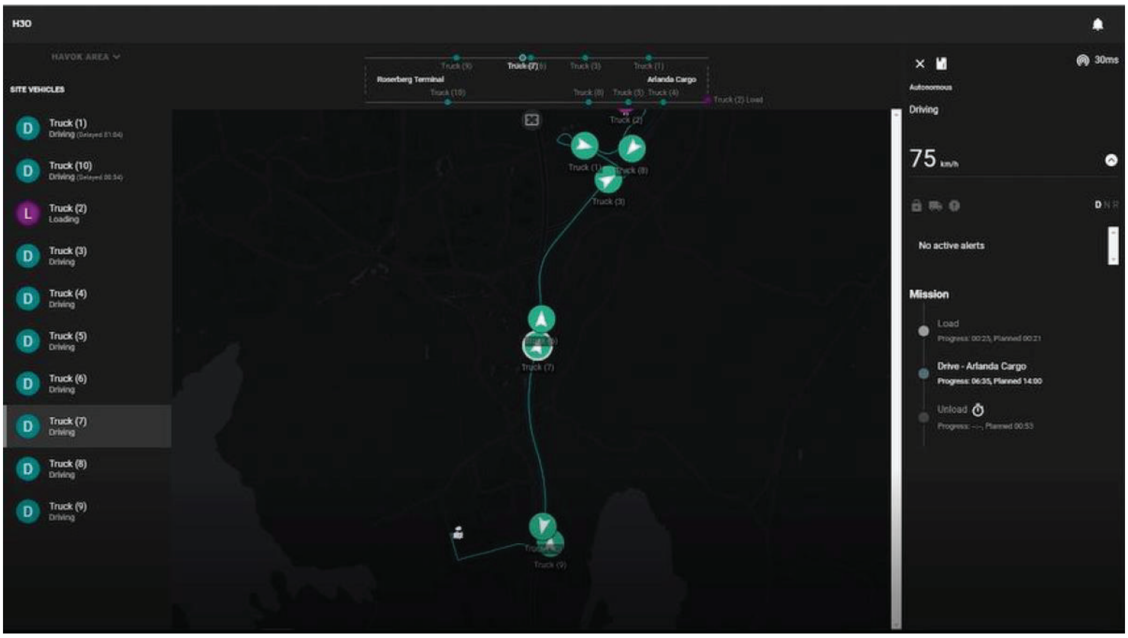
HAVOC
Heavy Vehicle Operation Centre

Public report



Project within Vinnova FFI Trafiksäkerhet och automatiserade fordon (TSAF)

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Content

1. Summary

Development trends suggest that, in spite of the optimistic announcements made by some stakeholders a few years ago, there are still technological challenges and regulatory constraints making heavy automated vehicles (HAVs) dependent on human control. Indeed, most HAV still require a human safety operator in the vehicle, and automated driving without a human "fallback" might be distant. At the same time, having a human safety operator in the vehicle jeopardises major anticipated benefits of HAVs – transport safety and efficiency. To bridge this gap, stakeholders are exploring remote operation technology, which enables HAV to be remotely operated by a human operator to some extent.

The purpose of the HAVOC project was to study operator work and HMI for remote monitoring and control of heavy autonomous vehicles. The aim was to answer the following research questions:

- What requirements are imposed on people and heavy vehicles for assessment, assistance, and driving?
- What is required to scale the ratio between the number of operators and the number of monitored vehicles?
- How should operator work be designed for transitions between assessment, assistance, and driving?

Initially, a series of stakeholder workshops were held to define the scope and use cases in the project. The HAVOC simulator was developed implementing the use cases in a Unity game engine with corresponding 3D-world and operator HMI to enable exploration of remote operation of ten vehicles in parallel. In the user study, 15 participants were invited to work for 1.5 hours and evaluate the system and work in terms of human-automation interaction. Human factors and HMI requirements were elicited for remote assessment, remote assistance, and remote driving operator tasks. The results show the importance of taking a systems perspective in developing and implementing remote operation control centres.

One of the major takeaways from the user study and the HAVOC project is the importance of a systems perspective in the analysis and design of future remote operation centres. The answer to questions such as "*How many operators are needed?, How many vehicles can be monitored and controlled?, What is the best HMI?, What are the most important operator tasks?*" etc., will always rely on the dependencies between multiple human, technical and organisational factors. The ability to deal with the dependencies between factors such as operators' skills and knowledge, operator tasks and training, HMI, vehicle capabilities, operational context, etc., lies in defining the envisioned work system and deciding what to design for. If a viable business case for remote operation is an operator:vehicle ratio of 1:1, 1:10 or 1:100 will place very different demands on overall human-automation systems design and work organisation. In this project, we have

only considered single operator work. In a real application, teamwork between remote operators, traffic planners, and field personnel can be expected, further stressing the socio-technical systems approach.

2. Sammanfattning på svenska

Utvecklingen mot självkörande fordon går snabbt framåt. Trots detta så finns fortsatt både tekniska, operativa och tillståndsmässiga utmaningar med fordon helt utan förare. Detta har föranlett ett ökade behov av att övervaka och styra fordon på distans. Behovet av fjärrövervakning kommer troligen finnas under lång tid framåt även då den autonoma förmågan ökar, även om behovet av att köra fordon på distans bör minska över tid givet att tekniska framsteg ökar fordonens förmåga att agera på egen hand.

En drivkraft för fjärrövervakning och styrning av fordon är behovet att kunna lösa avvikande situationer som fordonet potentiellt inte kan lösa på egen hand, som kan leda till t.ex. riskfyllda situationer eller att fordonet hindrar annan trafik. I dessa situationer kan operatören ta beslut antingen genom att hjälpa automationen bedöma en situation eller själv köra fordonet tills automationen är kapabel att ta över igen. Därmed kan antalet ”edge cases” som fordonet behöver klara av själv reduceras genom samarbete med en mänsklig operatör, vilket kan underlätta fordonens introduktion på marknaden.

Ett sätt att beskriva fjärrövervakning och styrning är utifrån kontrollmoder - strategisk, taktisk, och operationell nivå. I HAVOC projektet exemplifieras dessa moder av övervakning (remote assessment), assistans (remote assistance) och körning (remote driving). I övervakning så monitorerar operatören flera fordon som körs autonomt utan mänsklig inblanding. Vid assistans så hjälper operatören fordonet att ta beslut, men fordonets genomför själva handlingen. Vid körning så tar operatören över och kör fordonet på distans med hjälp av till exempel kameror, ratt och pedaler (eller andra sensorer och styrfunktioner).

