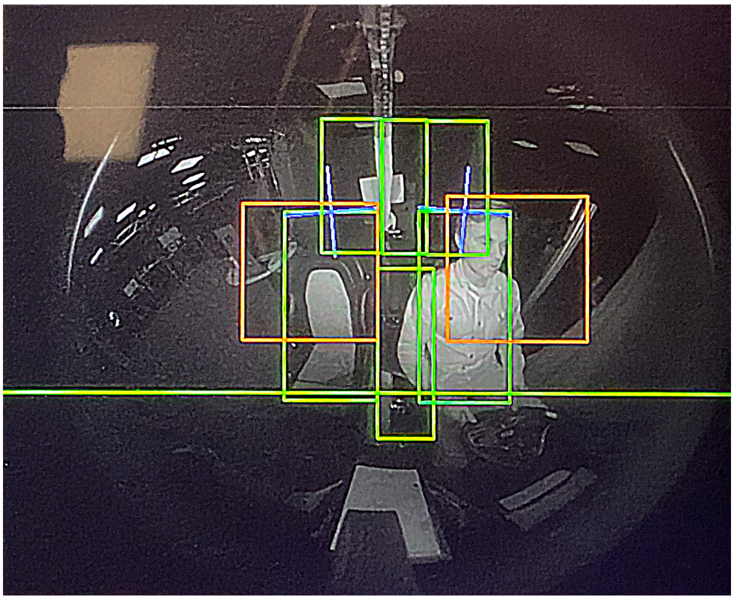
RE-ENGAGE

Design of adaptive human-vehicle interaction in autonomous cars using readiness classification

Public report



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Project within FFI Electronics, software and communication

Innehållsförteckning

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1 Sammanfattning

En av fördelarna med högt automatiserade fordon på SAE-nivå 4 [1] är möjligheten för förare att koppla bort sitt köransvar. Forskning visar att individer aktivt deltar eller önskar delta i olika aktiviteter när de befinner sig i autonomt läge, t.ex. umgås, arbeta eller helt enkelt luta sig tillbaka och njuta av en tupplur. För att detta ska vara möjligt måste det finnas åtgärder som gör det möjligt för föraren att vid behov återta kontrollen över fordonet på ett komfortabelt och säkert sätt.

Projektet RE-ENGAGE har integrerat användarupplevelse (UX) och maskininlärning (ML) i en tvärvetenskaplig ansats. Målet var att utforska, demonstrera och skapa lösningar som effektivt återengagerar föraren av en självkörande bil när föraren varit upptagen med aktiviteter som inte är relaterade till framförandet av fordonet. Detta uppnåddes genom att använda algoritmer för maskininlärning som kan känna igen olika aktiviteter utifrån kamerabaserade dataströmmar, t.ex. att se på film eller vila med slutna ögon. Detektering av dessa aktiviteter påverkade sedan hur ljud, ljus, haptik och textbaserade meddelanden aktiveras i förarmiljön. Designarbetet har skett genom att kombinera traditionell UX-design för fordon med Soma-design. Soma-design är ett angreppsätt som tidigare inte använts inom fordonsindustrin. I projektet har det använts i kombination med andra designmetoder för att skapa prototyper som aktiverar hela kroppen genom multimodala interaktioner.

Inom projektet genomfördes ett antal workshops och tre simulatorstudier. Prototyper togs fram genom ett iterativt arbetssätt i samarbete mellan Volvo Cars, Smart Eye, KTH och RISE. Prototyperna utvärderades både inom workshoparna (internt) och i simulatorstudier (externa deltagare).

Resultaten från simulatorstudierna visar att det finns både beteende- och upplevelsemässiga fördelar med att anpassa interaktionen med föraren utifrån förarens aktiviteter. Sammanfattningsvis är anpassning av interaktionssekvenser till förarens aktivitet både en komplex designuppgift och en teknisk utmaning. RE-ENGAGE-projektet har framgångsrikt utvecklat koncept, metoder och verktyg som kan underlätta framtida utveckling inom detta område.

2 Executive summary in English

One of the benefits of highly automated vehicles at SAE level 4[1] is the opportunity for drivers to disconnect from their driving responsibilities. Research indicates that individuals actively engage or desire to engage in various activities while in autonomous mode, such as socializing, working, or simply reclining and enjoying a restful nap. In order for this to be possible, there have to be measures in place for facilitating the driver in regaining control of the vehicle, when necessary.

The RE-ENGAGE project constituted a cross-disciplinary endeavor that integrated user experience (UX) and machine learning (ML). Its objective was to explore, demonstrate, and implement solutions that effectively re-engage the driver of an autonomous car when they are engrossed in non-driving related activities. This was accomplished by utilizing machine learning algorithms capable of recognizing different activities based on video data, such as reading a book or taking a power nap. The recognition of these activities then influenced the information presented through the interface to the driver. From an UX perspective a novel approach called Soma design was used to create prototypes that activates the whole body through multimodal interactions. In this way, it is possible for the driver interface to adapt to tasks not necessarily related to driving, in turn allowing for the driver interface to re-engage the driver back into the driving task.

