14		☑	☑	Can a remote driver indicate when it is safe to hand over the vehicle to a computer?	m
15			☑	What does a potential control switch look like? In terms of road safety, should this be carried out while driving ("on the fly") or at standstill? Is a combination of both conceivable or is it dependent on the environment?	m
16	☑	☑	☑	How should the job profile of a teleoperator be communicated in society and what role does the communication of the job profile of a teleoperator play?	m
17	☑	☑	☑	To what extent should requirements for the exper-tise of teleoperators be communicated to society and what additional requirements of society are to be expected for the expertise of teleoperators?	m
18	☑	☑	☑	To what extent does the place of work of teleope-rators (Germany vs. abroad) influence the accep-tance of remote assistance and remote driving in society?	m
19	☑	☑	☑	What are the requirements for training teleopera-tors and what are the requirements for checking the status of a teleoperator on a daily basis, parti-cularly with regard to potential edge cases/emergencies or exceptional situations?	m
20	☑	☑	☑	To what extent is communication between the te-leoperator and non-motorised road users neces-sary, and in what situations and in what way? To what extent does such communication contribute to greater acceptance of the technology?	m

Nr.	Case A	Case B	Case C	Research question	Temporal pri-oriti-zation
21		☑	☑	How should the interfaces between teleoperation and other systems be designed?	l
22		☑	☑	Can functions of teleoperation be distributed across different subsystems or be centralised?	l

Legend: Case A: remote assistance, Case B: Continuous remote driving, Case C: Event-based remote driving. The temporal prioritization is labelled s=short-term, m=mid-term and l=long-term.

5.1 Short-term research questions

1. **What are the requirements for transmitting data from the vehicle to the teleoperator for better support?**

Cluster: 1, 2, 3, 4

Use cases: B, C

It makes sense to offer the remote driver an impression of the driving situation as realistically as possible. Aspects such as image and sound quality, but also frame rate, latency and reliability play a role here. However, there are two ways to deviate from this realistic impression: On the one hand, the communication channel may make it necessary to use more abstract representations than in reality. On the other hand, the large number of sensors in a modern vehicle means that much more information is available than a simple image can communicate - such as the relative speed of other road users or the scenery behind visual obstacles (raindrops, vegetation). However, the effects of such information abstraction, scarcity or abundance are largely unexplored.

2. **What are the human effects of increased latency and jitter, changes in latency, and/or reduced fidelity?**

Cluster: 2, 3, 4

Use cases: B, C

While the technical effects of poor radio communication (and in particular variable quality) are well known in communications technology, the same cannot be said without qualification for the effects on teleoperators. This is true even for short journeys, but even more so for longer or repeated journeys over the course of a working day.

3. **What data can be transferred in the "overall teleoperation system"?**

Cluster: 1, 2, 3, 4

Use cases: A, B, C

The aim here is to clarify which data can be technically transmitted at all. For example, how reliably can the currently prevailing latency be made available for a teleoperator?

What restrictions are raised with regard to driving dynamics? There may also be differences between different TO providers, which can occur when switching one teleoperator between several workstations and when changing vehicles.

4. **What data does the teleoperator need and in which quality? What gradation, what prioritisation is there? Does this depend on the use case or the speed?**

Cluster: 1, 2, 3, 4

Use cases: A, B, C

If it is necessary to deviate from the optimum of the data to be transmitted, the question arises as to which data must be transmitted in which quality. For example, a high-resolution image with high latency may be worse than a low-resolution image with low latency. This must also be considered against the background of different applications and driving situations.

5. **What are the effects of latency etc. on the teleoperator? How high is the mental workload?**

Cluster: 2, 3, 4

Use cases: A, B, C

In addition to the quality of experience in terms of the performance of the system, the less technical aspect of quality metrics with regard to the workload on the teleoperator is of particular importance.

It is conceivable, for example, that teleoperators can largely get used to higher latencies, but not to higher jitter.

6. **What are the requirements for teleoperator monitoring in the workstation?**

Cluster: 1, 2, 3, 4

Use cases: A, B, C

This concerns, for example, the technical detection of distraction and fatigue. It may also be necessary to provide a human fallback level, in the sense of supervision at the workstation, and the teleoperation staff must be adequately equipped.

7. **How to deal with an emergency of the teleoperator (e.g. heart attack)?**

Cluster: 1, 2, 4, 5

Use cases: B, C

In principle, technical solutions such as the use of a "next generation e-call" are conceivable. However, this issue must also be examined in a social dialogue.

8. **How must the minimal-risk manoeuvre be designed?**

Cluster: 1, 2, 3, 4, 5

Use cases: B, C

A minimal-risk manoeuvre will probably be used in the event of disconnections or if the remote driver is unavailable (possibly for health reasons). In any case, a critical situation arises for road safety; the situation must be resolved in the best possible way. For example, is stopping in the lane preferable to stopping on the right-hand side of the carriageway in certain situations? Socially accepted behaviour can also play a role here.