Ett välfungerande system för fjärrövervakning och styrning av autonoma fordon beror emellertid inte enbart på teknisk förmåga hos fordonet och skickligheten hos den som övervakar. En förstudie genomförd av RISE [1] om fjärrövervakning och styrning av tunga autonoma fordon visade att ett systemperspektiv där helheten människa-teknik-organisation behöver adresseras för nå ändamålsenlig säkerhet och effektivitet. HAVOC-projektet har ytterligare fördjupat denna kunskap och exemplifierat hur ett sådant system kan designas och utvärderas.

Syftet med HAVOC projektet var att undersöka fjärrövervakning och styrning av tunga autonoma fordon från ett människa-teknikperspektiv för att öka kunskapen om hur dessa

[1] [1] https://www.saferresearch.com/library/final-report-human-factors-related-remote-control-automated-heavy

system bör designas i framtiden. Målet med projektet var att identifiera och jämföra behov och krav utifrån de olika kontrollmoderna: övervakning, assistans och körning.

Den övergripande forskningsfrågan i projektet är *"Hur bör kontrollcenter för tunga autonoma fordon designas från ett människa-teknikperspektiv?"* Därtill har tre detaljerade forskningsfrågor utforskats:

- *Vilka krav ställs på operatörer och fordon i övervakning, assistans och körning av tunga automatiserade fordon?*
- *Vad krävs utifrån ett människa-teknikperspektiv för att skala upp antalet fordon som en operatör kan övervaka (1:X förhållam)?*
- *Hur ska ett operatörscenter designas för att kunna växla mellan olika kontrollmoder (övervakning, assistans och körning)?*

Forskningsfrågorna utforskades genom workshops och ett användartest. Workshoparna innefattade diskussioner med problemägare på Scania för att definiera relevanta användningsfall och avgränsningar. Användartestet möjliggjordes genom utveckling av en simulatormiljö för övervakning och styrning av tunga autonoma fordon. I HAVOC simulatorn kan drift av tio autonoma fordon simuleras i ett hub till hub scenario och olika problem kan injiceras av testledaren (t.ex. vägarbete, hinder på vägen och sensorproblem med fordonet) för att simulera övervakning, assistans och körning. Operatörsgränssnittet togs fram med utgångspunkt från tidigare HMI arbete på Scania.

HAVOC simulatorn användes sedan för att genomföra en användarstudie med 15 personer som fick agera fjärroperatörer av tunga autonoma fordon. Deltagarna fick en kort introduktion och fick sedan arbeta ca1.5h i simulatorn. Deltagarnas uppgift var att övervaka tio fordon, hålla ett jämnt flöde av fordon mellan hubbarna samt att agera på larm från systemet. Efter varje larmevent fick deltagarna svara på frågor och skatta sin upplevda arbetsbelastning. Efter att testet var slut fich de även svara på frågor om sin upplevelse att arbeta som operatör och ge feedback på HMI och arbete.

Resultatet från användarstudien visade att uppgiften att övervaka tio fordon parallellt kunde lösas av en operatör givet de scenarier och det operatörsgränssnitt som användes i testet. Transitionerna mellan övervakning till körning och övervakning till assistans och tillbaka genomfördes utan större problem, operatörerna kunde snabbt komma tillbaka och återfå situationsmedvetenhet. Analys av subjektivt skattad arbetsbelastning visar på stora individuella skillnader i upplevd arbetsbelastning. Användarstudien beskrivs vidare i separat publikation (se kapitel 7).

HAVOC-projektet har bidragit till att öka den svenska konkurrenskraften genom utveckla och sprida kunskap om fjärrövervakning och styrning av tunga fordon från ett människa-teknik perspektiv (se kapitel 7 för dissemineringsaktiviteter och publikationer). Projektet har deltagit i flera internationella och nationella presentationer och workshops. Genom associering till SAFER och Scanias samarbete med KTH ITRL har kunskap spridits inom Sverige. Samarbete mellan OEM:er har främjats genom inkludering av Einride och Volvo CE i referensgruppen samt genom OEM:ernas deltagande i SAFER nätverket Road User

Behaviour. Projektet har bidragit till delprogrammet TSAF:s område F och D genom att ge konkreta exempel på hur operatörsarbete i fjärrövervakning och styrning kan designas och simuleras och vilka utmaningar som finns att utveckla denna typ av komplexa socio-tekniska system.

En av de huvudsakliga insikterna från projektet är behovet av systemperspektiv i utveckling och implementation av fjärrövervakning och styrning av autonoma fordon. Användarstudien ger exempel på hur förståelse för samspelet mellan operatören och tekniken i sin kontext är avgörande för säkert och effektivt arbete. Vid fjärrövervakning är operatören styrd av de möjligheter operatörsgränssnittet ger för att förstå vad som händer i verkligheten. Design av larmsystem och meddelanden, prioritering av larm, är avgörande för att guida operatörens beslutsfattande. De uppgifter som ska utföras (t.ex. assistera ett fordon som har problem) är avhängiga både fordonets förmågor och operatörens handlingsutrymme och möjlighet att förstå trafikmiljön utifrån tillgängliga sensorer. Användarstudien visar att vid fokus på problemlösning och körning av ett fordon kan inte övergripande övervakning upprätthållas utan måste delegeras eller skjutas upp, vilket pekar på behovet av organisatorisk uppbackning, osv. Svaret på den övergripande forskningsfrågan *”Hur bör kontrollcenter för tunga autonoma fordon designas från ett människa-teknikperspektiv?”* är därför att det behöver göras utifrån analys av hur alla dessa faktorer samverkar. HAVOC-projektet och dess användarstudie har utforskat ett litet tvärsnitt och exempel på dessa samverkande faktorer. Projektet har visat på hur ett socio-tekniskt angreppssätt för analys av denna typ av människa-tekniksystem kan ge värdefull information varifrån riktlinjer och krav för specifik systemdesign kan definieras.

3. Background

The challenge of heavy automated vehicles (HAVs)

Development trends suggest that, despite the optimistic announcements made by some stakeholders a few years ago, there are still technological challenges and regulatory constraints making heavy automated vehicles (HAVs) dependent on human control. Indeed, most HAV still require a human safety operator in the vehicle, and automated driving without a human “fallback” might be distant. At the same time, having a human safety operator in the vehicle jeopardises major anticipated benefits of HAVs – transport safety and efficiency.