The project included several workshops and three simulator studies. Prototypes were developed through an iterative approach in collaboration between Volvo Cars, Smart Eye, KTH and RISE. The prototypes were evaluated both in the workshops (internal) and in simulator studies (external participants).

The results from the simulator studies show that there are both behavioral and experiential benefits of adapting the interaction with the driver based on the driver's activities. In general, adapting HMI re-engagement sequences to driver activity is both a complex design task and a technical challenge. The RE-ENGAGE project has successfully developed concepts, methods, and tools that can facilitate future developments in this area.

3 Background

Studies show that when people get to experience autonomous vehicles, they quickly adapt to their new role as a passenger and begin occupying themselves with non-driver related tasks such as doing makeup, working, reading a book and texting [FFI TIC]. These types of activities can result in difficulty to re-engage in the driving task, and they can also induce discomfort [FFI TIC; FFI Harmonise].

Moreover, there are benefits in getting a broader understanding about what goes on inside the vehicle with the help of a Driver Monitoring System (DMS) that has the capability to detect non-driving related tasks. With this information the vehicle-to-driver interface can adapt and improve the in-cabin environment based on different situations, in terms of increasing the Experience Design Domains (EDD).

3.1 In-cabin driver activity recognition

This project built upon the work done by Volvo Cars where information about the in-cabin context has been used to reduce driver distraction [2], [3].

Machine- and deep learning applications in the automotive domain in general, and for driver monitoring in particular, are rapidly evolving. The research focuses on e.g. predicting maneuvers[4], identifying driver postures and activities[5], and driving styles[6]. However, little focus has been put on using the information to aid the user experience within the car. Recently, [FFI DRAMA] has contributed to this and developed an interior sensing framework and corresponding prototypes to recognize driver/passenger activities with the aim to provide meaningful inputs for applications to improve safety and comfort in highly automated vehicles.

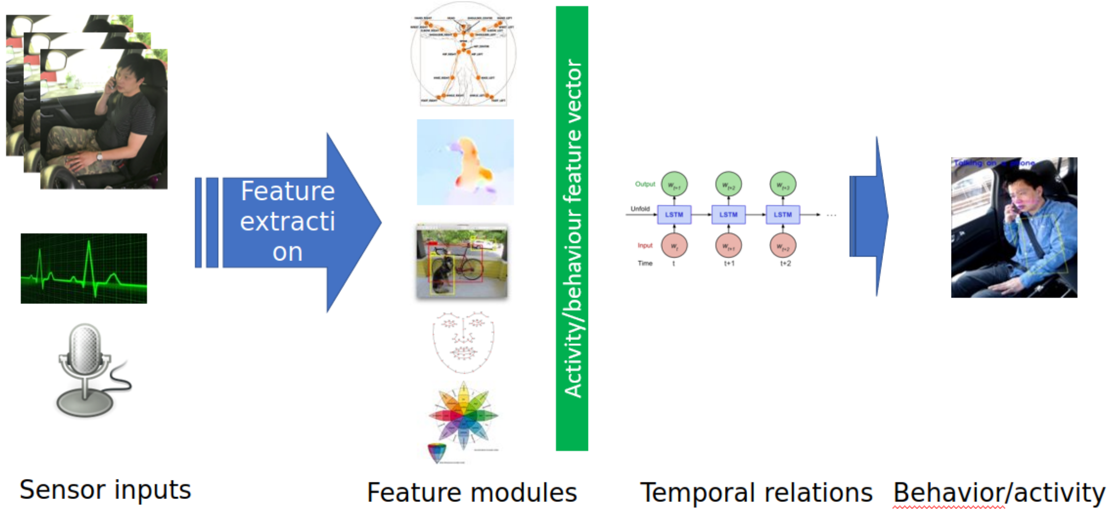


Figure 1: DRAMA behavior/activity recognition framework

In order for a vehicle to classify the current activity/state of the driver and pass this information on to the on-board computer, which can then choose the appropriate interaction/intervention to re-engage the driver. The vehicle also needs relevant information about the traffic context for meaningful classifications.

The human activity categorization problem has remained a challenging task in computer vision for more than two decades[7]. Unimodal and multimodal methods [8], [9] have shown great potential in this area.

However, the general framework for driver mapping based on multiple measures, as proposed in DRAMA (Figure 1), does not exist in literature.

