SAFER Pre-studies

Final Report

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VEHICLE AND TRAFFIC SAFETY CENTRE AT CHALMERS

Summary

Currently, most highly automated vehicles still require the presence of a human safety operator in the vehicle, and it is evident that automated driving without human "fallback" might be distant. On the other hand, having a human operator in the vehicle jeopardizes major anticipated benefits of automated driving – productivity. This is especially evident when it comes to heavy automated vehicles. To bridge this gap, stakeholders are exploring teleoperations technology, which enables highly automated vehicles to be remotely operated if necessary. But remote operation comes with its own challenges, both from technical and human behavior perspectives. In this SAFER co-financed prestudy, Scania and RISE have identified potential safety challenges and research gaps related to human behavior in the context of remote operation of heavy automated vehicles.

A general view of the human factors related challenges within the remote operation topic can be summarized by highlighting phenomena such as physical and psychological distancing, screen delays, network latency delays, inefficient interface designs, and human operator's cognitive limitations. These are not exclusive to one single operational level, or application type, and are often interrelated. A larger body of scientific work can be found related to human factors in remote operation in other domains (e.g., robotics, aerial drones, military). Some of the findings from these domains can have value for the automotive domain, however, generally design requirements are not directly transferable between domains as there are domain specific challenges.

An overall conclusion from the prestudy is that human factors in remote operation of highly automated road vehicles have been somewhat neglected by industry and research community. By providing an overall conceptualization of remote operation and its complexity, a theoretical framework, a state of the art overview, and a list of gaps and challenges, the expectation is that this pre-study will stimulate more activities in the area.

HUMAN FACTORS RELATED TO REMOTE CONTROL OF AUTOMATED HEAVY VEHICLES

Authors: Habibovic, A., Andersson, J., Castor, M., Meiby, L. and Rizgary, D.

1. Background

Current questions about automated vehicles (AVs) do not revolve around whether such technologies should or should not be implemented; they are already with us. Rather, such questions are more and more focused on how such technologies will impact evolving transportation systems, our social world, and the individuals who live within it and whether such systems ought to be fully automated or remain under some form of direct human control. It may be that human intervention does not necessarily need to be from inside the vehicle; instead the physical location of the human controller could be remote from the actual vehicle itself.

Regardless of the specific spatial relations between the controller and vehicle, the human operator will require effective situation awareness calibrated to ambient environmental demands at all times because the point at which any such human intervention will be required remains unpredictable as yet. Again, this raises the spectre of prolonged vigilance and its well-known decrement and response failure. This human-as-backup architecture, which removes the person from momentary control and instead places him or her in a supervisory context, in many ways defeats the very idea of automation in the first place. However, it is currently seen as a necessary transition phase, and a way to put automated vehicles on the market in the near future.

During the last five years of the AVs development boom, there has been a growth in the number of commercial companies promoting control concepts and technical solutions for teleoperation which enables more direct human control of heavy road vehicles, although from a remote location, i.e. remote driving. Many concepts and solutions for remote control exist with control targeting different levels of control of a vehicle, as exemplified in Figure 1. In this pre-study, we aim at identifying potential **safety challenges and research gaps related to human factors** in the context of remote control of heavy automated vehicles across these domains.

The pre-study has a quite limited budget (in total 200.000 SEK) and answers to many of the identified research questions remain thus unanswered, and many questions have not yet been formulated. The primary purpose of the report is to identify research questions that can be used as the starting point for new research projects, internal or external to the SAFER consortia.

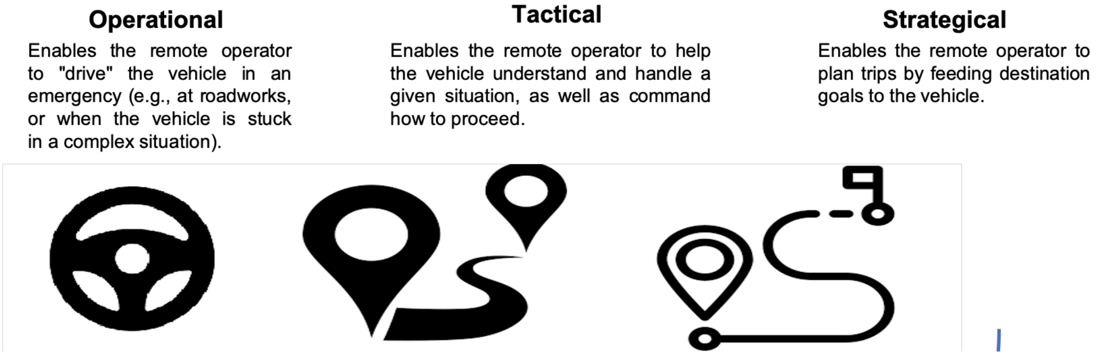

Figure 1. Conceptual sketch of control of a vehicle on different levels.

2. Project set up

2.3 Purpose

Currently, most heavy automated vehicles (HAV) require a human safety operator in the vehicle, and it is evident that HAVs without human "fallback" might be distant. At the same time, having a human safety operator in the vehicle jeopardizes major anticipated benefits of the automated driving – transport efficiency and safety. To bridge this gap, stakeholders are urgently exploring remote operation, which enables several HAVs to be remotely operated by one human operator. But remote operation comes with its own challenges, both from technical and human factors perspectives. In particular, human factor challenges are currently rather unexplored. The purpose of this pre-study is to identify potential safety challenges and research gaps related to human factors in the context of remote control of (heavy) automated vehicles

2.4 Objectives

The overall objective of the pre-study was to gather theoretical and practical experiences and knowledge, both from the area of remote control of automated vehicles and from other domains (e.g., traffic control centres at airports, nuclear power stations, etc.) where remote control has been in use for many years.

The following sub-objectives were envisioned at the start of the pre-study: 1) literature review to identify the state-of-the-art related to human factors and remote control of automated vehicles and remote control in other domains, 2) interviews and workshops with relevant stakeholders, 3) workshops to identify research questions for further research in the context of heavy automated vehicles within a transportation hub as well as between transportation hubs. All these objectives have been addressed as planned.

2.5 Project period

The pre-study has been carried out in the period January-April 2020.

2.6 Partners

The project partners have been Scania and RISE Research Institutes of Sweden. Several other SAFER-partners have participated in workshops and interviews and thereby indirectly supported the project.

3. Method and activities

The following methods were utilized in the prestudy:

- Literature review of the scientific literature, see 7.1
- Web search of relevant commercially available solutions, see 7.2.
- Web search of relevant Swedish and European projects, see 7.3 and 7.4
- Interviews with researchers and developers, see 7.3 and 7.5
- Workshops, see 7.5.

The prestudy was initiated by a review of relevant scientific literature, both specific to automotive applications as well as other domains, as well as a general review of remote driving companies (Figure 2). Concurrent with the literature review, a number of representatives from relevant Swedish research projects was interviewed. The results from this state-of-the-art review was transformed, during the internal WS0 into 50 draft research questions. These 50 questions were then discussed in a larger group with external representatives during WS 1, where the number of research question were limited down to 21, which in turn was discussed during a second workshop with other external experts.

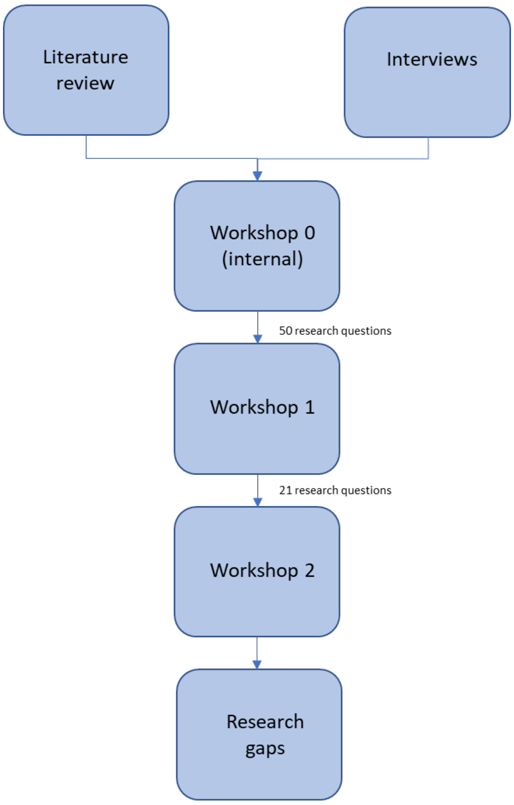

Figure 2. Schematic representation of the approach during the prestudy.

In the literature review, search phrases were divided into *Teleoperation and human factors* and *Teleoperation and human factors related to on-road vehicles*. In total, 19 search phrases were used in five databases/search engines, wherein eight search phrases were used in the first mentioned segment, and eleven search phrases were used in the last-mentioned segment. Choice of search terms were based on our review of focus areas: *human factors*, *automated vehicles* and *teleoperation*. Variations of sub-categories within human factors were used such as "cognition", and variation of related topics to teleoperation was used such as "remote control". Relevant papers and reports were selected from the search results based on title and abstract descriptions. Mainly, paper and reports were selected based on content relevant to human factors and teleoperation, whilst application domain was not restricted. The documents that considered human factors within teleoperation of other domain areas besides automotive, such as military vehicles, space rovers, drones and other robots were also selected, reasoning that best practices can be found in areas that have investigated teleoperation for a longer time. The documents were categorized in a three-step manner firstly based on the review/experimental orientation of the publication, secondly based on relevance categories, i.e. whether they were focused on cognition, HMI, neuroscience, behaviour, or simply more general within human factors. Lastly, they were also categorized based on domain area, i.e. automotive, aerial, maritime, robotics etc.

4. Results and Deliverables

Road traffic presents a complex, ever-changing environment where safety should be the primary concern. The results from our prestudy show that the success of remote operation will, however, be affected by many inter-dependent factors specific to the remote nature of the tasks. For example, challenges related to situational awareness, hand-over, telepresence, and workload might, if not properly accounted for in the design of HMI, lead to risky situations as well as poor experience and work conditions for remote operators.