Remote operation as a supplement to automation

To bridge this gap, stakeholders are exploring remote operation technology, which enables HAV to be remotely operated by a human operator to some extent. In the remote operation of HAVs, several different users can be identified, depending on the use case

(Figure 1). This human-as-backup architecture, which removes the person from momentary control and instead places them in a supervisory context, in many ways defeats the very idea of automation in the first place. However, it is currently seen as a critical transition phase, and a way to put HAVs on the market shortly.

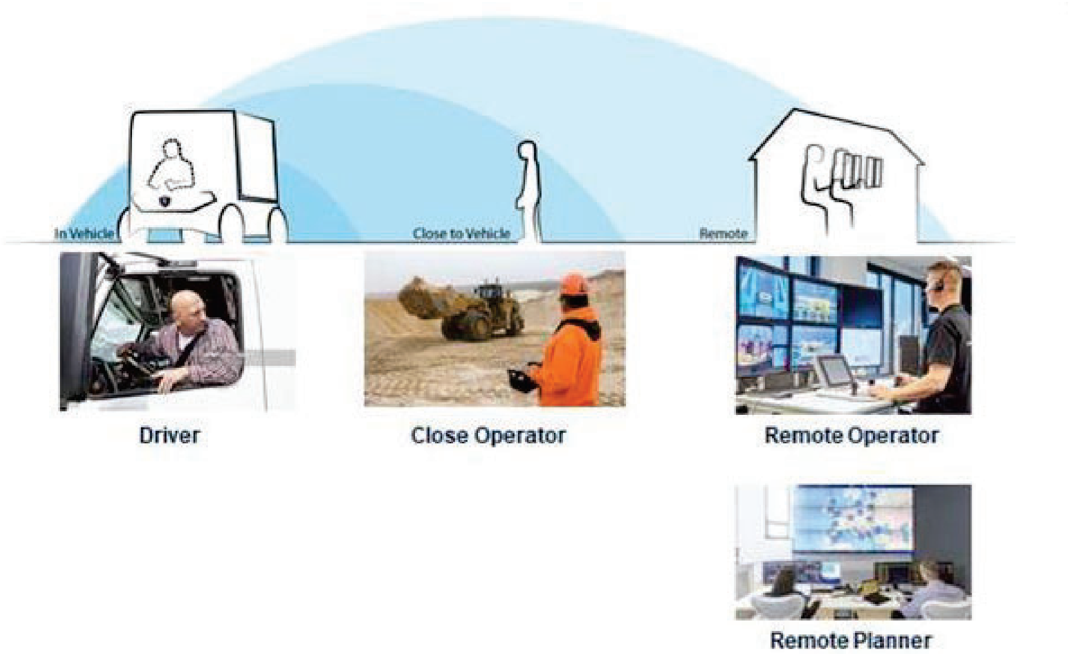

Figure 1. Example user roles in remote operation.

Applications of remote operation

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 when 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, allow the vehicle to drive into the plastic bag, or guide around the object by taking control through a remote steering 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 synchronisation 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 levels 4 and 5 can be introduced to the market.

That is, the 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 active driving, other tasks emerge when the operator acts remotely, supported by automation. In tactical and strategical operations, 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 utilised 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 driving**: Enables the remote operator to "drive" or evacuate, the vehicle in an emergency (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.

4. Purpose, research questions and method

The project's purpose was to **compare and contrast different needs and requirements posed on the human operator and HAV** in the following remote operating modes: remote assessment, remote assistance and remote driving.

The project's overall research question is *How should a remote operation centre be designed from a human factors perspective?* The specific research questions include:

1. What requirements are posed for humans and HAVs for remote operating applications: assessment, assistance, and emergency driving?
2. What is required from a human factors perspective to scale up the number of vehicles a human operator can remotely operate (1:X ratio)?
3. How should a remote operation centre be designed to allow the operator to swap between remote operating applications (assessment, assistance, emergency driving)?

As a starting point, the project used the technical platform for a remote operation called Intelligent Control Environment (ICE) that Scania has developed in a previous FFI project. In the current form, ICE, similar to other remote platforms, supports strategic remote operation (and, to some extent, tactical). This project intended to extend the capability of ICE by enabling it to support operational and tactical operational levels from a human-factors perspective (Figure 2).

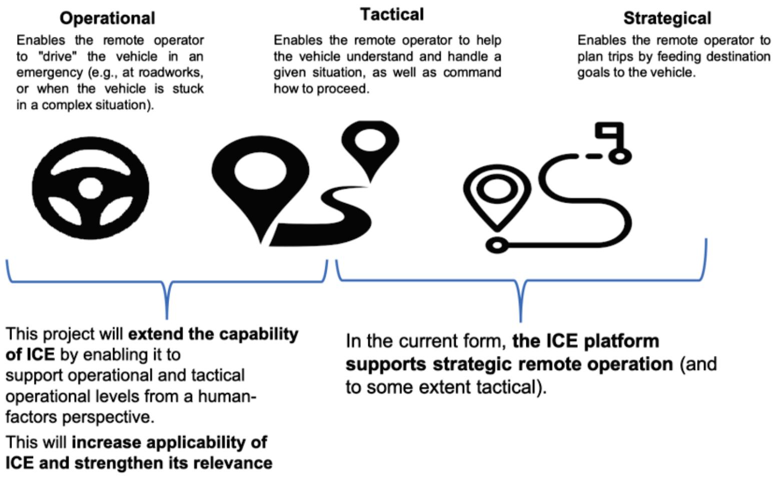

Figure 2: Technical platform ICE will enable practical exploration of human factor aspects.

The project was performed in seven work packages – Project coordination, ODD and use cases, Identifying requirements, Design and implementation of the concept, Evaluation methodology, Evaluation and Dissemination (see chapter 6).

5. Objective

The project's goal has been to explore and elicit requirements for the design of the future remote operation of heavy vehicles by designing a simulator environment for remote control and performing user tests with operators. The project specified seven work packages to reach this goal, each with a specific set of deliverables. The deliverables D1-D7, as stated in the research proposal, can be found in the left column in chapter 6, together with an overview of results connected to each deliverable in the right column. Detailed results can be found in the publications (see chapter 7), appendix (at the end of this report), and the requirements webpage (see link in the list of dissemination).

6. Results and deliverables

Seven work packages with corresponding deliverables were defined at the beginning of the project. Table 1 describes the results from each deliverable.

Table 1. Work packages and corresponding deliverables.