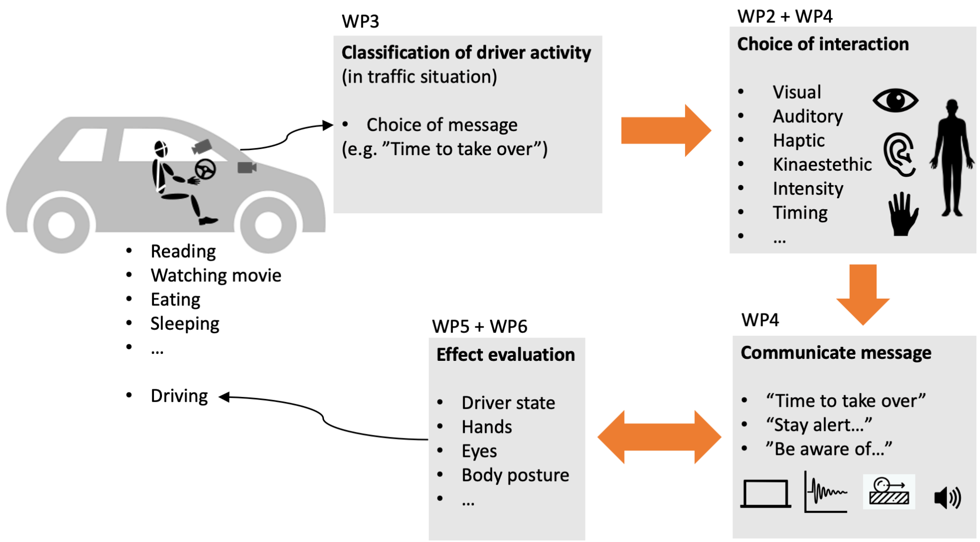


Figure 2: The re-engagement cycle and connection to project work packages

3.2 Soma design

Soma Design or Soma Aesthetics can be explained as an approach to design that works towards improving the connections between sensation, feeling, emotion, subjective understanding and values [10]. When applying this to designing a prototype, it means to imagine the end users' bodies and movements when interacting with the prototype. In the case that the prototype is related to driving a vehicle and interacting with its human-machine-interface, the soma design approach entails analyzing the habitual movements and positions of the body in that interaction. If the positions and movements of the drivers do not lead to positive and comfortable experiences, there is an opportunity to correct the design.

Soma Design is a fairly recent design framework that is gaining traction in the interaction design world. It addresses a gap in the design work on embodied interaction[11], providing a direction and stronger connection to aesthetic considerations. Soma Design has successfully been applied to many different domains, but to our knowledge, not yet to the in-car experience. This said, the car industry has since long been concerned with the user experience of everything from the dashboard to the sound of the car door closing. Soma Design fits into the industrial design tradition that has for many years engaged with design of vehicles.

There is scientific support for a multimodal HMI approach. Auditory and vibrotactile feedback have for example shown to lead to shorter take-over times[12]. Driving a car is not solely a matter of being alerted to dangers or controlling the vehicle, it is also a user experience that can bring pleasure. [13] frames pleasant driving experiences as becoming embodied with the car, being one with the road and the general experience of traveling. Our design aim is to reduce the time it takes for the driver to regain control of the car which must be in harmony with the overall embodied experience of traveling.

4 Purpose, research questions and methods

4.1 Purpose, aim and research questions

The aim of the project was to investigate, demonstrate and implement solutions that re-engage the driver in an autonomous car when immersed in non-driving related activities. The specific research questions were:

- **RQ1** - Detection: How can the activities, such as watching a movie and resting best be detected and correctly classified by machine learning algorithms in real-time constraints?
- **RQ2** - Reliability: How reliable are the machine learning algorithms in classifying and differentiating between the activities?
- **RQ3** - Interaction: How should re-engagement interactions be designed to create pleasurable tailored experiences when moving between non-driving related and driving related activities?

The work was divided into 6 interdependent work packages (WPs, Figure 3). The project was cross-disciplinary between the user experience and machine learning fields of research.

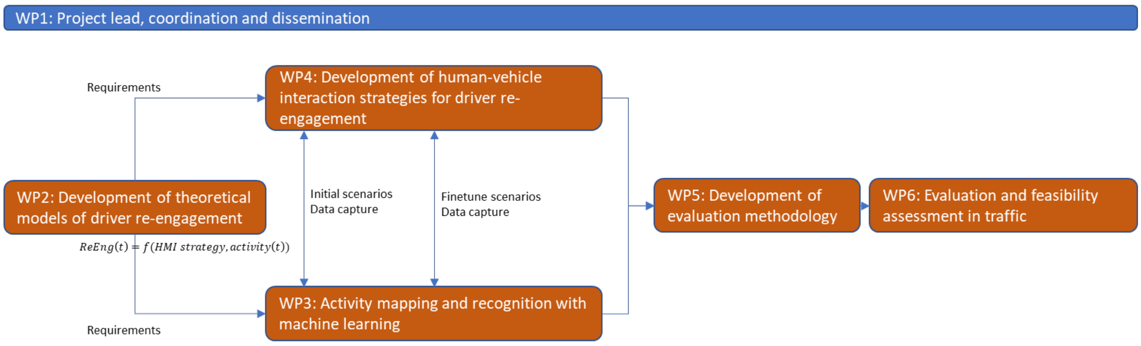


Figure 3: RE-ENGAGE workpackages

4.2 Methods

4.2.1 Soma design workshops

Two soma design workshops were done in the project. Researchers from KTH hosted the first workshop in Stockholm (Figure 4), where the concepts of soma design were explored. Methodologies to articulate bodily experiences were introduced and early prototypes of shape changing design materials for the vehicle context were explored. One finding of interest was the strong sensation of relaxation when an