The deliverables from this prestudy can be summarized in the following way:

- A theoretical framework for remote operation
- Conceptualization of remote operation and its complexity
- Understanding of the current state of the art, as well as understanding of what questions have been (or are being addressed) in related research projects.
- List of challenges and research gaps from a human factors' perspective.
- Established a network among Swedish researchers with interest in the field.
- Developed a knowledge base to be used in continuation research project(s).
- A paper draft is under development.

These results and deliverables are described in more detail in the following sections.

5. Theoretical framework for remote operation

As apparent from the review of the field, research and development concerning remote control is a complex field with many variables that influence design decisions, as is the case in most human factors related projects. This section describes a framework and a model on how the field and remote driving applications could be structured and analysed further.

To characterise remote driving, a system of system approach with emphasis on the interplay between humans, technology and organisation was deliberately chosen. Technology is here used in a broad sense, where it can be seen as both "hard" (i.e. vehicles, infrastructure and control systems) and "soft" (i.e. legislation, regulation) systems (Vicente, 2003). The dimensions in Figure 4 are based on a framework developed for domain comparison (Osvalder et al., 2009), while the "properties" within the circle are items that have emerged throughout the pre-study. The purpose of the figure is not to give an exhaustive list of factors that influence remote driving, but rather with broad strokes aid understanding and paint the canvas of remote driving complexity.

A model from the Resilience Engineering tradition, which can be useful for analysis is the Extended Control Model, ECOM, by Hollnagel and Woods (2005). The ECOM model presented in Figure 3 consists of four interconnected levels of control tasks. The tracking level describes the controls that are needed for real-time control of a vehicle, i.e. control on an operative level. The regulating layer describes target values and controls that are needed for tactical control. The monitoring layer checks whether the vehicle is enroute to the destination and monitors signals from the environment. The targeting level determines the destination. Each layer of control is checked by the above layer in order for the vehicle to meet the goal, but changes on a lower level can affect upper levels, e.g. if there is a pothole in the road the trajectory of the vehicle should be changed.

The ECOM models levels can be compared with the distinction between operational, tactical and strategical level of control that was used in the prestudy discussions.

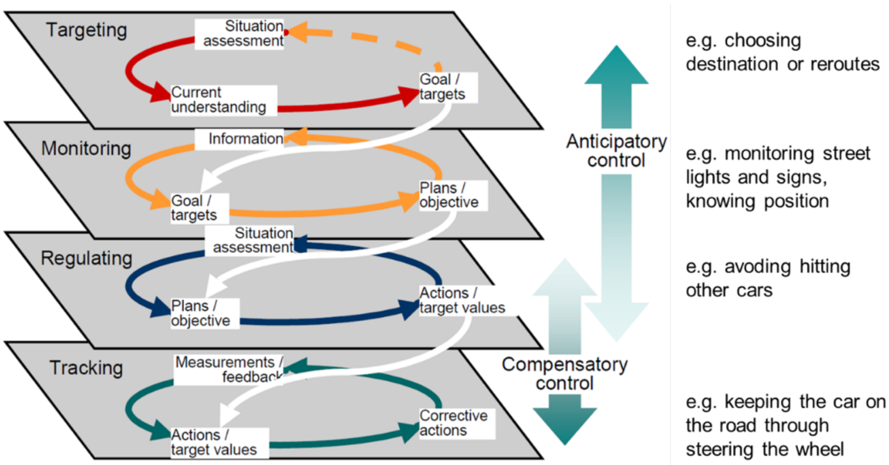

Figure 3. Extended Control Model, ECOM (Hollnagel & Woods, 2005).

6. Remote operation and its complexity

Despite the anticipated benefits, remote operation comes with its own challenges, both from technical and human behaviour perspectives. Remote operation is a rather complex and often involves several parallel activities. Figure 4 provides some insight to how different factors influence the design of a specific remote operation application.

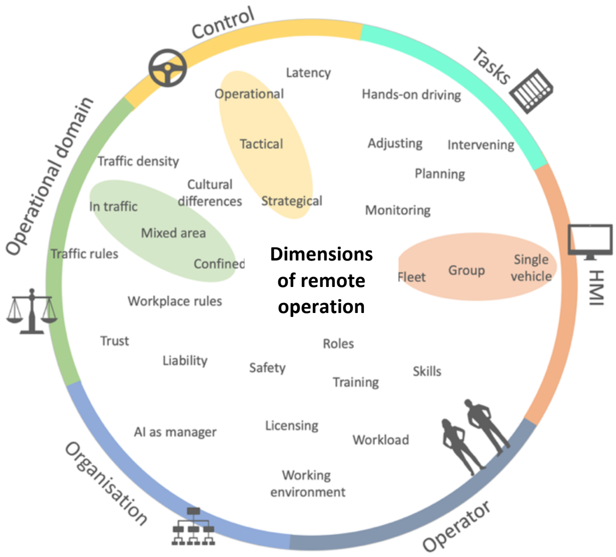

Figure 4. Dimension of remote operation.

The operational domain in Figure 4 is the static and dynamic environment where the driving takes place. The traffic and the infrastructure together with laws, regulations and implicit culture define the constraints that the remote operator has to act within. Control can be exerted on operational, tactical or strategical level, often intertwined, and in combination with automated driving functions. Apart from operational driving there are also other tasks that emerge when the driver acts remotely supported by automation. In tactical and strategical control, it is likely that the remote driver will instead monitor and plan for several vehicles at a time and intervene only when something does not go according to plan. The different control modes and new tasks call for new types of human-automation interfaces to support both monitoring and operational driving as well as efficient shift between these modes. Human operators in remote driving might need other skills and training compared to drivers of manually operated trucks. Cognitive workload can be expected to vary and rapidly change if drivers have to address issues with several trucks needing assistance at the same time (depending on number of trucks controlled simultaneously). The traditional organisation of transport companies is likely to undergo change in the face of increasing use of automation. When remote drivers control several trucks, fewer trucks will be needed, the training and licensing might be subject to change. The question of liability in case of an accident may also be unclear if the responsibility between the human driver and automatic control system is blurry.

The basic dimensions described in Figure 4 are also interconnected. Figure 5 describes some of the dependencies that influence the design of remote control systems. The yellow circles are the dimensions from Figure 4 and the pink squares describe (non-exhaustive) examples of how the dimensions can be interrelated. The purpose is to illustrate the need for a system perspective in design of remote driving systems, since a design decision will have an effect on other parts of the system.

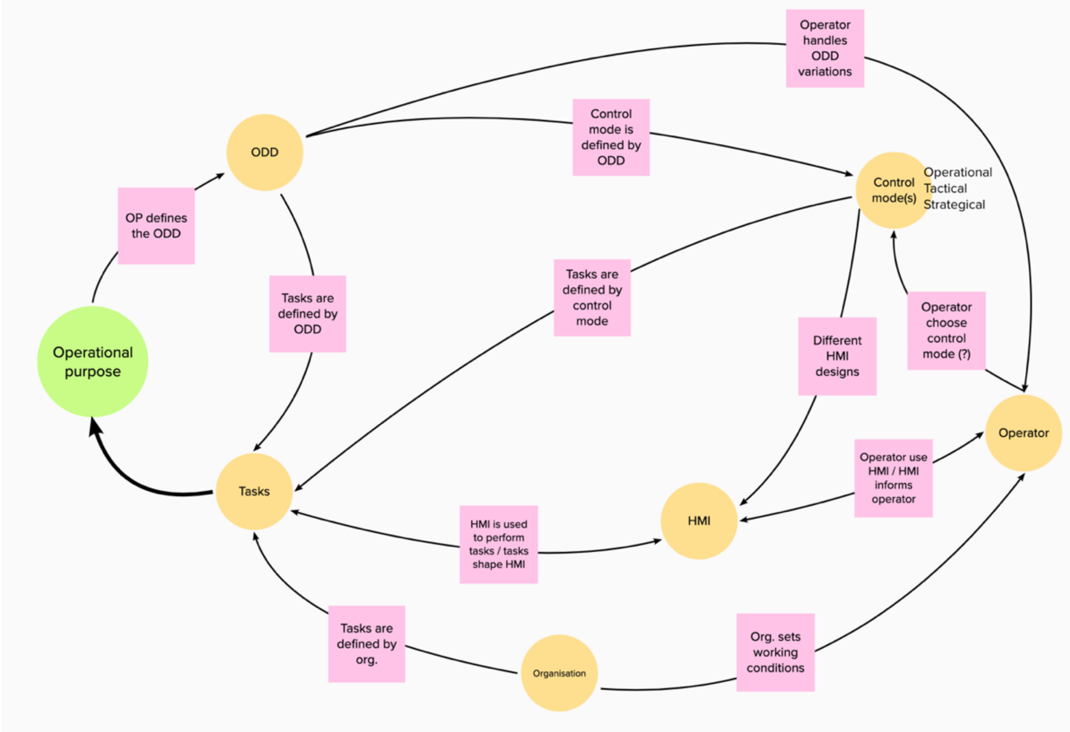

Figure 5. Remote control dependencies.

On top of that, in remote operation a number of different users can be identified, depending on the use case, with some example users identified in Figure 6.

Figure 6. Example user roles.

One primary driver for remote operation is the expected need to be able to override decisions, traffic regulations and impasses that the logic controlling vehicles on SAE level 4 can get stuck in, leading to unsafe situations or traffic jams. One example could be a situation where sensors in the vehicle interpret a plastic bag in the street as a foreign object that blocks the traffic. A remote operator could then be notified, quickly assume control, assess the situation and allow the vehicle to drive into the plastic bag, or guide around the object by taking control through a remote wheel. A remote operator could also be managing the local coordination for the vehicle within a hub, e.g. a logistics terminal, with all the complexities and synchronization with other vehicles and logistics processes that need to be managed within the hub. The notion is thus that remote driving functionality reduces the need to solve many of the edge cases that could appear in real traffic situations. This could enhance the pace with which vehicles on level 4 and 5 can be introduced to the market.