WP1 – Project coordination	**Results**
D1.1: Bi-weekly project meetings, 2-3 steering and reference group meetings	Project meetings were held continuously as needed. A reference group with representatives from Volvo CE, Einride, VTI, Voysys and ICTech was established, and two reference group meetings have been held.
D1.2: Status reports to FFI (2-3 time/year)	FFI reports were sent in according to plan.
D1.2: Project agreementt	The project agreement was signed according to plan.
WP2 – ODD and use cases	
D2.1: Description of trends and the role of remote operations for various scenarios.	Use cases were developed in workshops with the project participants and business and technology representatives as stakeholders within Scania. Selection criteria were based on current and future business needs. A survey of business actors is presented in Appendix A.
D2.2: A list of 10-15 selection criteria. **D2.3:** A list of ca ten relevant use cases where 2-3 most relevant/urgent use cases are pinpointed and described in detail for further investigation in WP3-WP6.	Rather than a list of criteria, the choice of focus for the project was based on business needs elicited from interviews and workshops with stakeholders at Scania. Hub-to-hub operations (combination of confined area and highway driving) were chosen as the overall context. The specific use cases considered loading bulk/cargo, dispatching the AV, leaving the hub, entering a highway, driving on a highway, exiting a highway, entering the hub, and unloading. The events considered as disturbances included obstacles on the road, delays, vehicle stand-stills, road accidents, sensor system degradation, and loading operator requesting help. Findings were documented in a collaborative software (Miro).
WP3 – Identify requirements on the remote operator and HAV	
D3.1: Literature review	The literature review served as a basis for background sections in the academic publications listed in the dissemination chapter. A literature review was performed as part of writing academic papers (see publications). In addition, a state-of-art review was conducted to map the actors in the teleoperation domain (See Appendix A).
D3.2: Initial list of requirements on remote operators and HAV	Initial requirements for development of the simulator environment were derived in collaborative workshops and fed into the development work. In the development, there was a trade-off between existing platform components that could be

	reused and the development of new features to fit the project's scope and evaluations. Within the hub-to-hub scenario, ten triggering events were defined as potential anomalies that operators may need to handle in future operations. From the ten, five triggering events were chosen for further exploration to exemplify and enable testing of transitions between assessment, assistance and driving control modes. The events included traffic disturbances, obstacles on road, sensor failures and vehicle limitations that motivated transitions from assessment to driving. HMI was developed corresponding to the assessment, assistance and driving control modes. The HMI also included a task based HMI to assess vehicle flow. The HMI and corresponding requirements are described in the publications and the interactive webpage (http://tinyurl.com/havocproject).
WP4 – Design and implement concept for a remote operation center	
D4.1+4.2: Prototypes of low- and medium fidelity HMI concepts.	M4.1 and M4.2 were merged into an iterative development phase resulting in a high-fidelity concept based on the ICE simulation platform. The HAVOC simulator consists of a number of building blocks; game engine back-end, 3D world, test leader control station. operator assessment and assistance work station (HMI), and operator driving work station (HMI). The 3D-world was modelled in Unity and consisted of two hub environments with loading docks (Arlanda and Rosersberg). The game engine back-end enables simulation of vehicles and traffic interaction in the 3D world. The test leader control station made it possible to start/stop the simulation and inject the triggering events as needed. The operator workstations with associated HMI enabled assessment, assistance and driving of vehicles in the simulator. The operator work stations are described in more detail in the interactive web page and academic papers.
WP5 – Evaluation methodology	
D5.1: Theoretical framework	A theoretical framework based on socio-technical systems theory was used as a tool for analysis of the findings from the user study. The framework will be presented in an upcoming journal paper (see list of publications).
D5.2+5.3: Evaluation methodology for Iteration 1+2, incl. metric and tools, analysis approach, experiment design and participant recruitment.	A methodology for evaluation was defined for the high-fidelity iteration. Qualitative and quantitative data was collected during the user test, with an emphasis on qualitative approach using think aloud protocols and interviews. In addition, subjective ratings of workload and user experience were used. Time to detection was used to measure operator focus on the driving task. The evaluation methodology is further presented in publications and webpage.

WP6 – Evaluation	
D6.1+6.2: Description of experiment execution, and findings from Iteration 1	Iterations 1 and 2 were merged into a concept and simulation with higher fidelity and evaluated with 15 participants. The qualitative findings from the user study were analysed using affinity mapping in a collaborative software (Miro). Each cluster was summarized, and the summaries were mapped to the socio-technical systems model. The subjective ratings were analysed to compare operator workload and experience between tasks. The insights are described in detail in publications.
D6.3: List of recommendations for remote operation center design and relevance for ICE	To present and disseminate the findings in an accessible way to practitioners, the HMI requirements derived from the project have been published as an interactive webpage. Link: https://tinyurl.com/havocproject Major insights are disseminated in academic publications. Future directions include e.g. further research on remote operator HMI, use of AI in vehicles, as operator support and resulting human-AI collaboration, and how the socio-technical systems perspective on remote control can be operationalized. As a result HAVOC 2 proposal is under discussion between partners.
WP7 - Dissemination	See chapter 7 in this report.