Figure 4: Soma design workshop 1

Figure 5: Soma design workshop 2

inflated seat cushion is rapidly deflated. In addition, other sensations of heat, vibration and movement was explored. The second workshop was hosted by Volvo Cars in Gothenburg (Figure 5). The prototypes from the first workshop had then been iterated by the team at KTH. A seat cushion prototype was developed to better produce the sensations of relaxation discovered in the first workshop. This prototype was used in further testing with the workshop participants on a small test track at the Volvo Cars premises.

4.2.2 Student projects

The project involved several student projects – one MSc thesis (VCC/Chalmers), one BSc thesis (RISE/Gothenburg University), and one Volvo Cars graduate program project (VCC). In addition, two students from KTH worked with prototype development and workshop preparations under supervision of Prof. Kristina Höök.

The MSc thesis explored the impact of adding friction to certain parts of the interaction during a take-over situation, the students iterated different stakeholder inputs into a concept leveraging expert interviews, surveys, and workshops which resulted into an HMI implementation in a driving simulator. The HMI concept was evaluated with 6 participants and was later demonstrated for experts using an on-road test vehicle. The thesis resulted in a thesis report [14] and a scientific journal paper *(Bley et. Al., Accepted Subject to Revisions)* submitted to a special issue titled: Issue on Engaging with Automation: understanding and designing for operation, appropriation, and behavior change in the Journal of Personal and Ubiquitous Computing. The students were employed by Volvo Cars after their thesis.

The BSc thesis examined user experience in relation to engagement in non-driving related tasks (NDRA) (video watching and lego building) as well as timing of the take-over requests (TOR). It included investigating a holistic view of the experience in a take-over scenario. Participants of the study were divided in two groups, with static and dynamic time frames. Static time frame entailed that the TOR was issued at fixed times for both NDRAs, compared with the dynamic time frame where the TOR was presented at different times depending on which NDRA the participant was engaged in. The two NDRAs were in turn divided into high and low engagement. Engagement level in NDRA showed a clear effect on how the participant experienced the take-over scenario, while the timing did not. Participants showed a preference for the static time frame of TORs. However, preference of time frame did not depend on which time frame the participant experienced during the test. A main influence on how participants reasoned about the preferred timing of the TOR was attitudes towards AVs. The BSc thesis resulted in a thesis report [15].

The graduate project resulted in an investigation of how pneumatics and electronic seat motor controllers may be used to enable more 'high-resolution' interaction could take place using the seat as the communication channel. The graduates implemented both the required electronics and software protocols to integrate both pneumatics in one simulator rig, and electronic motor control functions in a production car seat for another simulator.

4.2.3 UX design workshops

Several UX design workshops were conducted to create a tailored, user-centric, and delightful experience. Each workshop was held around the driving simulator to replicate real car sensations as accurately as possible.

Two preliminary workshops were conducted around a whiteboard to generate diverse ideas for the takeback sequence. Subsequent workshops involved illumination and sound designers. The illumination workshop explored lighting options and placements, while the sound workshop determined suitable sound types and their synchronization with on-screen notifications.
Multiple cross-functional workshops were held to align sound, lights, haptic feedback, and graphics for a cohesive experience. The driving simulator provided an invaluable platform for testing and refining the user experience.

These workshops played a crucial role in designing a seamless transition, combining real-life sensations with creative elements to engage drivers effectively.

4.2.4 Simulator testing

The major testing and data collection activity in the project was a simulator study conducted in a vehicle simulator at Volvo Cars Open Innovation Arena. Initially, the project aimed for an on-road Wizard-of-Oz study with test vehicles driven from the back seat. The on-road study setup was however discarded due to the need for a more exploratory approach in combination with a controlled experiment design. The simulator environment was found to be more flexible in terms of implementing new HMI design prototypes, which was necessary to fulfil the purpose of the study.

In the simulator experiment, the iMotions platform was used as a tool to facilitate collection, analysis, and interpretation of data. The tool allows for simultaneous data collection and analyses of a range of various sources synchronized in time. Video and sensor data can also be annotated post-hoc. The platform can visualize sensor data and video recordings during and after data collection.