That is, remote operation can be done on operational, tactical or strategic control modes, which are often intertwined, and carried out in combination with automated driving functions. Apart from operational driving, there are also other tasks that emerge when the operator acts remotely supported by automation. In tactical and strategical operation, it is likely that the remote operator will instead monitor and plan for several vehicles at a time and intervene only when something does not go according to plan. Remote operation is envisioned to be utilized for the following applications:

- **Remote assessment**. Enables the remote operator to investigate (debug) issues. In remote assessment the information flow is one-way, i.e., the vehicle sends error messages and system state information to the human operator, but the operator cannot directly control the vehicle. This is always relevant and can be seen as a base case for remote operation.
- **Remote assistance:** Enables the remote operator to help the vehicle understand and handle a given situation. This is sometimes relevant.
- **Remote emergency driving**: Enables the remote operator to "drive", or evacuate, the vehicle in an emergency situation (e.g., at roadworks, or when the vehicle is stuck in a complex situation). This is rarely relevant, but very critical when it is needed.

To summarize, remote operation is mainly envisioned for the following applications: remote assessment, remote assistance and remote emergency driving. The design of the remote operation for these applications will be defined by a variety of inter-related factors including operational design domain, control level (operational, tactical, strategic), task nature, HMI, operator skills and training as well as organization type and its overall approach to remote operation and automated driving.

7. State of the art

This section presents the state of the art regarding human factors in remote operation. It is based on literature review as well as interviews and workshops with relevant stakeholders.

7.1 Literature review

Teleoperated vehicles have been used in many domains during the last 100 years. Nicolai Tesla demonstrated the first radio-controlled prototype of a four-foot ship in 1898[1]. The DH-82 B QueenBee has been said to be the mother of all airborne drones, known also as **Unmanned Air Systems (UAS)**[2] and became operational about 1935. The Soviet Teletank[3] that became operational in the at the same time is another example, this time a heavy ground vehicle operating in pair with a manned tank with a distance of up to 1500 meters between the vehicles. The teletank has also as of 2016 been "reborn" in the Vikhr remote controlled tank[4]. In modern warfare the number of systems and applications are many, with the US system MQ-9 Reaper being one well known operational example. For the MQ-9 Reaper a crew of two operates the UAS's navigation, sensors and weapons "anywhere" on the globe from a remote control station. The availability of smaller drones for both recreational and professional purposes has also increased extensively that last few years. In the professional maritime domain, Remotely Operated Vehicles (ROVs) have been used for many years.

The number of **civilian and military applications** of remotely operated vehicles are too many to list in the current report, but the US DoD is the world's largest operator of unmanned systems, with many different operational systems. The US Department of Defense Unmanned Systems Integrated Roadmap 2013-2038 (DoD, 2013) exemplifies many of the unmanned military systems of today, i.e. covering both systems that are called autonomous to some degree and systems which are remote controlled rather than capable of autonomous behaviour. The more recent version of the same roadmap, covering 2017-2042 (DoD, 2017) highlights four critical research themes for the future of unmanned systems for military application. The four research themes identified there are:

- **Interoperability** (Common/Open Architectures, Modularity and Parts Interchangeability, Compliance/Test, Evaluation, Verification and Validation, Data Strategies, Data Rights)
- **Autonomy** (Artificial Intelligence and Machine Learning, Increased Efficiency and Effectiveness, Weaponization, Trust)

[1] https://patents.google.com/patent/US613809A/en
[2] https://en.wikipedia.org/wiki/De_Havilland_Tiger_Moth#Training
[3] https://en.wikipedia.org/wiki/Teletank
[4] https://rtd.rt.com/series/combat-approved-series/vikhr-reborn-as-robot/

- **Network Security** (Cyber Operations, Information Assurance, Electromagnetic Spectrum and Electronic Warfare)
- **Human-Machine Collaboration** (Human-Machine Interfaces, Human-Machine Teaming)

Some of the critical needs, e.g., weaponization, will not be applicable for the applications considered by the current prestudy, but most of the needs will be relevant during future development of both remote driving applications and more automated vehicles. However, the current report from the prestudy focuses on the Human-Machine Collaboration aspects.

Within the **military domain** there have been many studies concerning the operator to vehicle ratio, i.e. how many vehicles one operator can control. Cummings and Guerlain (2007) and Chen, Barnes, and Harper-Sciarini (2010; 2011) provide reviews of numerous experiments targeting the question of how many autonomous vehicles (for several different military domains and automation levels) a human operator can control in a supervisory control mode, ranging from 1-12 vehicles. The conclusions concerning the ratio from these types of studies are very dependent on the operational context and the level of autonomy that has been implemented and will therefore not be summarised in this report. The literature also contains publications sceptic to the relevance of questions regarding operator-vehicle ratio (e.g., Galster, Knott & Brown, 2006) and usefulness of automation levels discussions to guide design (e.g., Department of Defence, 2012) as the operational context and the actual tasks that an operator has to conduct during different phases of a mission are more useful to discuss in order to inform system design.

Concerning safety analysis there is much to be learned from other transportation domains, such as **railways and aviation**, where elaborate processes concerning risk analysis and definition of safety cases have been developed. These safety cases are reviewed and approved by regulatory agencies after each significant change to vehicles or operations. Safety/risk analysis methods such as CSM-RA, i.e. Common Safety Method-Risk Assessment (European Railway Agency i.e. ERA, 2016) and RAMS (Mahboob & Zio, 2018) are examples from the railway domain. Similar safety analysis methods from the aviation domain have for example been defined by the International Civil Aviation Authority, i.e. ICAO, see ICAO (2018) and ICAO:s Safety website[5].

For **unmanned remote ship operation**, Wahlström et al. (2015), identified the following most prominent challenges (and research gaps): information overload, boredom, mishaps during changeovers and handoffs, lack of feel of the vessel, constant reorientation to new tasks, delays in control and monitoring, and the need for human understanding in local knowledge and object differentiation (e.g., in differentiating between help-seekers and pirates). They have also identified a few positive aspects of remote operation of ships: lack of seasickness and physical damage to the crew in harsh weather conditions, and the

[5] https://www.icao.int/safety/safetymanagement/Pages/default.aspx

possibility to functional specialization. A recommendation from the study is that the control centres should reflect agile command and control.

In **remote operation of container terminals and container cranes**, the following challenges have been highlighted (Karvonen et al, 2012): constant reorientation to new tasks (the remote container operators have continuously to reorient themselves to the demands of new tasks at small intervals such as lifting a new container from trucks' chassis every 30 seconds, whereas in conventional operation the task durations were much longer) and deteriorated sense of spatial dimensions in video feed-based control.

For **remote operation of forestry vehicles**, obstacle avoidance and route planning (e.g., knowing when to steer between or around small obstacles and when to not avoid them) are highlighted as potential issues as well as (lack of) comprehensive object evaluation (Ringdahl, 2011).

Several review studies on the human factors of remote operation in **various domains** present common factors, namely; the time it takes to complete a task, errors of operators, response time, situational awareness and operator's well-being (Brannigan et al., 2008; Chen, Haas & Barnes, 2007; Haans & Ijsselsteijn, 2012; Wahlström et al., 2015; Gatsoulis, Virk, & Deghani-Sanij, 2010; Zunjic, 2015). Latency is described as a challenge that increases overall time to complete tasks, can decrease efficiency, and results in increased number of errors. Similarly, a decrease in frame rate can result in decrease of usability, decrease in efficiency, and increase number of errors. Moreover, insufficient situational awareness leads to failure (Gatsoulis, Virk, & Deghani-Sanij, 2010). Hand-over/Hand-off between operators is also a critical phase where risk of failure is increased, and therefor changing operators need to be planned and executed carefully (Wahlström et al., 2015).

Regarding embodiment and telepresence Haans and Ijsselsteijn (2012) state that two technological factors can have an effect: interactivity and vividness. Vividness implies level of detail in the digital environment and number of sensory modalities that are included from a real operation scenario.

Best practice in operation centres is applied by analysing workflows of the real task and designing the remote operation centre around the workflows and the human operator (Brannigan et al., 2008). In other words, applying a user centred design focusing on factor such as optimum seating distance, information presentation, task simplification, noise and light optimization.

The studies of a more experimental nature show also some commonalities. The researchers investigated human factors using different human machine interfaces (HMI) mainly through varying field of view by e.g., using head-mounted displays (Almeida, Patráo, Menesez, & Dias, 2016; Bout et al., 2017; Cabrall et al., 2019; Cherpillod, Floreano, & Mintchev, 2019; Hosseini & Lienkamp, 2016) and augmented reality solutions (Hedayati, Walker, & Szafir, 2018). Some investigations explored using multiple sensory feedback systems. Latency/video delay showed to be a prevalent factor (Bidwell,

Holloway, & Davidoff, 2014; Cabrall et al., 2019; Chucholawski, Sauer, & Lienkamp, 2016; Davis, Smyth, & McDowell, 2010; Liu et al., 2016; Lu, Zhang, & Yang, 2019; Wintersberger et al., 2019; Wojtusch, Taubert, Graber, & Neergard, 2018), and testing different types of latency (fixed vs. variable) in teleoperation appears to be common (Davis, Smyth, & McDowell, 2010; Liu et al., 2016; Wintersberger et al., 2019). Some of the articles focused on mitigating the effects of poor latency by using predictive displays – displays that predict movement of the teleoperated vehicle and produce a smoother video during latency (Chucholawski, Sauer, & Lienkamp, 2016; Davis, Smyth, McDowell, 2010; Lu, Zhang, & Yang, 2019).