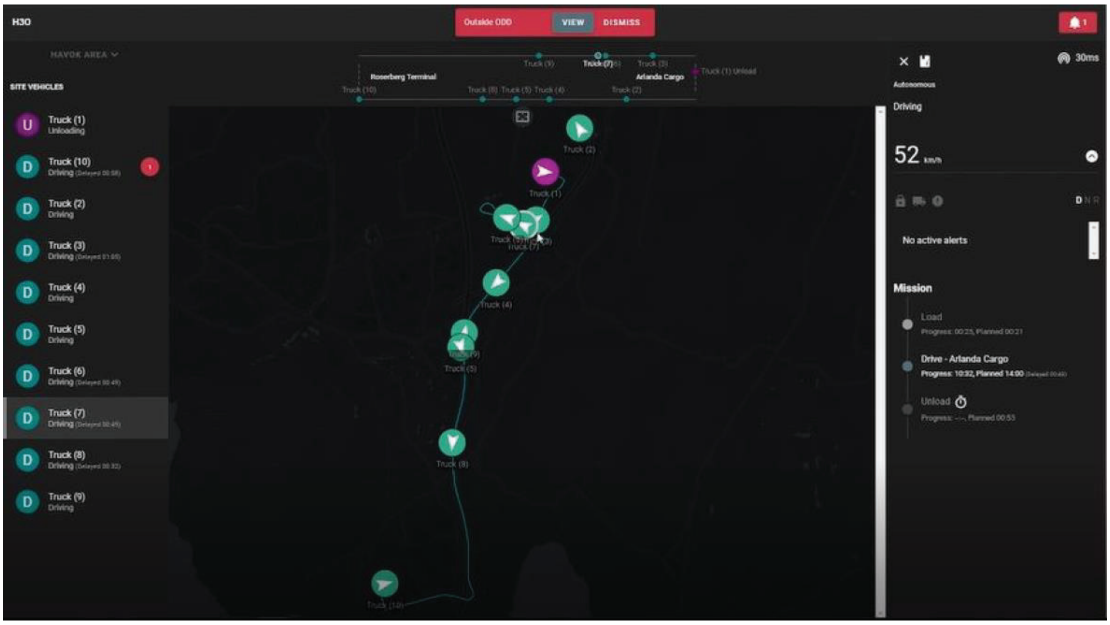

Figure 3. Example view of the HAVOC simulator HMI

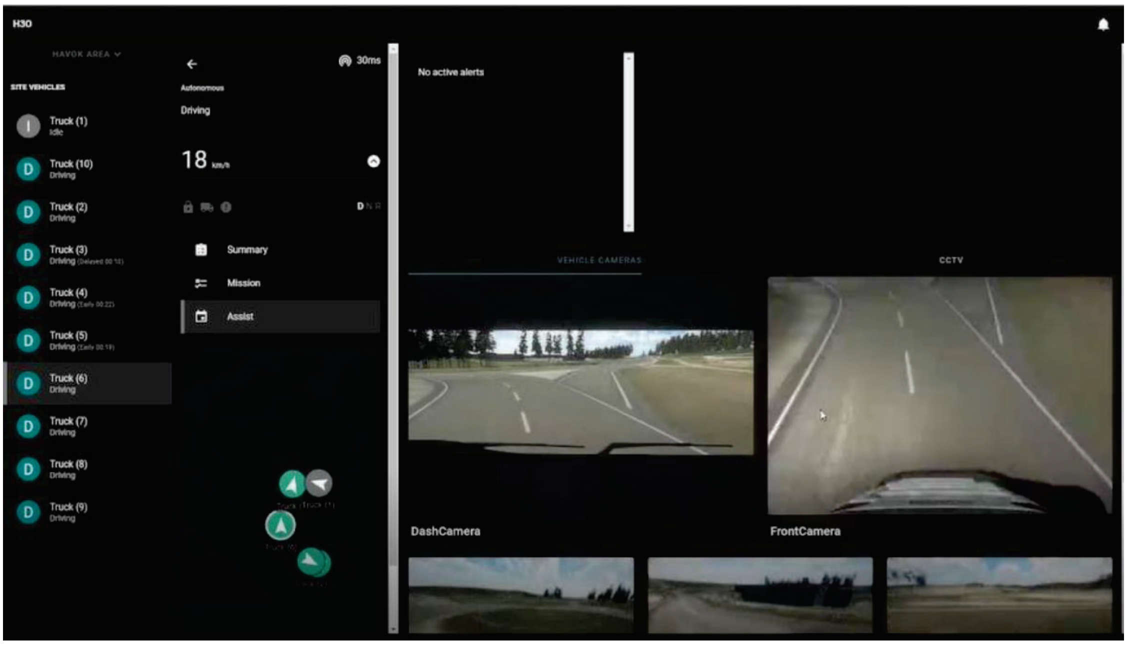

Figure 4. Example view of the HAVOC simulator HMI

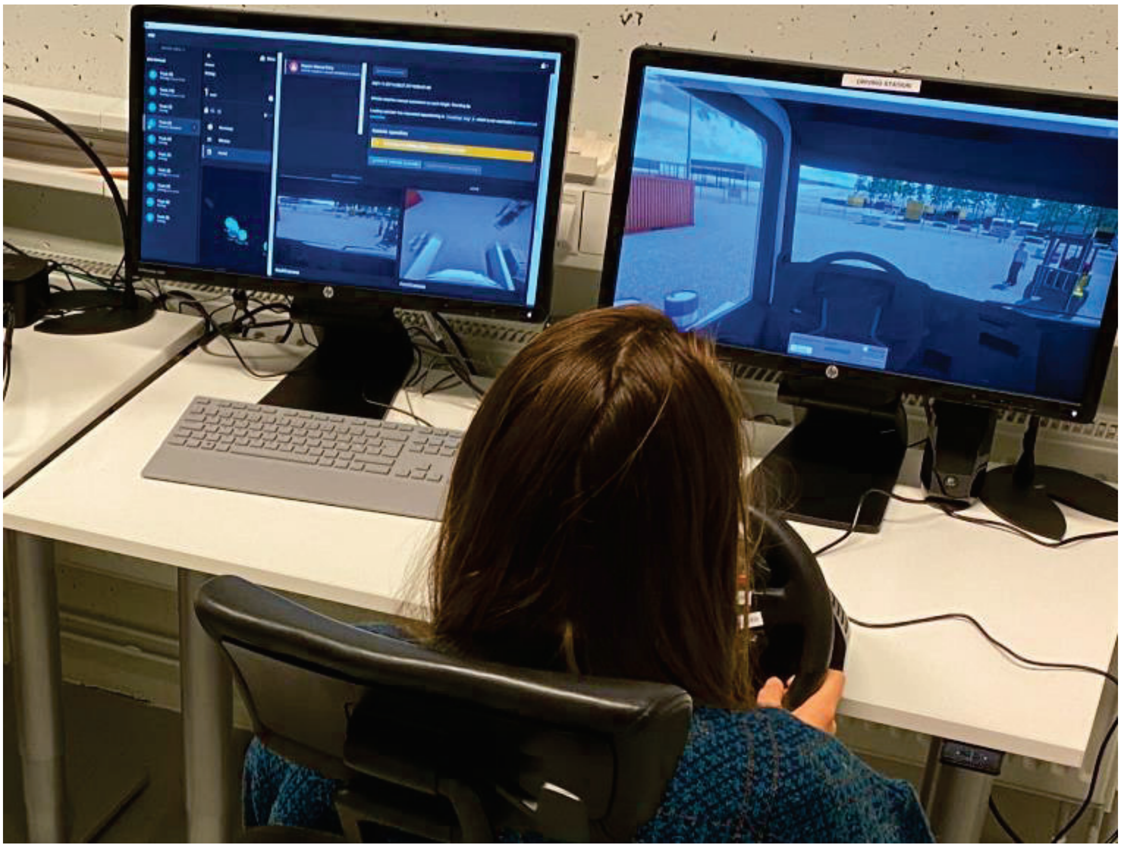
Figure 4. Overall view of the HAVOC remote operation simulator setup

Results with relevance to FFI

In the application, the project highlighted how it would contribute to the overall FFI goals and the specific TSAF program goals.