5 Goal

The RE-ENGAGE-project has contributed to the development of safety in automated vehicles by providing knowledge of how the range of take-over times can be accommodated for by adapting the HMI to driver activity in time critical situations. The project also fulfilled the following FFI goals:

- **Increased the Swedish capacity for research and innovation**: The RE-ENGAGE project has developed and strengthened the collaboration between industry (Volvo Cars and Smart Eye, academia (KTH) and research institutes (RISE) by inventing new approaches and tools to design human-system interaction in autonomous vehicles.

- **Developing internationally interconnected and competitive research and innovation environments in Sweden:** During the project Volvo Cars started their collaboration with Stanford University on neurocognitive measurements during simulated driving. A simulator study using fNIRS measurement to investigate brain readiness in autonomous drive to manual driving handover situations.
  RISE were invited to the Dagstuhl seminar on Radical Innovation and Design for Connected and Automated Vehicles [16]. The seminar was held in Germany with distinguished peer researchers from the United States, Germany, United Kingdom, Australia, the Netherlands, Austria, Finland and Sweden.
- **Promoting the participation of small and medium-sized companies**: Project partner Smart Eye is an SME.
- **Promoting the participation of subcontractors**: Smart Eye is a Tier 1 supplier. Specifications for seat actuators in terms of movement and shape changing functionality will bring future collaborations with subcontractors.
- **Promoting cross-industrial cooperation**: SOMA design is a cross-industrial research area, where the designs and concepts can learn from one industry to another (e.g. from furniture manufacturer Ikea to Automotive OEM VCC)
- **Promoting cooperation between industry, universities, and higher education institutions**: Two student theses and one graduate project were completed. One MSc thesis was hosted by Volvo Cars, and a BSc thesis was hosted by RISE. In total, four female university students were supervised during their thesis work.
- **Promoting cooperation between different OEMs**: The project has been associated with SAFER research area Road User Behaviour, where several vehicle OEMs are present. SAFER works as an arena for disseminating general research knowledge in the field.

Further, the project meets specific FFI EMK goals related to machine learning and human- machine interaction.

FFI EMK Goals	**RE-ENGAGE results**	**Success metric**
Machine learning goal – individualized functionality	The project addressed the challenge of creating individualized functionality by means of machine learning by tailoring the choice of HMI strategy to the individual driver's activity.	The research platform and working prototype algorithm is able to classify activities that can be used to trigger the HMI intervention.
Human-machine interaction goal – safe control transitions	The project addressed the challenge of re-engaging a driver in the driving task after sustained simultaneous exposure to automated driving while watching a movie or resting. Given that drivers' states may vary depending on automation capabilities and engagement in NDRT's a re-engagement strategy that is beyond a one-size fits all is required so that drivers may feel calm in regaining control without adding frustration or over-stimulation by excessive use of feedback.	Multimodal HMI combinations adapted to the driver activities have been developed, demonstrated and tested, as well as qualitative and quantitative evaluation results.

The proposal listed expected results from the project. The corresponding results are listed below:

- **Knowledge and guidelines on multimodal activity-based HMI:** Multimodal HMI-design concepts have explored, and the results have generated findings of relevance for Volvo Cars as a vehicle OEM and Smart Eye's development of in-vehicle sensing systems. The knowledge gained in the project has strengthened RISE position a research partner.

- **Knowledge on in-cabin activity and its connection to the re-engagement time:** In-cabin activities have been explored and strategies for activity-based HMI have been implemented in prototypes. The project took its starting point in activities such as eating, drinking, reading etc., and generalized the approach with driver readiness metrics towards the end of the project.
- **A prototype implemented in a Smart Eye demonstrator**: Smart Eye implemented systems for the simulator testing as well as for demo purposes at the CES2023 conference, see deliverable D3.4.
- **Enhanced activity assessment by Smart Eye**: Smart Eye developed their activity assessment in the project, see deliverable D3.4.
- **Requirements on HMI and algorithm design feeding into Volvo Cars agile working processes:** The Safe Vehicle Automation Team has continuously implemented learnings from the RE-ENGAGE project into their product definition.
- **Estimate of potential safety risks and negative experiences of activity-based HMI**: The simulator experiments have given insights on how different HMI sequences affect experiences in autonomous driving. User experience and driving behavior after take-back was evaluated using a mixed methodology framework.
- **A mixed methodology framework for evaluation of machine learning algorithms**: The evaluation ML algorithms consist of both assessment of being able to use driver activity recognition for adaptive HMI, as well as the assessment of classification reliability from final simulator experiment.
- **A list of questions and ideas to be further explored in future:** See chapter 8.
- **At least one master thesis and two scientific papers**: Scientific results include two theses, one graduate project, one journal paper submitted. In addition, three publications are planned on results from the simulator study, experimental methods, and the designer tool (composer/sequencer) developed in the project.
- **At least one international workshop/seminar on activity-based interaction**: Two workshops were held on activity based interaction and Soma design at KTH and Volvo Cars. Two workshops on embodied cognition was held within a SAFER pre-study in collaboration with Skövde University and Folksam. RISE participated in an international seminar on radical design for future autonomous vehicles at Dagstuhl.
- **At least two tests on public roads demonstrating the potential benefits of activity based human-vehicle interaction in traffic:** Three simulator studies were performed in the project. The plan of public road testing was discarded due to the need for a flexible HMI implementation and a controlled testing environment, best accommodated in a simulator setting.