Moreover, several experimental studies investigated situation awareness (Bout et al., 2017; Hosseini & Lienkamp, 2016; Wojtush, Taubert, Graber, & Neergard, 2018), spatial awareness (Bout et al., 2017), tele-embodiment/tele-presence (Almeida, Patrão, Menesez, & Dias, 2014), workload (Chucholawski, Sauer, & Lienkamp 2016; Davis, Smyth, & McDowell, 2010; Haduch & Mitchell, 1995; Liu et al., 2016; Lu, Zhang, & Yang, 2019; Wintersberger et al., 2019; Wojtush, Taubert, Graber, & Neergard, 2018), user experience (Hedayati, Walker, & Szafir, 2018; Wojtush, Taubert, Graber, & Neergard, 2018), emotions (Nie et al., 2019), anticipatory interaction ratio - amount of actions able to make without waiting for visual response from interface (Bidwell, Holloway, & Davidoff, 2014), driving performance (Liu et al., 2016; Hosseini & Lienkamp, 2016; Wintersberger et al., 2019; Davis, Smyth, & McDowell, 2010; Cherpillod, Floreano, & Mintchev, 2019), neural activity (Bhat et al., 2017; Nie et al., 2019) and behaviour (Bhat et al., 2017).

Results from these experimental studies indicate that remote operation is more feasible using HMI that mitigate the psychological lack of presence (Almeida, Patrão & Menesez, 2014; Bout et al., 2017; Haduch & Mitchell, 1995). Head-mounted displays are a feasible option for mitigating psychological lack of presence (Almeida, Patrão & Menesez, 2014; Bout et al., 2017; Hosseini & Lienkamp, 2016) and for better driving performance (Cabrall et al., 2019). Augmented reality head-mounted display (ARHMD) interface is significantly superior to popular modern interface. Faster, more accurate and safer task completion were observed in teleoperation with ARHMD (Hedayati, Walker, & Szafir, 2018). Situational awareness, user workload and user experience have an impact on efficiency and effectiveness of teleoperation interfaces. Comprehension of the situation and reduction of unnecessary workload is thus crucial design factors for operator tasks (Wojtush, Taubert, Graber, & Nergaard, 2018). Regarding emotions, operators performed worse when in a higher arousal state (Nie et al., 2019). Variable latency is more detrimental to teleoperator performance than fixed latency (Davis, Smyth & McDowell, 2010; Liu et al., 2016; Wintersberger et al., 2019). Latencies above 300 ms have an effect on performance (Wintersberger et al., 2019). AIR scores decrease as time delay increase (Bidwell, Holloway, & Davidoff, 2014). Mitigating lag and latency can to some degree be done using predictive visual displays (Chucholawski, Sauer, & Lienkamp, 2016; Davis, Smyth & McDowell, 2010; Lu, Zhang, & Yang, 2019).

On a final note, the assessments in these experimental studies were mainly done using: workload (NASA-TLX, pupillometer, secondary task performance); situation awareness

(SART); driving performance (lateral & longitudinal distance to other vehicles, collisions, lateral lane conformance, max steering angle, lane offset); and user experience (UEQ, SUS). Other scales and assessment methods were used for example simulator sickness (SSQ), electroencephalography (EEG) for neural activity recording, self-assessment manikin (SAM) for measuring arousal and emotions, anticipatory interaction ratio (AIR), task completion time, task accuracy, controllability, and sensation of velocity.

A general view of the human factors related challenges within the remote operation topic can be summarized by highlighting phenomena such as physical and psychological distancing, screen delays, network latency delays, inefficient interface designs, and human operator's cognitive limitations. These categories are not exclusive to one single operational level, or application type, and are often interrelated. A larger body of scientific work can be found related to human factors in remote operation in other domains (e.g., robotics, aerial drones, military). Some of the findings from these domains can have value for the automotive domain, however, generally design requirements are not directly transferable between domains as there are domain specific challenges. In future work, there is value in providing a framework that lists human factors challenges within the domain categories that have been presented in this literature review. Such literature could facilitate the development of best practices in HMI design for teleoperation.

7.2 Remote driving companies

During the last few years, a number of commercial companies have launched platforms for remote driving, with quite similar concepts. A visit to all the listed commercial actors' websites reveals concepts that, at least on a conceptual HMI related level, are quite similar. To the extent possible to evaluate during the prestudy, these solutions appears to primarily implement the most basic driving tasks, e.g. controlling the wheel, speed control, but many of the other control tasks (blinkers, lighting, etc) needed in a normal truck or bus appears to have been left out. The prestudy has not investigated the different actors' solutions from a deeper technical perspective due to the limited prestudy budget.

The prestudy team identified the following actors with solutions that are marketed, but there surely exists a number of other companies with existing or forthcoming solutions. Note that the following list is in no particular order.

- Voysys, https://www.voysys.se
- Starsky Robotics, https://www.starsky.io
- Phantom Auto, https://phantom.auto
- Kodiak Robotics,https://kodiak.ai
- Roboauto, https://www.roboauto.tech
- Qibus, http://qibus.com
- Ottopia, https://ottopia.tech
- Fleetonomy, https://www.fleetonomy.ai
- Designated Driver, https://designateddriver.ai
- Pilot Automotive Labs http://www.pilotlab.co

  - https://www.youtube.com/watch?v=CJiJ3n73OBI
  - https://www.youtube.com/watch?v=7tpjarMyB5Q
  - https://www.youtube.com/watch?v=s-2IbpuFcy4
- Autonomous Solutions, ASI https://www.asirobots.com/platforms/nav/?tracking=Excavator+Explore+Nav
- Scotty Labs bought by DoorDash in 2019
- drive.AI bought by Apple 2019
- Oshkosh Defence with the Terramax product line https://oshkoshdefense.com/advanced-technologies/terramax-unmanned-ground-vehicle-technology/#performancehttps://www.autonews.com/shift/military-working-make-its-autonomous-technology-smarter
  - https://www.youtube.com/watch?v=yqPUH5SwY54
  - https://oshkoshdefense.com/wp-content/uploads/2019/02/17327_TerraMax_OvrVw_A4ss_LowRes_4.20.2015.pdf
- There is also a range of solutions for operators close to the vehicle and remote control of bodybuilding equipment such as cranes and other equipment, examples are
  - http://remoquip.com/
  - http://www.nerospecoscon.com/portfolio-item/hard-line/
  - https://torc.ai/remotetask/

7.3 Relevant Swedish research projects

As evident from the different reviews in Section 7 above, many companies have developed remotely controlled or teleoperated vehicles, for a long time. However, the new requirements of driving vehicles on public roads at high speed leads to new requirements of both technical, legislative/traffic rules and human factors related nature.

The prestudy team identified a number of recent or current Swedish research projects which are described in this section. A rough indication of project timelines is presented in Figure 7 below.

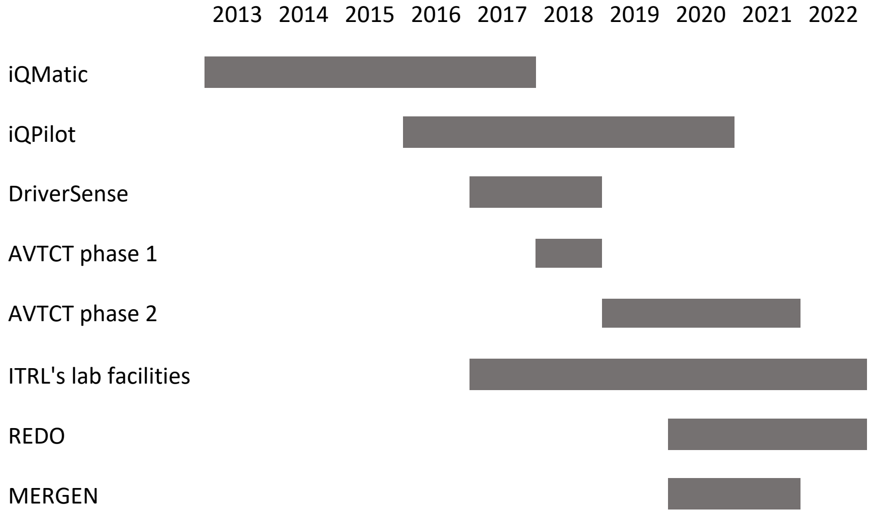

Figure 7. Timeline for described projects

iQMatic & iQPilot

Scania has from 2015 to 2020 been managing two autonomous vehicle projects from the VINNOVA FFI program which has relation to remote driving capabilities, although the main project focus was on vehicles on SAE level 4. Both the iQMatic and the iQPilot projects were early technical development projects related to AVs, with some HMI related work packages, e.g. development design concepts and prototyping for a control room enabling control of fleets of AVs in the iQMatic project.

During the larger AV-demo at Scania in June 2017 Scania and Ericsson, the iQPilot conducted a demo of a remote driving application where the AV test bus shown in Figure 1 was driven around Scania's test track. The bus was controlled from the remote driving station shown in Figure 2. Ericsson had established a 5G network node at Scania to enable the demo. A video presenting the demo-application is publicly available[6].

[6] https://www.youtube.com/watch?v=lPyzGTD5FtM

Figure 8. Scania's Autonomous test bus.

Figure 9. Remote driving station used to control the test bus during the 2017 demo.

The focus of the iQPilot demo was to demonstrate low-latency video streaming that enabled remote driving and in that regard was a clear success (Inam et al., 2016). Given the 5G focus, the design of the HMI of the driving station was not evaluated in the project. The HMI consisted of a very low latency video stream (centre screen), displays showing current and assigned speed, gear selection, latency times and network coverage (lower right), overview views from the command and control system ICE (Intelligent Control Environment, a Scania product) on the sides and pedals and wheel for control.
Contact: Anders Ställberg Scania, George Dibben Scania, Jimmy Selling Scania.

DriverSense

Within the DriverSense project an experimental platform based on a game engine has been developed in order to design and validate digital onboard user interfaces for self-driving and remotely controlled vehicles. A set of selected case studies including Head-Up

Displays (HUDs), Augmented Reality (AR) and directional audio solutions have been conducted, see Lungaro, Tollmar, Saeik & Mateu Gisbert (2018). Psychophysiological measurement such as eye-tracking was used during the analysis of results. The project was managed by Konrad Tollmar at KTH Mobile Service Lab (MSL) with participation from Ericsson, Tobii, and Universidade Federal de Minas Gerais and ran from 2017 to 2018.