- *Increasing the Swedish capacity for research and innovation, thereby ensuring competitiveness and jobs in the field of vehicle industry*.
  During the project, the importance of remote operation capability for actors in the automated vehicle domain seems to be steadily increasing. Appendix A shows several mainly foreign actors, with a high focus on the remote control as a necessary complement to autonomous capability. The HAVOC project has contributed to developing and spreading knowledge within this field of research (see deliverables and dissemination activities), thus improving the Swedish capacity for research and innovation.

- *Developing internationally interconnected and competitive research and innovation environments in Sweden* and *Knowledge and competence development at research institutes and companies.*
  The HAVOC project has actively contributed to international connections in the EU, Asia and the US. For example, a workshop series has been held (and will continue) with the German research institute DLR. The project has also had international contacts via ISO TK238 SC39/WG8, where an international group on remote operation has recently started, and RISE is part. Contributions to conferences have also yielded new international connections for RISE.

- *Promoting cooperation between industry, universities and higher education institutions.*
  The project has contributed to workshops together with the KTH competence centre ITRL. Master thesis students were planned to be engaged in the project but were not realized due to the covid pandemic. The project has been associated with SAFER competence centre hosted by the Chalmers University of Technology.

- *Promoting cooperation between different OEMs.*
  In addition to Scania, Volvo Construction Equipment and Einride have been part of the reference group as representatives of Swedish OEMs. In the Road User Behaviour group within SAFER, a number of other OEMs (e.g. Volvo Trucks, NEVS) are also represented. For future follow-up projects to HAVOC, it is a goal to involve more than one OEM.

Results with relevance to the TSAF program

The project addresses mainly subareas F and D in the FFI-program *Trafiksäkerhet och automatiserade fordon (TSAF)*. The left column states the expected results as formulated in the research proposal. The right column explains how the expectations have been fulfilled.

Expected results from research proposal	Fulfilment
Program area F – Automated vehicles in the transportation system	
By identifying requirements and developing novel HMI concepts that enable remote operators to support automated driving systems in different applications, the project will create a certain redundancy for HAVs: *Baserat på nivå av automatisering behövs också olika grader av redundans.* Success criteria: The project has identified requirements for at least 2 remote operation application areas from a human perspective and developed and evaluated at least 2 HMI concepts with respect to these requirements. The concepts incorporate operational and/or tactical remote control of HAVs.	The HAVOC project has fulfilled the stated success criteria by identifying requirements and evaluated HMI for assessment (strategic control), assistance (tactical control) and remote driving (operational control). The requirements and the resulting HMI solution is presented in the HAVOC results webpage. The developed HAVOC simulation platform supports design and evaluation of future solutions that will serve as redundancy for autonomous vehicles by remote control by means of human operators.
These concepts will be integrated in a remote operation center (ICE) that is currently considered as inevitable for upscaling of HAV, and as such, the project will contribute to the development of digital infrastructure that supports a gradual transition to automated transport: *Fysisk och digital infrastruktur som stöder en gradvis övergång till automatiserad trafik och därmed också hantering av övergångsperioden upp till full automatisering.* Success criteria: At least 2 HMI concepts have been implemented and evaluated in a simulator that is based on the existing platform ICE. The concepts extend the current functionality of ICE, from allowing only strategic control to allowing strategic, tactical and operational control. This, in turn, will create new research platform to be used in future research projects.	The HAVOC project has partly fulfilled this success criteria by designing and implementing a simulator environment that enable testing and evaluation of remote assessment, assistance and driving, giving input to improve the ICE platform capability. The concepts have however not been implemented in the actual ICE platform but can serve as inspiration for further work. Detailed concepts are presented in research papers and on the HAVOC results webpage. Link: https://tinyurl.com/havocproject
By enabling HAVs to be safely and cost-efficiently operated even in situations that are	The evaluation scenario and use cases has considered several safety related and

beyond current capabilities of automated driving systems, the project will contribute both to improved transport safety and efficiency: *Även om huvuddrivkraften för forskning och utveckling som faller inom detta område inte är att förbättra trafiksäkerheten och ta ett signifikant kliv mot att uppfylla nollvisionen är det en förutsättning att trafiksäkerheten bibehålls eller förbättras.* Success criteria: The evaluation has considered at least two safety-related aspects and at least two efficiency-related aspects.	efficiency related aspects. Safety related aspects include the information needs during remote control, needs for reassurance of situation when acting under scarcity of information and how the evaluated situations can be assessed (access to additional camera views etc). In terms of efficiency the simulations showed that, under given circumstances, control modes and HMI, ten automated vehicles could be controlled in parallel without effects on performance. It was also concluded that the ratio operator:number of vehicles will depend on several factors not only failure rate, but also vehicle capability, HMI, organizational support, etc. stressing the need for a systems perspective in design of human-automation collaboration for remote control.
Program area D – Driver support and related interfaces between driver and vehicle and interfaces with other traffic	
A remote operator can be considered as a vehicle driver that is not spatially located in the vehicle, or a driver that has got a new role and tasks given the increased level of automation in the vehicle. Similar to regular vehicle drivers, it is thus crucial to develop proper HMI for remote operators. The major focus of the project is to identify requirements that are posed on remote operators and design HMI addressing these requirements: *Förändringar i teknisk komplexitet hos fordon och vägsystem, ökad tillgänglig information för fordon och förare samt hantering av informationssystem såsom telefoner, navigations- och ruttplaneringssystem mm kommer att innebära en förändrad roll för föraren. Utmaningen är att ta hand om den nya rollen.* Success criteria: The project has identified requirements for at least 2 remote operation application areas from human perspective and developed and evaluated at least 2 HMI concepts with respect to these requirements.	The HAVOC project has explored remote operator work and the how the role of the operator will change when transitioning between assessment, assistance and remote driving.