6 Results and deliverables

First, the research questions are answered followed by a description of how each deliverable has been fulfilled.

WP1 – Project lead, coordination and dissemination	The project has been on-going with at least ten all partner meetings per year, with some periods of more frequent meeting in those stages of the project that required it, as well as with weekly meetings for some periods between some of the project partners. Four university students have completed thesis work within the project, two students writing one BSc thesis at RISE, and two students writing one MSc thesis at Volvo Cars.
D1.1: At least ten all partner project meetings per year	All partner meetings have been planned as bi-weekly meetings and became weekly meetings during some periods of the projects where more frequent discussions were required.
D1.2: Two status reports to FFI per	Project status reports have been prepared and submitted to FFI every 6 months according to the schedule.

year or upon request	
D1.3: Presentation/poster at one scientific or industrial conf. per year	The project has had challenges in producing academic results early on in the project. In 2020 and part of 2021, in-person user studies were not possible due to the covid pandemic. Later, lack of electronic components delayed the development of the Smart Eye system to be used in the simulator. Therefore, the main simulator study was performed late in the project resulting thus delaying scientific publications. Smart Eye was at Consumer Electronics Show (CES) 2023 with a booth demonstrating driver monitoring technology and discussing the RE-ENGAGE project.
D1.5: At least two scientific papers in journal and/or conferences	See section 7.2 for the list of publications.
WP2 - Development of theoretical models of driver re-engagement	WP2 answered RQ3. The theoretical framework used in this project in relation to driver re-engagement is called is called soma design or soma-aesthetics[10]. In short, soma design puts focus on the physical aspect of interaction in order to create engaging designs. The driving tasks can be seen from this perspective as the driver becoming embodied with the vehicle and the surrounding environment by the physical activities that driving entails, including steering, using the pedals, engaging with the vehicle-driver interface as well as experiencing the motions of the vehicle and the road surface vibrations from the wheels to the seat. This view can also apply to non-driving related tasks with the goal of creating a more comfortable travel experience in highly automated vehicles. When designing the re-engage experience in this project the body of the driver was considered as an integral part of the design. A mapping of human senses and whole-body experiences were connected to driver re-engagement for designing interactions that were determined by driver's current activities.
D2.1: A chapter in the final report on driver re-engagement state-of-the-art based on soma-aesthetics and embodied cognition	A literature study was conducted on re-engagement, soma aesthetics and embodied cognition.
D2.2: At least two workshops on theoretical foundations	RISE participated in a SAFER pre-study on embodied cognition together with Skövde University and Folksam[17]. Two Soma design workshops were performed at KTH and VCC, led by Prof. Kia Höök and the soma design team at KTH.
D2.3: A theoretical model of driver re-engagement	In terms of theoretical views, driver re-engagement has been explored from the embodied cognition perspective as well as from the Soma design perspective. These theoretical concepts are relatively new and unexplored in the automotive domain. The Soma design approach proved useful to innovate experiences for in-vehicle HMI design. For the second Soma design workshop in the project, a "Soma design exercise book" was developed, adapting the theoretical approach to a practical design method useful in the vehicle domain.
D2.4: A list with an initial set of	The set(s) of scenarios of interest are selected as the representative situations where the activities are expected to be common and conceptually