9. **What framework conditions need to be considered when analysing tasks and requirements for teleoperators?**

Cluster: 1, 2, 3, 4, 5

Use cases: A, B, C

Here it is important to consider the fit between person and task on the one hand and the fit between person and environment on the other. Which qualification is required for which job profile? Training and further education as well as the organisation of training courses are also based on this.

10. **What is the basis for the decision to define an area of operation for remote driving?**

Cluster: 1, 2, 3, 4, 5

Use cases: B, C

Network coverage will probably play a decisive role here. But different TO use cases can also have an influence. Last but not least, the designation of an area of operation for remote driving can be significantly influenced by social acceptance.

11. **To what extent is it necessary to communicate the workplace of teleoperators and other relevant working conditions (e.g. safety standards and responsibilities) to society?**

Cluster: 2, 5

Use cases: A, B, C

Other socially relevant questions also arise in connection with responsibility, such as

- To what extent is the handling of a situation different when teleoperated/digitally controlled vs. on site (responsibility from a distance, mental workload from a distance; e.g. risk of injury as a driver)?
- Liability issues? Dealing with guilt? Personal responsibility and responsibility of employers if teleoperated? Do the same responsibility requirements apply to teleoperation compared with drivers in a vehicle?

12. **Do remotely assisted and remotely driven vehicles have to be labelled and, if so, what should the vehicle labelling look like?**

Cluster 1, 2, 4, 5

Use cases: A, B, C

- How must the vehicles be labelled so that it is known that the vehicle is being teleoperated (visible to outsiders)?
- Should it be possible for outsiders to contact the teleoperator (additional requirements for teleoperators)?

5.2 Mid-term research questions

13. Which role does teleoperation play in the gradual market launch of autonomous vehicles?

Cluster: 1, 5

Use cases: A, B, C

Teleoperation is a mandatory part of an autonomous vehicle and there is an assumption that their ODD can complement the ODD of the autonomous driving function. It could therefore represent a function that has a major influence on mission fulfilment. There is also the assumption and research question of whether teleoperation can increase confidence in autonomous vehicles.

Based on these two assumptions, the research question can be raised as to whether and what role teleoperation plays in the gradual market launch of autonomous vehicles.

14. Can a remote driver indicate when it is safe to hand over the vehicle to a computer?

Cluster: 2, 4

Use cases: B, C

The decision to hand over control of an autonomous vehicle to a human is usually made on the basis of a combination of factors and has been well researched. The reverse decision has received less attention to date.

15. What does a potential control switch look like? In terms of road safety, should this be carried out while driving ("on the fly") or at standstill? Is a combination of both conceivable or is it dependent on the environment?

Cluster: 1, 2, 3, 4, 5

Use cases: C

A switch during standstill has different technical and human requirements than a switch while travelling. Such considerations could also depend on the current driving situation or environment, such as speed or the number of road users. Mixed traffic consisting of manually operated, autonomous and remote driven vehicles could also play a special role here. The previous involvement period of the teleoperator may be a decisive parameter.

16. How should the job profile of a teleoperator be communicated in society and what role does the communication of the job profile of a teleoperator play?

Cluster: 2, 5

Use cases: A, B, C

When developing tasks and requirements for the teleoperator, the question arises as to what extent and which aspects of this job profile should be communicated to society in order to promote acceptance of mobility services based on teleoperation among potential users and those affected. This can also make the job attractive to potential employees. Specifically, the following questions can be derived:

- To what extent should society be made aware of what jobs and the work and tasks of remote assistance/remote drivers look like? What effects can this have on the acceptance of the technology and the profession in society?
- To what extent does this help to make the job more attractive to potential employees?
- What is the profile of a teleoperator (the "image" of it) that prevails in society?
- The potential of teleoperation as a narrative in society: What added value can be seen in teleoperation and what are the main reasons for introducing or using teleoperation on the roads?

17. To what extent should requirements for the expertise of teleoperators be communicated to society and what additional requirements of society are to be expected for the expertise of teleoperators?

Cluster: 4, 5

Use cases: A, B, C

- To what extent should the requirements for the teleoperator be communicated in society?

At this point, emphasis should be placed on safety, but also a realistic idea of what a teleoperator should achieve and what competences are required for this. It can be assumed that an iterative development of the image of a teleoperator in society will be necessary. For example, do people expect "air traffic controllers" or are lower or possibly completely different requirements/qualifications required?

- What should be communicated to society and how should teleoperation be presented to the public so that people can evaluate it?
- What is the socially accepted threshold of expertise for a teleoperator?
- Do the expectations of experts and society differ with regard to fitness to drive?
- What weighs more heavily in the evaluation of a teleoperator or an evaluation of teleoperated vehicles and mobility services by society: training and skills of the teleoperators or the equipment and how teleoperation works technically and operationally? What are the ideas, expectations and reservations in this regard?
- How could it be ensured that teleoperators have the same sense of responsibility as drivers on the road? What character traits can ensure that teleoperators always act responsibly?

18. To what extent does the place of work of teleoperators (Germany vs. abroad) influence the acceptance of remote assistance and remote driving in society?