7. Dissemination and publications

How are the project results planned to be used and disseminated?	Mark with X	Comment
Increase knowledge in the field	X	The HAVOC project has contributed to increased knowledge in remote operation of heavy vehicles by showing both practical examples (HMI-design and simulation) and giving theoretical insights (e.g. definitions of a systems perspective to remote operation).
Be passed on to other advanced technological development projects	X	The knowledge and results from the HAVOC project will be passed on to advanced technological projects at Scania and other Swedish industry OEMs. Results have been presented at SAFER and to Einride.
Be passed on to product development projects	X	The knowledge and experiences from the HAVOC project have been passed on to project development projects at Scania.
Introduced on the market		
Used in investigations / regulatory / licensing / political decisions	X	RISE is part of ISO TK238 SC39/WG8 recently started group on remote operation, and will support the development of standards with knowledge from the HAVOC project.

7.1 Dissemination

- The project was presented by RISE at the Automated Road Transportation Symposium (ARTS) 2021 as a part of the breakout session Remote Support for Automated Vehicle Operations. The audience consisted of about 35 professionals from various international organisations. July 15, 2021. (https://onlinepubs.trb.org/onlinepubs/Conferences/2021/ARTS/B403Agenda.pdf)

- The project was presented by RISE at the FISITA Intelligent Safety Conference 2021 as a part of the breakout session Technical Session Three: Impacts of Human Factors on Safety. The audience consisted mainly of Chinese professionals. July 16, 2021. (https://www.fisita.com/post/welcome-to-the-fisita-intelligent-safety-conference-china-2021)

- The project was presented at the EU Connected and Automated Driving (EUCAD) conference 2021 as a part of the breakout session Human Factors of remote control operation: what are the lessons learned and future challenges? The audience were representing vehicle manufacturers, suppliers, software development companies, governments, public transportation companies, European commission as well as

university and other research institutes and came from Europe, Japan, Canada, Brazil etc. April 22, 2021.
(Presentation recording available at: https://youtu.be/T6TrrxtIy6U HAVOC presentation starts at 6m10s)

- The project was presented by RISE at the Japanese SIP-ADUS 2021 workshop break out session on Human Factors in Mobility Services, October 29, 2021. The audience consisted of around 60 international peers. (https://en.sip-adus.go.jp/evt/workshop2021/breakout.html#hf)

- The project was presented by Scania at the Scania Innovation Day.

- Two remote operation workshops with German DLR team working with human factors and UX in remote teleoperation during spring 2022. Collaboration will continue.

- The project was associated to SAFER and the Road User Behaviour group at SAFER in the beginning of the project. Project results were presented at SAFER Research & Project day 2022-03-11 with around 100 persons from the SAFER community attending.

- HAVOC has been mentioned in three short OMAD newsletter articles reaching 1600 subscribers in Sweden: https://omad.tech/?s=havoc

- RISE is part of the ISO TC/SC39 WG8 where guidelines for remote operation of automated vehicles are being discussed and developed and HAVOC will contribute with knowledge from the project to support the development of standards.

- Presentation at Einride Lunch&Learn seminar 2022-04-13 with participants from Sweden and the US.

- Webpage with requirements and findings published online: www.tinyurl.com/havocproject

RISE continues research on remote operation within the EVOLVE project together with Ericsson, KTH and Dynorobotics (https://www.ri.se/sv/vad-vi-gor/projekt/evolve). RISE also leads the project GLAD where remote control of small delivery vehicles is a part (https://www.ri.se/en/what-we-do/projects/glad-goods-delivery-under-the-last-mile-with-autonomous-driving-vehicles)

7.2 Publications

- Andersson, J., Rizgary, D., Söderman, M., & Vännström, J. *Exploring remote operation of heavy vehicles – findings from a simulator study*. Paper submitted to Human Factors and Ergonomics Europe Chapter Conference, Turin, 2022.

- Vreeswijk, J., Bin, E., Habibovic, A., Madland, O., & Hooft, F., *Remote support for automated vehicle operations.* In Road Vehicle Automation 9 Book (Ed. Gereon Meyer, VDI/VDE-IT, and Sven Beiker, Stanford University). Expected publication July 2022.

- Andersson, J., Rizgary, D. & Söderman, M. *Remote operation of automated vehicles: A systems perspective*. Journal paper to be submitted.

8. Conclusions and future research

The socio-technical systems perspective on remote operation
One of the major takeaways from the user study and the the HAVOC project in general is the importance of a systems perspective in analysis and design of future remote operation centers. The answer to questions such as "*How many operators are needed?, How many vehicles can be monitored and controlled?, What is the best HMI?, What are the most important operator tasks?"* etc., will always rely on the dependencies between multiple human, technical and organizational factors. The ability to deal with the dependencies between factors such as operators' skills and knowledge, operator tasks and training, HMI, vehicle capabilities, operational context, etc. lies in defining the envisioned work system and deciding what to design for. If a viable business case for remote operation is an operator:vehicle ratio of 1:1, 1:10 or 1:100, will place very different demands on overall human-automation systems design and work organization. In this project we have only considered single operator work. In real application team work between remote operators, traffic planners and field personnel can be expected further stressing the socio-technical systems approach.

Future research
Future research directions from the socio-technical perspective include methodologies to explore and design for dependencies between operators, technology, and organization. Cybersecurity from the operational perspective is an additional layer that should be further explored. Another upcoming topic that can have a significant impact on the operator:vehicle ratio is how to support operators using AI-agents and explainable AI for decision support. RISE continues research path within the Vinnova funded EVOLVE project.

9. Participating parties and contact persons

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Appendix A – Actors in the remote vehicle operation domain

A visit to all the listed commercial actors' websites reveals concepts that, at least on a conceptual HMI related level, are quite similar e.g., using pedals, steering wheel, and screens. Some of these solutions include multiple levels of remote control: remote assessment, remote assistance, and remote driving.
These are some but not all the solutions that exist from commercial actors, and there surely exists several other companies with existing or forthcoming solutions. Note that the following list is in no particular order.