scenarios of interest	distinguishable. Scenarios were formulated that fit within the theoretical model of driver re-engagement and whole body activity recognition. The initial set includes: Eating, Drinking, Reading Resting, and Interacting with phone. For the final simulator study, “Watching a movie” and “Resting with eyes closed” while driving/riding on a highway were chosen as scenarios.
WP3 - Activity mapping and recognition with machine learning	WP3 answered RQ1 and RQ2
D3.1: Requirement specification. Scenario specification and activity profiles.	Requirement specification, scenario specification and activity profiles were formulated. RE-ENGAGE has established the user scenarios in which a driver take-over request is necessary when the automated vehicle is transitioning from a road where automation is allowed to one where it is not. In these cases, the automated vehicle must provide sufficient timely notice for the driver to take over, which is measured in minutes. To ensure a smooth transition, the system needs to understand the driver's state, as factors such as sleeping, eating, drinking, and distractions will affect the timing of the response time to the take-over request. To understand the driver’s readiness to take over RE-ENGAGE has developed Driver Readiness signals that assess three dimensions: the driver's visual attention (eyes on road or on other areas of interest), physical readiness (non, either or both hands on steering wheel), and cognitive state (no talking or distractions) before allowing the driver to take over.
D3.2: A preliminary training dataset (1st iteration) and an evaluation dataset (2nd iteration). Datasets should be gender equal suitable for training of the chosen behaviors	In order to assure good function of the RE-ENGAGE algorithm described above, it is important to have a diverse and representative training dataset. The training datasets include the following: A training dataset (1st iteration): This dataset was collected in the early stages of the project, and includes a wide range of driver behaviour and states. The dataset includes a representative sample of drivers from different genders, age groups, ethnicities, and backgrounds with the target to train driver state detection algorithms. An evaluation dataset (2nd iteration): This dataset was collected to evaluate the performance of the algorithm with respect to the driver interaction and the intended use is to tune HMI versus driver state. The dataset includes a diverse range of driver behaviour and states, and a variety of different driving scenarios linked to re-engaging the driver. The evaluation dataset is limited in diversity as the target is a proof of concept.
D3.3: Architecture design alternatives	Two architecture design alternatives have been evaluated during the project: (i) Adaptive HMI actions based on detected driver activities: A preliminary prototype (Virtual Prototype 1, Figure 9) had been developed and used to test this approach. (ii) Adaptive HMI strategies (predefined sequences of HMI actions) based on detect activities and driver readiness states. The final implementation of the architecture is documented as part of the demonstrator and is illustrated in Figure 6. The full system is however not implemented as this is not within the HMI target for the project.

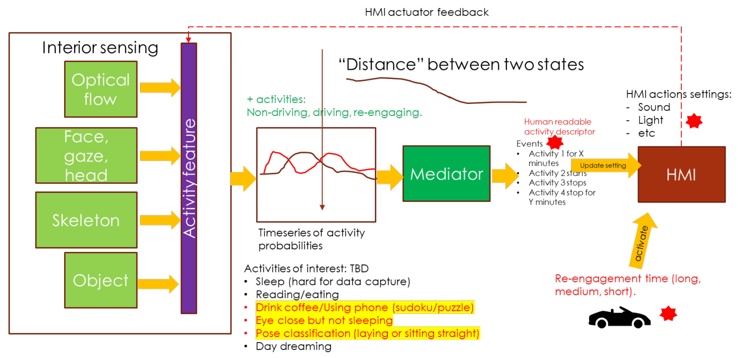


Figure 8: Architecture alternative 1

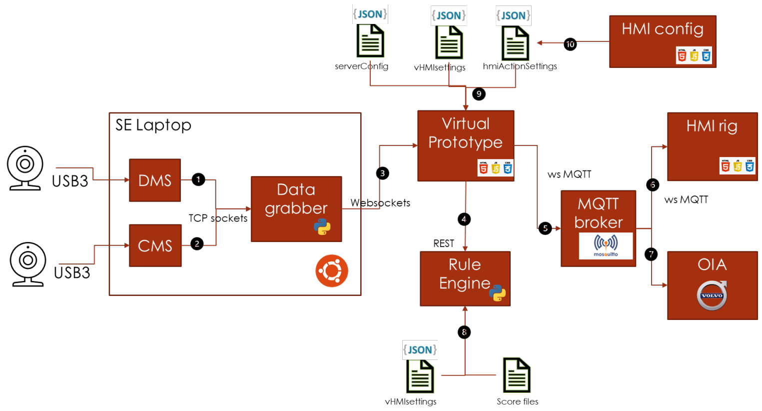


Figure 7: Architecture alternative 1

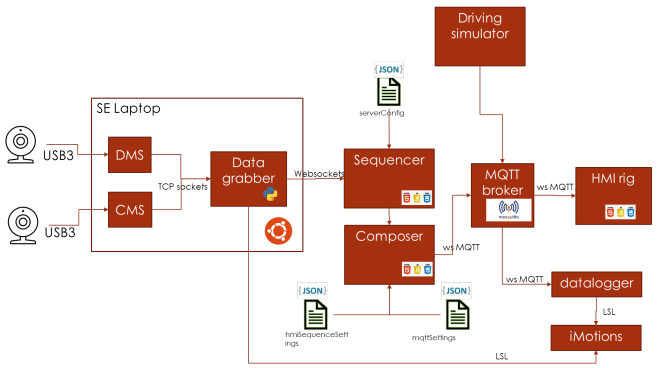
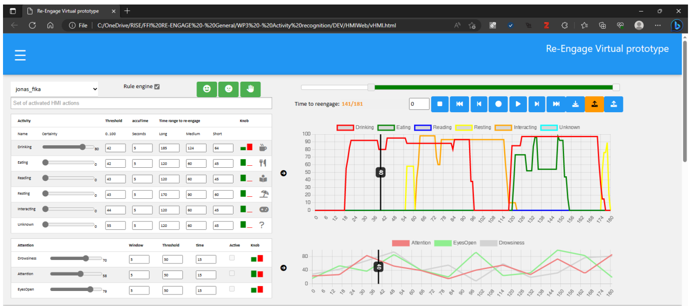