MSL has also participated in 5GAA activities together with Audi, Ericsson, Italdesign, Pirelli, Qualcomm, TIM and Tobii[7] in order to investigate how 5G connectivity and vehicle to vehicle information systems can be used to improve safety by AR highlighting of pedestrians, aquaplaning warning between connected tires, as well as connected and adaptive road signs.

Contact: Konrad Tollmar KTH Mobile Services Lab.

AVTCT phase 1 and phase 2

The SAFER prestudy team interviewed leading researchers in the AVTCT project[8] (Automated Vehicle Traffic Control Tower), funded by DriveSweden. The AVTCT phase 1 project was a prestudy, while phase 2 is running from 2019-04-01--2021-03-31. Participants in the AVTCT project phase 2 are the Integrated Transport Research Lab at KTH (coordinator), Mobile Services Lab at KTH, Carmenta, Ericsson, Scania, Volvo, and the Swedish Transport Administration. More information is available at ITRL's website[9]
The scope of the AVTCT project is to shed light on questions such as:

1. The architecture of a system with automated vehicles and one or several control towers, including responsibilities and information flows.
2. Investigating the requirements on cellular connectivity, computational infrastructure, and sensors in the traffic tower environment, in order to guarantee the performance of the AVTCT operation
3. Increasing knowledge about human interaction with the system at different levels and for different tasks, by utilizing the testbed for experiments and simulation.
4. The role of traffic control towers within the transportation system. In the analysis the AVTCT project uses a broad scope and consider control on strategical, tactical and operational control levels along with the identification of relevant user centric use cases. The project also discusses how indirect control, e.g. through the use of infrastructure, can be utilised. Hierarchies of control towers, from operators to regulatory agencies are included in the analysis.
5. A significant development effort concerning lab facilities from remote and autonomous driving is also conducted within ITRL, where the AVTCT project contributes.

Contact: Jonas Mårtensson KTH, Konrad Tollmar KTH. Bas Oremus Scania.

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[7] https://www.kth.se/aktuellt/nyheter/kth-gor-bilen-smartare-1.944051
[8] https://www.drivesweden.net/en/projects-5/avtct
[9] https://www.itrl.kth.se/research/ongoingprojects/automated-vehicle-traffic-control-tower-phase-2-1.917776.

ITRL's lab facilities

Examples of ITRL's lab facilities investments relevant for the prestudy are the RCV-E vehicles, see **Error! Reference source not found.**, and the Campus 2030 effort, which encompasses an instrumented and digitalized campus. ITRL is applying for a permit to drive the RCV-E vehicles remotely and autonomously on KTH Campus and if successful the RCV-E vehicles could be driven with permit over the whole campus after summer 2020. More information is available at ITRL's website.[10]

Contact: Jonas Mårtensson KTH, Mikael Nybacka, KTH

Figure 10. RCV-E test vehicles at KTH/ITRL.

REDO

The REDO project is a current Swedish project focused on remote driving that started in January 2020 and ends in November 2022. Participating organisations are VTI, KTH Vehicle Dynamics/ITRL, Ericsson, Einride, Voysys, CEVT, NEVS and Ictech. A number of different aspects and foundational research questions of both technical and human factors related nature will be addressed and studied experimentally in the REDO project. The prestudy team conducted two interviews with leading researchers in the REDO project, see 5.1 for REDO work package 2 – Remote driver studies during teleoperated driving and 5.2. for work package 3 – Remote driving feedback and control during teleoperated driving. The REDO project also encompasses a work package 6 concerning Laws and regulations, which not is described further in the current report, but which will be a key factor for remote and autonomous driving introduction.

Contact: Jan Andersson VTI for WP 2, Mikael Nybacka KTH for WP 3.

[10] https://www.itrl.kth.se/research/ongoingprojects/research-concept-vehicle-model-e-1.917925

MERGEN

The MERGEN project PhD project at KTH – Integrated Transport Lab (ITRL) by Robin Palmberg that started in the fall of 2019. His thesis work investigates the driver monitoring aspects of remote driving, i.e. can heart, brain and eye related measures such as heart rate variability, EEG and pupil dilation be used to assess the cognitive state of the remote driver. MERGEN stands for Multi-purpose biometric Evaluation Research tool Grounded in Emerging Network technologies. More information is available at ITRLs website[11].

Contact: Robin Palmberg, KTH

7.4 Relevant European projects

For automated road vehicles, very few initiatives addressing human factors in remote operations are identified on European level (and internationally in general). The ongoing EU-project SHOW (where RISE coordinates the Mega/Twin site Sweden and leads the Dashboard WP) utilizes the Ericsson Connected Traffic Tower solution for remote assessment (dashboard) and for sending tactical missions to vehicles, mainly shuttle buses. The focus of SHOW is mainly on demonstration rather than in-depth human factors design and evaluation. There are a few other EU-projects related to technical aspects of remote control, e.g., TransAID, MAVEN, 5G NetMobile. In addition, a few studies related to human factors have been carried out by researchers at Technische Universität München. Examples of topics explored there include head-mounted display (HMD) and haptic feedback for improved telepresence, connection and latency concerns, and prediction methods for path planning as well as interactive path planning.

There are, however, several examples of relevant projects from other domains. In order to improve safety and traffic regulation, many European countries are in process of developing remote tower management. The idea is that the person monitoring and controlling the traffic does not have to be located in the tower itself, but can operate from a distant site. This new system is supposed to allow monitoring the traffic in small airports thanks to cameras, radar screens and radio transmission. The operator would control the airport by looking at screens where the situation is displayed in a similar way as what s/he could see "out of the window" in a tower on the airport. In the EU-project MOTO[12] (the embodied reMOte TOwer), the objective is to develop technologies to enhance the current Remote Tower concept, by integrating multimodal human-system interaction. The outcomes of the project include *scenarios of embodied cognition* in tower operations, in order to understand and explore the role of the embodied cognition during high-performing operations of remote control, *user requirements* for multimodal remote towers and augmenting manned airport tower operations, and multimodal solutions able to reduce workload. In particular, the project explored Brain-Computer Interface application as a means for addressing workload.

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[11] https://www.itrl.kth.se/research/ongoingprojects/mergen-multi-purpose-biometric-evaluation-research-tool-grounded-in-emerging-network-technologies-1.946255

[12] http://www.moto-project.eu

In a collaboration between Swedish and German researchers, complexity factors related to remote towers at airports were identified. The focus was on workload management. The work was conducted within the CAPMOD-project[13] and is based on a simulation. One main factor is the availability of relevant information. Within the switching conditions, emergencies at one airport reduced handling qualities which was not the case in the condition where both airports were visible to the controller. Furthermore, the ratio of situations with critical handling qualities was increased. Complexity is influenced by unforeseen events or traffic with unforeseen behavior. In many countries, e.g., in Germany, Visual Flight Rules (VFR) traffic does not require a flight plan, hence, VFR traffic constitutes unforeseen events for the air traffic controller's preplanned actions. One important takeaway from the study is that there is not a single factor, but the interplay of events at both airports, that drives the complexity.

In German project VICTOR[14] (Virtual Control Tower Research) from 2010 the focus was also on remote air traffic control. The goal was to develop an air traffic controller workstation for a tower facility which is used to remotely monitor and manage one or more regional airports. The project derived requirements from a human factors perspective and developed a workstation based on these, again highlighting the complexity of the remote operation and inter-dependency between several factors.

The newly started EU project SAFEMODE[15] project aims to design and validate a risk-informed framework to support Human Factors analysis in design and operations (Human Risk-Informed Design, HURID). Case studies will address known and emerging risks, such as increased levels of automation and remote operations (unmanned ships and drones). As such, the focus is both on maritime and aviation. As for the time being, the project has no public results.

7.5 Interviews and workshops

Interview REDO project: WP 2

Jan Andersson at VTI is managing a work package focusing on remote driver studies during teleoperated driving in the REDO project. The prestudy team interviewed him 2020-03-02. The primary content of this work package concerns experimental studies of fundamental human factors aspects of remote driving. Within the work package a series of experiments will be conducted in VTI's Simulator III. The independent variables of these experiments will be:

- Latency.
- Information presentation (placement of information, field of view and perspective)
- Type of driving task/traffic conditions. The task driving task will be varied both in terms of quantity and complexity.

[13] https://www.sesarju.eu/sites/default/files/documents/sid/2018/papers/SIDs_2018_paper_33.pdf
[14] https://human-factors-consult.de/en/projects/aviation/victor/
[15] http://safemodeproject.eu

The primary dependent measures that will be used in the experiments are derived from the Traffic Conflict Technique developed at Lund University, see for example Laureshyn & Várhelyi (2018).

Interview REDO project: WP 3

Mikael Nybacka at KTH Vehicle Dynamics/ITRL is managing the REDO work package concerning remote driving feedback and control during teleoperated driving, focusing on technical requirements and possibilities associated with remote driving. The prestudy team interviewed him 2020-02-19. In a wider sense the work package addresses questions regarding the design of the ARDAS (Advanced Remote Driving Assistance Systems) functions of the future. One of the human factors research questions of the work package regards the use of motion feedback from the vehicle's movement to the driver, especially since future vehicles can be over-actuated in order to give them new capabilities.

The work in this work package will consist of research and experiments on:

- Remote driving feedback:
  - Study what vehicle behaviour and events that needs to be fed back and perceived by the remote driver.
  - Designing and analysing driver support models to support a better performance of remote driving precision.
  - Study what level and type of feedback is needed, with regards to kinaesthetic or vestibular senses.
- Remote driving vehicle control:
  - Develop methods to attenuate bad driving commands, including packet loss or wrong and unexpected input.
  - Develop methods to be able to drive the vehicle during fault operation, which will interface to remote driving feedback and driver support models.

Interview Voysys

The SAFER prestudy team visited Voysys AB in Norrköping 2020-03-02 and were able to try out Voysys remote driving solution, both with the larger visual dome system and their smaller driving station. In the demo application a scale 1:8 remote control car was driven around a test truck, but Voysys system is operational at a number of customers with full size vehicles. Their VR solutions was not tested during the visit.