Cluster: 2, 3, 4, 5

Use cases: A, B, C

Various aspects can play a role here, for example to what extent does the transport culture of the country in which the teleoperators are employed (if outside Germany) differ from the transport culture in Germany? To what extent are teleoperators less affected if they have no emotional connection to the country in which they drive the vehicles? The question also arises as to how, in this case, the monitoring of the teleoperator (ability, suitability, fitness to drive while driving the vehicle etc.) is ensured if the teleoperator is based outside Germany?

19. What are the requirements for training teleoperators and what are the requirements for checking the status of a teleoperator on a daily basis, particularly with regard to potential edge cases/emergencies or exceptional situations?

Cluster: 3, 4

Use cases: A, B, C

In addition to daily tasks, responsibilities and knowledge, the training of teleoperators will probably also include additional training(s) to prepare for exceptional situations. For example, to enable teleoperators to initiate appropriate preventive measures in the event of potential network disruptions ("dead spots") on the route, there is a need to anchor the handling of such situations in the overall training concept, not only in the basic training, but also in short-term, daily instructions for special situations. This also raises the question: What procedures should the teleoperator be familiar with?

To ensure safe operation, it is also necessary to analyse which daily inspections/check-ups are required and what information is needed as a result. It is assumed that the deployment of a teleoperator starts with a query as to whether he/she can expect any special features for the route or the area of deployment. The availability of real-time information and a comprehensive, up-to-date database on network coverage is a prerequisite for carrying out daily check-ups of the route. Daily check-ups not only focus on the teleoperator himself or herself (e.g. fitness to drive during the journey: fatigue, alcohol, drugs etc.), but also on the teleoperated vehicle (e.g. truck: load safety etc.).

20. To what extent is communication between the teleoperator and non-motorised road users necessary, and in what situations and in what way? To what extent does such communication contribute to greater acceptance of the technology?

Cluster: 1, 2, 5

Use cases: A, B, C

This question relates to analysing the requirements from affected persons on the teleoperation and the extent to which a communication option would increase acceptance of the technology. The answer to this question has direct implications for the design of the technology on the one hand and the requirements for teleoperators on the other. More in-depth questions on various very specific design options are addressed in the corresponding clusters.

5.3 Long-term research questions

21. How should the interfaces between teleoperation and other systems be designed?

Cluster: 1, 2, 3

Use cases: B, C

This involves intermodality, the establishment of ad hoc networks and systems, as well as the inclusion of mobility data (in Germany over the “Mobilithek”). The sharing of resources with regard to data, the transport area as a whole and possible sector coupling is of particular importance here.

22. Can functions of teleoperation be distributed across different subsystems or be centralised?

Cluster: 1, 2, 3

Use cases: B, C

What architectures need to be provided and what role do digital twins play?

6 Conclusion

This report focuses on the need for research in the field of teleoperation of vehicles in public road transport. Three specific use cases were considered: remote assistance as support for autonomous vehicles by adding control recommendations or information, continuous remote driving and event-based remote driving as direct takeovers of the control of vehicles from a distance. With the aim of supporting the safety of autonomous driving and integrating new mobility concepts, new technologies and new forms of control into existing traffic in a usable, safe and efficient manner, research should be structured at an early stage with its requirements. Technology is not at the centre of this. The aim is to enable a complex socio-technical system to be balanced by identifying stabilising and destabilising factors. The relationships and interactions need to be investigated. To analyse the needs of this complex area of research, five basic levels were identified, which structure the content of the report and are labelled as clusters: "Vehicle, area of operation and functional safety", "Ergonomics and occupational safety", "Communication technology", "Driving suitability, skills and personnel requirements" and "Social aspects and road safety". These levels, their specific thematic range and their (complex) interlinking with each other demonstrate the multidimensional character of the research field of teleoperation. Research funding could start here in order to advance the subject area in a correspondingly interdisciplinary and holistic manner. For each level, the state of the art in science and technology was comprehensively analysed on the basis of the three use cases. Based on this, research gaps and requirements were identified by formulating specific and detailed research questions. The review of the current state of research fundamentally revealed how rudimentary the research situation still is in the field of teleoperation in the automotive sector at the time of writing this report.

A total of 174 research questions were identified, which are both specific to individual clusters and cross-cluster. The decisive factor here is that, in addition to a series of individual questions that need to be addressed in the respective research areas, a series of system questions were also identified that are particularly relevant for teleoperated systems due to their high degree of networking. These research questions can best be considered as the interlocking of different influencing and control loops. At the "sharp end" of a teleoperated system, the control loop between the workstation, control centre, teleoperator, communication technology, vehicle and environment must be investigated. A degradation or malfunction of this control loop would lead directly to risks for people and organisations. But there are also influencing and control loops at the "blunt end" of teleoperation, for example for the selection and training of teleoperators or for determining social requirements and establishing acceptance, which must be sufficiently scientifically understood in order to be able to develop, operate and utilise teleoperated systems in a promising manner.

Based on the temporal relevance (long-term, mid-term, short-term), the content was prioritised. Finally, the overall document provides a detailed overview of the current research situation and opens up, structures and encourages future research work.

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