Name of company	Company description	Remote operation levels	Type of vehicles	Source
DriveU.auto	DriveU.auto a company based in Israel, developed, and is deploying a software-based connectivity platform for teleoperation of robots and Automated vehicles.	*Remote assessment *Remote driving	*Automated vehicles	https://driveu.auto/
Voysys	Voysys is based in Norrköping in Sweden, and they offer live virtual reality production software. Product Voysys VR Producer allows depth-based stitching of 360° video, switching & changing camera positions, and rendering additional graphics & virtual screens on top.	*Remote driving	*Automated vehicles	https://www.voysys.se/
Einride	Einride is based in Stockholm in Sweden and their pod Pod operates with remote oversight and remote drive capability. Einride Saga is a digital platform for shipping networks.	*Remote assessment *Remote driving	*Freight pods	https://www.einride.tech/

Phantom Auto	Phantom Auto is based in California San Francisco. Phantom Auto enables operators to remotely control vehicles across sites. Employees can remotely monitor, guide, and operate forklifts and other vehicles.	*Remote assistance *Remote driving	*Logistics vehicles (Pallet jacks, counterbalances, trucks, robots)	https://phantom.auto/
Designated Driver	Designated Driver is based in Portland, and they offer seamless teleoperation of autonomous and non-Automated vehicles.	*Remote assessment *Remote assistance *Remote driving	*Automated vehicles	https://designateddriver.ai/
Imperium Drive	Imperium Drive is a London based company that develop remote driving technology for Automated vehicles. The company has piloted a mobility service that utilize remote driving to drive the vehicle to customers in Milton Keynes in England.	*Remote driving	*Remote mobility service vehicles	https://imperiumdrive.com/
Vay	Vay is a company based in Berlin, Germany. The company has piloted a mobility service that utilize remote driving to drive the vehicle to customers.	*Remote driving	*Remote mobility service vehicles	https://vay.io/
Ottopia	Ottopia Technologies, a company based in Israel, engaged in the design, development, and commercialization of teleoperation systems. Robotaxi fleet operator company Motional utilizes Ottopia's teleoperation solutions.	*Remote assessment *Remote assistance *Remote driving	*Automated vehicles	https://ottopia.tech/

Carmenta	Carmenta is based in Gothenburg, Sweden. Carmenta’s software development kits make it possible to create and deploy state-of-the-art 2D/3D geospatial applications and build geospatial Command & Control and intelligence systems.	*Remote assessment *Remote assistance	*Automated vehicles	https://carmenta.com
RoboAuto	The Czech Republic based company RoboAuto develops and integrates industrial vehicles remote control. Secondly, its HD mapping detects and maps custom objects in video materials, e. g. road signs or trees.	*Remote driving	*Automated vehicles	https://roboauto.tech/
Waymo	Waymo is based in California, USA, and develop technology for Automated vehicles. The company develops the technology for robotaxi fleet operation and truck freight operation.	*Remote assessment *Remote assistance	*Robotaxi *Autonomous trucks	https://waymo.com/
Cruise	Cruise is an American company based in California that develop technology for Automated vehicles, and their main focus is on robotaxi fleet operation.	*Remote assessment *Remote assistance	*Robotaxi	https://www.getcruise.com/
Yandex	Yandex is based in Moscow, Russia. Yandex is a technology company which provides a search engine as well as other digital services. Yandex is developing a robotaxi service as well as autonomous delivery vehicles.	*Remote assessment *Remote assistance	*Robotaxi *Autonomous delivery vehicles	https://sdg.yandex.com/

Argo AI	The American company Argo AI is based in Pennsylvania, USA. The company develops technology for Automated vehicles which is intended for an autonomous ride sharing service.	*Remote assessment *Remote assistance	*Robotaxi	https://www.argo.ai/
Nuro	Nuro is based in California, USA. The company focuses on developing medium sized autonomous delivery vehicles.	*Remote assessment *Remote assistance *Remote driving	*Medium sized autonomous delivery vehicles	https://www.nuro.ai/
Ericsson	Ericsson is based in Stockholm, Sweden and work with communication technology. The company explores using cellular networks for teleoperation.	N/A	*Automated vehicles	https://www.ericsson.com/
Combitech	Combitech is a tech company based in Växjö, Sweden. Combitech is exploring teleoperation platforms in control towers which can be used for Automated vehicles.	N/A	*Automated vehicles	https://www.combitech.se/
Zoox	Zoox is based in California, USA. The company is developing Automated vehicles intended for a mobility service.	*Remote assessment *Remote assistance	*Autonomous shuttles	https://zoox.com/
Aurora	Aurora is a company based in Pennsylvania, USA. Aurora develops technology for Automated vehicles. Their technology is applicable to long-haul trucking, autonomous delivery vehicles as well as robotaxi services.	*Remote assessment *Remote assistance	*Robotaxi *Autonomous trucks *Autonomous delivery vehicles	https://aurora.tech/

Baidu	Baidu is based in China and is primarily a provider of an internet search engine. The company develops technology for Automated vehicles including robotaxi, autonomous trucks and autonomous shuttle buses.	*Remote assessment *Remote assistance *Remote driving	*Robotaxi	https://apollo.auto/
Starship Technologies	Starship Technologies is an Estonian company that develops small autonomous delivery vehicles.	*Remote assessment *Remote assistance *Remote driving	*Small autonomous delivery vehicles	https://www.starship.xyz/
TuSimple	The American company TuSimple develops technology for autonomous trucks. The company utilizes teleoperation as a backup for their autonomous long-haul testing but has recently been able to do testing without teleoperation.	N/A	*Autonomous trucks	https://www.tusimple.com/
Pony.ai	Pony.ai is based in USA and China. The company is developing a robotaxi service and has also explored autonomous delivery services.	*Remote assessment *Remote assistance *Remote driving.	*Robotaxi *Autonomous delivery vehicles	https://pony.ai/
AutoX	The China-based company AutoX is developing a robotaxi service. AutoX has been piloting robotaxis in China and USA.	*Remote assessment *Remote assistance *Remote driving	*Robotaxi	https://www.autox.ai/

These actors utilise remote control for different purposes. Some of them, e.g., Voysys, Phantom Auto, and Designated Driver, market these solutions for others to buy and use, which entails that their solutions often are operable in multiple types of vehicles. Imperium Drive and Vay use remote control to relocate otherwise manual ride-sharing vehicles to customers. Other actors mainly focus on developing automated commercial vehicles such as robotaxis, autonomous delivery vehicles, and autonomous trucks that utilise remote control solutions as a backup safety measure. The American companies Waymo, Argo AI, Aurora and Cruise who are developing robotaxis exclude remote driving, whilst Chinese companies Baidu, Pony.ai, AutoX that work in the same domain utilise remote driving." Our tele-assist specialists won't be sitting in a distant room turning a wheel, pressing a pedal, and otherwise directly engaging the controls of a remote vehicle. We're taking a different approach because we're not comfortable with the risks posed by remote control driving." – Aurora [1]

[1] https://aurora.tech/blog/teleassist-how-humans-collaborate-with-the-aurora