Voysys primary mission is to supply technical solutions for teleoperation that has the network coverage, bandwidth and latency that is required for safe and effective remote driving. The unique selling points of Voysys solution is their algorithms comparing latency times from several concurrent network carriers, securing a stable connection. This fights latency peaks and provides the lowest 4G/LTE latency in any moment. Their solutions include adaptive video packaging and easily can accommodate cameras already located on the vehicle, regardless of their positioning, whereas some other suppliers' solutions only accommodate one camera with a specific placement.

Voysys statement is that 4G connectivity will be satisfactory, at least with their use of several carriers and constant comparison and seamless switching between different carriers in order to get a low and stable latency. Voysys has achieved latency times down to 60 millisecond "glass to glass" over the 4G network with their solution. Voysys has also developed a number supporting products such as a network simulator, bandwidth and network latency measurement tools, and a cybersecurity protocol. Through their use of a purpose built, latency optimised 3D engine, augmented reality (AR) features are straightforward to implement in their system.

During the visit, the prestudy team noticed the importance of visual references to the own vehicle, e.g. the wheels in Figure 6, in order to conduct precision manoeuvring. Voysys mentioned that their customers, using Voysys' open SDK had implemented a number of Augmented Reality features that support the manoeuvring, e.g. virtual future wheel tracks, braking distance visualisation, and predictive displays of where the vehicle actually is or will be located.

Figure 11. Voysys dome equipped driver station.

Figure 12. Voysys smaller driver station.

Workshop 1

The prestudy team organised a half day workshop at the Integrated Transport Research Lab (ITRL) at KTH 2020-02-18. Seven PhDs, one PhD student and one senior product development manager, all with experience of autonomous vehicle R&D from KTH, Scania and RISE participated.

During the workshop the participants shared their remote driving related experiences from a number of projects, e.g. AVTCT, Mergen, and DriverSense.

At the end of the workshop a total of 50 research questions (pre-generated and during-the-workshop generated) were prioritized by the participants through a simple voting process, conducted after a quick review of all the questions. The intent from the prestudy team was to conduct an initial assessment of interest in different types of research questions. The criteria for the participants vote for a specific research question was that, given that they had a very limited number of votes, that they personally would like to be involved in a project studying that specific research question. The results from this research question prioritisation are presented in section 8.2.

Workshop 2

Another workshop with a similar format as the one described above was organised by the prestudy team to be held at RISE in Gothenburg 2020-04-01. Due to the Covid-2019 situation the workshop was transformed from a physical meeting into a teleconferencing format with introduction, free discussion and a set of votes concerning research questions administered through the Mentimeter tool. 12 experienced researchers and product developers participated in the workshop. One from academia, four from research institutes, five from industry and two from a regulatory agency. Six had human factors related PhDs and the other six were senior product designers or research program managers. Four of the participants were from the prestudy team and thus also participated in workshop 1.

Based on the research questions that were used in workshop 1, a curated set of these research questions draft where used during workshop 2. Between the workshops the research question drafts were developed further, i.e., rephrased, combined, some were removed, and new aspects were added based on the literature review and continued discussion in the prestudy team. A set of 21 draft research questions were then used as discussion stimuli during the second workshop.

The results from the Mentimeter votes concerning research question prioritisation are presented in summarised form in section 8.3.

8 Research gaps and challenges

In this section, the information collected by the prestudy team regarding research gaps and research questions for future projects is presented.

8.1 Literature review research questions

The general view of relevant research questions from the literature review can be summarized by highlighting phenomena such as psychological distancing, screen delays, network latency delays, inefficient interface designs, and human operator's cognitive limitations.

8.2 Workshop 1 research questions

To conclude the results from workshop 1, Table 1 presents the research question drafts that received the most amount of votes from both the first and second vote. In the first voting 50 research questions were available, and all that received less than two votes were removed. In the second vote 12 research questions were available.

Table 1. Research questions with most votes during workshop 1.

Draft research question	2nd vote	1st vote
What are the differences between different remote control concepts and control levels, on operative, tactical and strategical levels, e.g. wheel, waypoints, start-destination, and when are they suitable?	**4**	**4**
How do we define ODD's (Operational Design Domains) for remote driving and remote control? How do we methodologically describe the properties and prerequisites for different ODD's, as these ODD descriptions form the foundation for HMI design decisions, e.g. which information elements are important when?	**4**	**3**
What are the maximum number of vehicles that are controllable given different ODDs, context, and types of deviations? Can a remote driver simultaneously be responsible for more than one vehicle?	**4**	**3**
Which tasks will a remote driver actually manage, given different solution concepts. Which scenarios should we base the design on?	**2**	**3**
Are there effects of psychological detachment when the driver is not physically present in the vehicle, e.g. it feels like a game, and how can this be avoided?	**1**	**3**
Will skill decay affect driver who only use the remote driving capability sometimes as different types of skills (e.g. perceptual, psychomotor, procedural, cognitive) typically show different decay effects?	**1**	**3**
Which information and functions does an operator need in order to swiftly intervene and take over a vehicle when needed? For example, regarding visibility, field of view, temporal development of traffic situation/history, classification of other road users, identification of root cause for alert to operator.	**4**	**2**
Is it possible to design an HMI that enables control on an operational level while still providing required policy awareness for a geographical or temporal zone?	**2**	**2**
Task analysis of the information that current drivers of classical vehicles use during driving.	**2**	**2**
Can we identify information security challenges that are specific for remote driving and which has direct HMI implications? Does remote driving capability enhance or decrease AV market introduction from an information security aspect?	**0**	**2**
Which aspects of latency (Quality of service, bandwidth, packet loss, latency variance etc) are the most relevant to address for remote driving?	**0**	**2**
Should the HMI present raw data or a sensor-fusioned and interpreted feed? Which image takes the longest time to interpret? Is streaming video from the vehicle needed or can the operator control the vehicle on an onboard fusioned and interpreted image?	**0**	**2**

Looking for clusters, the top four rows indicate a need for more structured and mature descriptions of the use cases and operational design domains, as well as methods for the definition of them. Understanding of the operational domain and the requirements derived from the tasks that operators perform form the basis for HMI design, so this cluster in not very surprising. There are also several questions relating to HMI design among these "top 12" questions.

8.3 Workshop 2 research questions

At the beginning of the Mentimeter session of workshop 2, the participants had the opportunity to bring forward one or two research questions that they considered important, before they saw the research questions defined by the prestudy team. The responses from the participants were:

- The interaction between roles/responsibility split.
- Training.
- What precision is required for control on an operational level for different use cases and why?
- What is the most important defining condition for enabling remote drive or not: infrastructure/ODD, HMI, users' education or something else?
- How do we bring forward a systems perspective on remote control (Man-Technology-Organisation), and widen the scope?
- How and when should hand-over be done?
- How give the remote driver enough information with information overload?
- How to scale up?
- How to build trust with robots in the city transporting people?
- "The hot potato" and out of loop...for systems/operations that is not "safe enough" to be fully trusted in automated "modus".
- Functionality supporting the operators' need to switch between control levels and situations.
- How can remote control contribute to new mobility services and solutions?
- Security.
- Team player approach: when to hand over? How to build trust? Certification?
- What are the methodological needs in terms of research infrastructure?
- Systems safety of remote driving.
- Responsibility and legislations.
- What would be required from HMI, infrastructure and user education in order to safely allow for emergency evacuation of AV:s who have stopped in a public highway corridor?
- The hitchhiker perspective, i.e. non-authorized persons hitchhiking with future autonomous vehicles.
- With the exponential technology development pace in mind, how do we understand the technological phase and how do we design solutions that can work over time.

The participants were then asked four general questions concerning their opinions concerning remote control with results presented in Figure 13, Figure 14, Figure 15 and Figure 16.

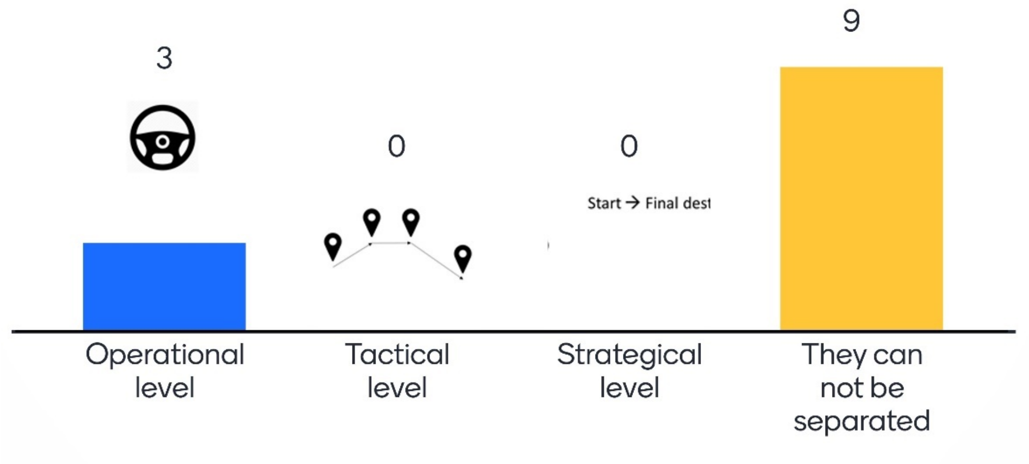

Figure 13. Answer to the question "Which of these control levels require the most R&D attention the coming five years?".

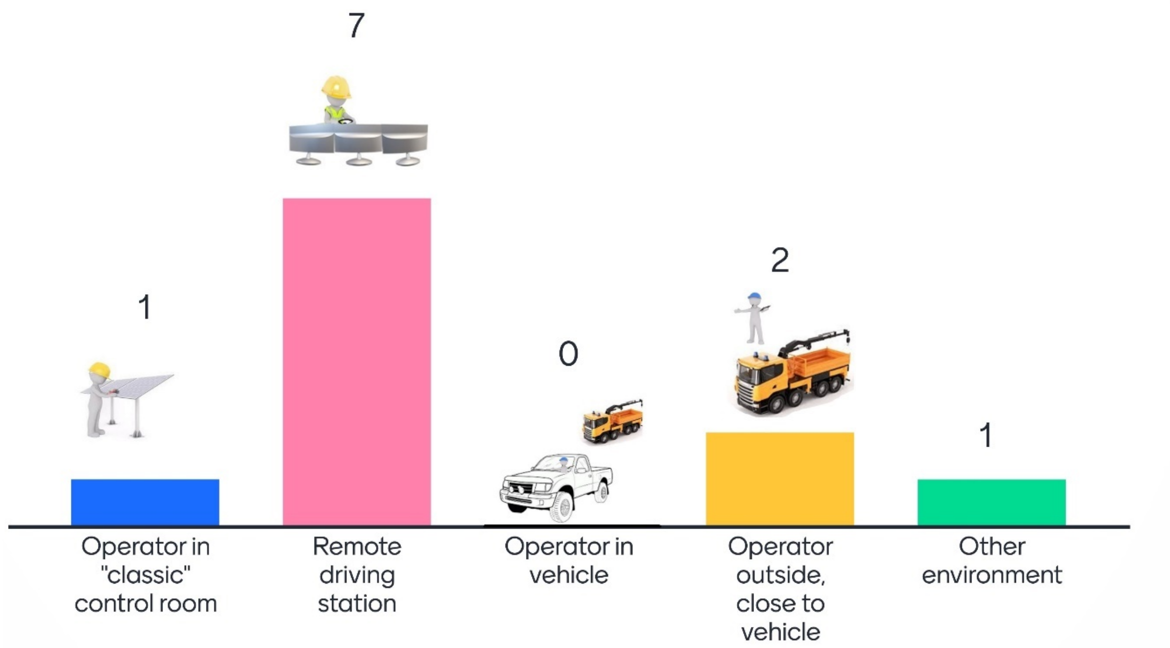

Figure 14. Answer to the question "Which of these operational environments require the most R&D attention the coming five years?".

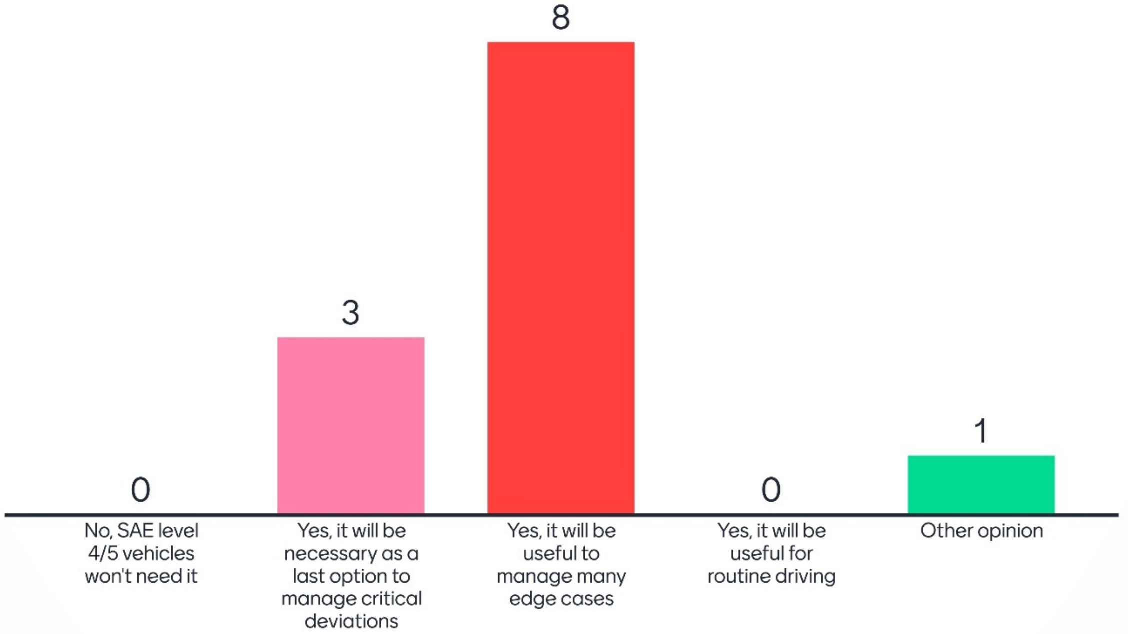

Figure 15. Answer to the question "Do you consider remote control on an operational level, i.e. remote driving, to be an important capability within 5 years?"

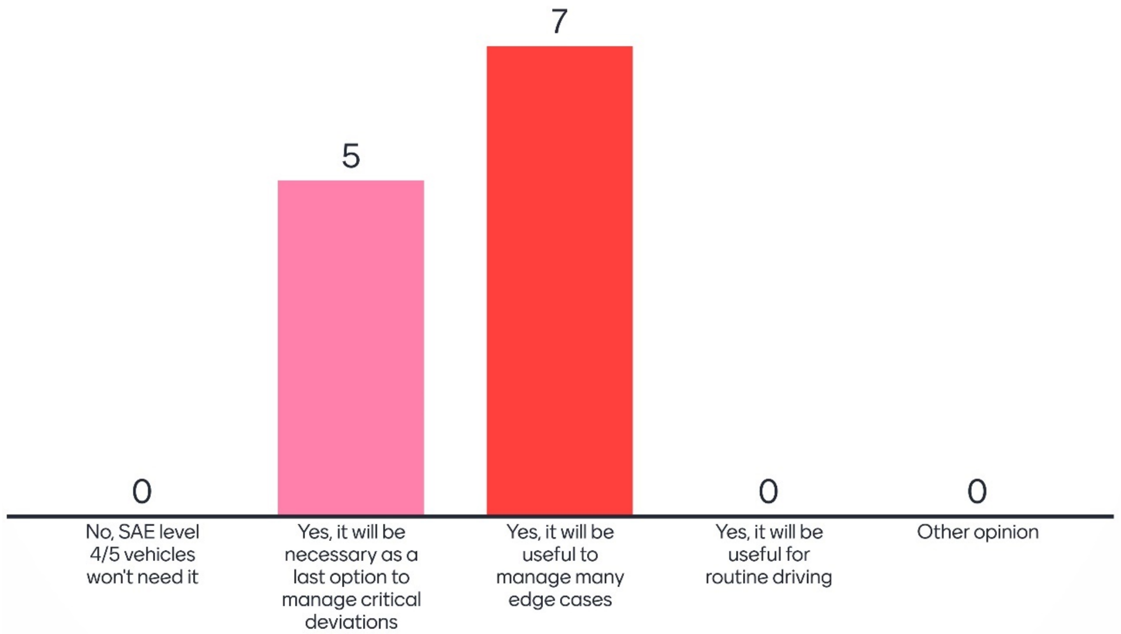

Figure 16. Answer to the question "Do you consider remote control on an operational level, i.e. remote driving, to be an important capability within 10 years?".

The prestudy team then presented 21 curated research questions, which could be useful for scoping of new research project proposals. Based on the results of workshop 1, the literature review and discussions within the prestudy team, 21 research questions had been selected. The workshop participants then for each research question were asked to

estimate and vote concerning the research questions suitability as a project research question. Answer alternatives were 0 = lower and 1 = higher. They also estimated and vote concerning the timeframe within which a project or R&D results was needed. Answer alternatives were 0 = shorter timeframe, within 5 years and 1 = longer timeframe, within 10 years.

The 21 research questions were presented in three sections, with sections relating to the operational domain, the operator and the human-machine interface, with seven research questions in each section. Figure 17 below show all the ratings in one grid, after postprocessing of results. Due to technical limitations in Mentimeter only 20 votes can be done on the same slide, so for the Vigilance and driver in the loop question, the visualisation, i.e. dot 21 has been entered manually into the figure. Results are presented in visual form with only short descriptions.

Figure 17. Result of votes for all 21 research questions merged into one grid.

Note that great care should be applied when interpreting these types of results. The intent was primarily to initiate discussion during the workshop and to get some very rough indication concerning the merit and urgency of the presented research questions. But the overarching observation is that almost all research questions cluster in the lower, right quadrant, which indicates that the participants consider them valid research questions that could be used to scope future projects. They all were considered urgent and should be addressed within the timeframe of five years.

Given the curated nature of the of the research questions that were presented to the participants this clustering might not be very surprising. However, the ordering of research questions based on the responses might provide some recommendation concerning the prioritisation of research questions, see Table 2 below, although care should be taken when interpreting these results.

As an example, for the research question ranked in the top of Table 2, Handover procedures / Safe stops needed, there was full consensus that it was a suitable research question for a project and that results were needed within a short timeframe, i.e. within five years.

Almost all of the research questions received a “needed within a short timeframe” rating. There is some variance, but hardly useful as an indication of which research questions to prioritise. For the Suitable as research project there is more variance among the responses from the participants.

For some questions one to three participants chose to skip answers because they considered themselves not being able to assess it. The mean percent values in Table 2 represent the percent of voters that actually did vote for that specific question. The quotient between votes and voters are therefore also presented in Table 2 for full transparency.

Table 2. Research question discussed during workshop 2 and voting results.

Research question	**Suitability as research project.** Means from voting participants below, with 1,00 indicating full consensus on suitability as research project	Votes of 1, i.e. suitable as research project question/number of voters	**Needed in timeframe.** Means from voting participants with 0,00 indication full consensus that project is needed within five years	Votes of 0, i.e. projects necessary within 5 years/number of voters
Handover procedures / Safe stops needed?	1,00	12/12	0,00	12/12
Differences between operational, tactical, strategical control. Use cases and maximum number of vehicles controllable	1,00	12/12	0,18	2/11
Perceptual aspects and feedback design (visual, auditive, haptic), e.g. FOV	0,92	11/12	0,00	0/11
Trust, responsibility, automation surprises, human-centric automation	0,92	11/12	0,08	1/12
Information needs for swift intervention	0,91	10/11	0,00	0/11
Comparison MD, RD, AD / Task analysis for remote driving	0,90	9/10	0,10	1/10
Sensor and view control needs	0,83	10/12	0,00	0/11
Information security challenges, specifically HMI implications	0,83	10/12	0,08	1/12
Vigilance and driver in the loop	0,83	10/12	0,18	2/12
ODD definition	0,82	9/11	0,09	1/11
Control room requirements	0,80	8/10	0,00	0/11
Psychological detachment	0,75	9/12	0,08	1/12
Precision manoeuvring requirements	0,75	9/12	0,08	1/12
Augmented Reality design	0,75	9/12	0,17	2/11
Traffic regulations in mixed traffic	0,73	8/11	0,18	2/11
Driver's license / certification for remote drivers	0,70	7/10	0,20	2/10
Present raw data vs interpreted data	0,70	7/10	0,20	2/10
Suppress or enhance info during deviations	0,64	7/11	0,08	1/11
Latency effects / 5G or 4G needed	0,55	6/11	0,09	1/11
HMI for latency effect reduction	0,55	6/11	0,17	2/11
On-site support functions	0,45	5/11	0,09	1/11

At the end of the workshop the participants were asked to describe their main take-away from the workshop. Their entries are presented below (a few positive comments concerning the workshop format have been removed):

- Further R&D is needed!
- How do we create the first step towards alignment of solutions for remote control to take on safety and efficiency challenges in traffic?
- Do not look separately on different control levels.
- Similar or even the same challenges in all "vehicle" domains. Sweden, could benefit from a national "range" of automation-dilemma research, sine all individual project seems too small to rely get to the core of the problems...
- Better understanding of remote control and related research challenges.
- Knowledge and experiences from related control room "industries" should be further investigated.
- There is a need to look at this from different perspectives. But there is also a lot to learn from different domains. We should probably address it from multiple angles.
- How is this affecting work opportunities in the industry?
- A good overview of research interests in remote control and remote driving based.
- There is a need for open architecture supporting remote driving.

Through the two workshops, even though the voting used different stimuli and procedure, nine PhDs and eight senior products developers or research program managers have been given the opportunity to prioritise within the curated set of draft research questions.

To conclude the analysis of results from workshop 2, it primarily became a validation of the research questions that had been defined before, along with some prioritization information, even though all the presented questions were considered quite urgent.

9 Conclusions, Lessons Learnt and Next Steps

In this section, a number of conclusions made by the prestudy team is presented.

- On a general level, the question whether an adequate, or optimal, remote driving station is a replica of the driver environment of a truck cab of today or "something else" needs to be answered. It might well be that a remote driver station and it's HMI contain more other and other functionality that what a driver of today has available, indicating that the question needs R&D attention.
- A lot of research and innovation has been done regarding remote operation, both in automotive and in other domains. However, our rather extensive review shows there is a lack of understanding of design and human factors requirements. Consequently, there is a risk that HMI solutions developed are not properly designed. Indeed, our impression is that the solutions been suggested are mainly driven by technology developments, rather than user needs, preferences and experiences. There are, of course, examples of studies where such aspects have been considered, however, a more systematic and holistic approach is needed, especially to achieve large scale implementation of automated driving systems with the support of remote operation.
- The design space is quite large given the many different concepts, scenarios and ODDs where remote driving can be a useful capability. Figure 5 describes remote control dependencies that in Figure 18 have been transformed into a more linear recommendation on how to approach a project. We suggest starting with definition of the ODD where the vehicles will operate. The requirements emerging from the static and dynamic environment will guide when and where different control modes are suitable. Further, there will be a need to specify ODD related tasks (predicting and reacting to changes in the driving environment) as well as control mode related tasks (operational driving, tactical guidance or strategic monitoring and the shift between these modes). When tasks have been described the operators' roles and responsibilities can be defined. Finally, the remote driving HMI can be designed in accordance with the operator's needs in the current work system.

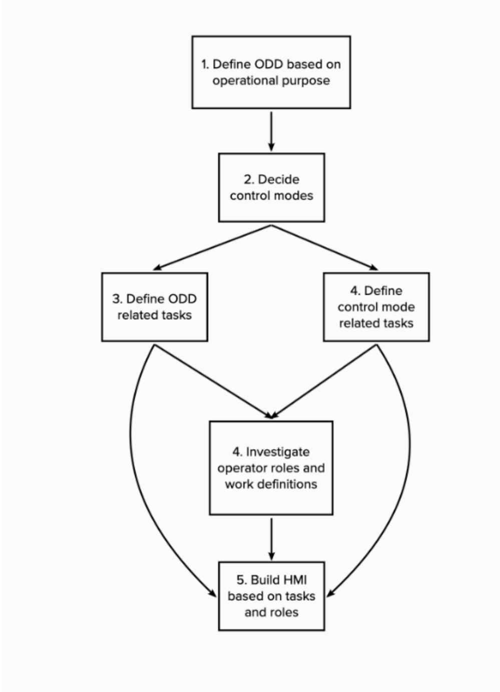

Figure 18. A recommendation on how to approach projects on remote operation (based on the dimensions and interdependencies presented in Section 6)

- This raises the need to point out that best practice for HMI development is an iterative approach with user needs analysis, concept generation, design and testing in several cycles. Given the complexity of interactions between human cognition, system design, and the traffic environment it is quite rare to be able to design a safe and efficient HMI without these iterations. The design of R&D projects, with regards to expected results, timelines and funding must accommodate for this complexity.
- The different control levels should not be observed/designed for in isolation, all control levels are valid and applicable in most applications. Effort should be spent on HMI and system functionality that supports the operator when switching between control levels and task. A greater challenge for vehicle OEM's (Original Equipment Manufacturer) than the design of a marketable remote driving solution or a remote control system working on a more strategical command level, will be to develop a vehicle and control system architecture that enables "seamless" transition (or with as little cognitive load on the operator as possible) between different modes of control. The system, with its HMI, needs to make it very explicit what different work tasks for the human operators means and who has the responsibility. Explanation of context and its effect on decisions by the automation, boundary conditions and overview of mode states and transitions between modes also require careful design of the HMI. Experiences from other domains shows that these are features that often is lost during the automation of a processes, with operators being outside of the control loop as a result. The safety implications of this cannot be ignored and safety assumptions must also be analysed carefully. As an example, consider that when a system error happens it may well be that it

affects all the vehicles in a fleet at the same time. The assumption that a remote operator can monitor a fleet of vehicles and take control of them one at the time to help them then falls. The operator then becomes forced to go from a supervisory role of many vehicles into the very challenging role of manual controller for each vehicle in the fleet.

- Despite that fact that there are quite a few commercial actors as well as R&D projects active in the field, there are many human factors related research questions that require further attention. The prestudy report presents a quite wide range of different types of research questions drafts that are relevant to remote control and remote driving. These research questions have been defined, reviewed and refined by a number of specialists and should provide a good start for anyone interested in definition of a human factors related remote control or remote driving R&D project. This list of research questions fulfils the primary purpose of the prestudy. Before systems become operational in real traffic on a wide scale, many of these research questions will need to be addressed to some extent. Returning to the figure theoretical framework and model for remote operation (see Section 5 and 6), the 21 research questions have been approximately mapped to the dimensions in Figure 19, indicating both that the model is useful for organisation of research questions in this domain and that the identified research questions address different dimensions of remote driving.

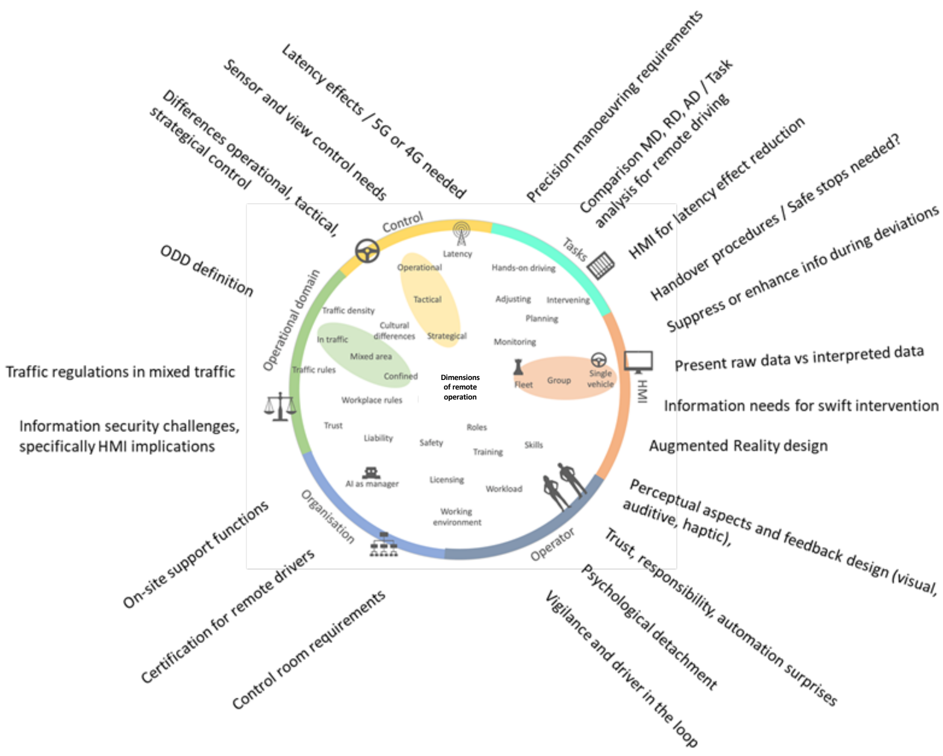

Figure 19. Research questions mapped to the identified dimensions of remote operation.

10 Dissemination and Publications

In addition to this report, a paper draft is under preparation and is aimed to be submitted to a conference. The project results have also been presented in an online seminar to SAFER partners. Also, SAFER partners have taken part of the results (and contributed to results) by participating in our workshops and interviews. The results have also been presented at an internal online seminar at Scania. How have the results been spread or will be spread? The project results will serve as a basis for an FFI project on this topic.

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