Figure 6: Architecture alternative 2

A suitable vehicle architecture alternative to fulfill the RE-ENGAGE selected scenarios includes the following key components:

1. A sensor suite (only cabin camera part of the demonstrator): This includes cameras, lidar, radar, in cabin cameras that allows the vehicle to perceive its external environment and detect when it is transitioning from a road where automation is allowed to one where it is not. The interior sensing subcomponent captures information of driver activities and behaviours for driver state monitoring system.
2. A perception and decision-making module: The module process the data from the sensor suite and use it to make decisions about the vehicle's actions. It is also responsible for determining when a driver take-over request is necessary and providing the driver with sufficient notice via a predefined HMI strategy.

	3. A driver state monitoring system: The algorithms use the in-cabin cameras to monitor the driver's state, such as attention level, physical readiness, and cognitive state and deem when the driver is ready to take over in a safe way. 4. A human-machine interface (HMI) including display, voice, seat control and active safety belt and controls for the driver (on steering wheel) that allow the driver to interact with the vehicle and take over control when necessary. 5. A communication system (optional, not in demonstrator): In a future this system would allow the vehicle to communicate with other vehicles, infrastructure, and the cloud, in order to share data like the autonomous state and receive updates on road conditions and traffic. 6. An actuation system (not part of demonstrator but included in the simulation environment) including the vehicle's powertrain and control systems, and would be responsible for executing the vehicle's actions, such as steering, braking, and acceleration. These components are integrated to provide a seamless transition between automated and manual driving, while ensuring the driver is ready to take over when necessary.
D3.4: Proof-of-concept algorithm that can classify in-cabin non-driving related activities and interactively communicate with the HMI system	A proof-of-concept activity detection implements the needs from D3.1. The enhanced activity detection included, among others, body pose (out of position) and hand position detection (hands off steering wheel) that was implemented using machine learning primarily based on CNNs[18]. The final activities were grouped in order to make an estimate on the driver readiness using a combination of driver monitoring output including gaze, head-pose, eyeblinks enhanced with speaking detection and classification of in-cabin and non-driving related activities. The output of this module is the input to the HMI and decision module. The proof-of-concept algorithm for activating HMI functions is taking into account the driver's state and driver readiness level include the following steps: • **Monitor the driver's state**: Use cameras to monitor and classify in-cabin and non-driving related activities. The module detects the driver's attention level, physical readiness, and cognitive state. The information is used to determine the driver's readiness to take over control of the vehicle. • **Determine driver readiness level**: based on data from the vehicle's sensor suite and perception and decision-making module to determine when a driver take-over request is necessary for the driver to take over control. • **Activating the HMI functions**: Based on the time to take over and the driver's state, the algorithm activates the HMI functions in a graduated manner. For example, if the driver readiness level is high, i.e. the driver is alert and engaged, the algorithm may only activate a display with a message to prepare for manual driving. But if the driver readiness is low and the driver is drowsy or distracted, the algorithm may activate an audible warning, active seatbelt and moveable chair to wake up the driver. If the driver does not take over control within a certain period of time, the algorithm can bring the vehicle to a stop or initiate an emergency stop.

	To support test and integration the in-cabin activity detection was implemented in a Smart Eye demonstrator with activity detection was implemented. This demonstrator was during the project moved to RISE for further testing supporting Master Thesis work and tuning in the project.
D.3.5: A proof-of-concept prototype that can activate HMI functions in a test vehicle	A proof-of-concept prototype that can activate HMI functions in a test vehicle was developed. The prototype was moved to a driving simulator as real drive tests were a problem during Covid time. It was also easier to provide repetitive test scenarios. As part of the project, a first proof of concept implementation of the HMI has been developed by RISE. This includes a driver activities detection module (integrated with CMS/DMS system via a datagrabber), rule based adaptive HMI action activation control, and a virtual HMI module incorporating a display  *Figure 9: Virtual Prototype 1 screenshot* and audible prompts, which were used to understand the final requirements. In the final demonstrator the project partners made the final architecture concept that included: • A real-time classification of in-cabin and non-driving related activities implemented by Smart Eye. • The HMI module was redesigned by Volvo Cars to work within the vehicle or simulator setup, and enables the use of additional HMI features, including a display, audible information, active seatbelt, and adjustable seat position. Key PoC's components are as described below. *Product Simulator* Unity is a real time rendering game engine, in which a highway environment was created. The signals from the steering wheel and pedals controlled a virtual Volvo XC40, using the Product Simulator package. This package allows for a fully functional 3D model to be controlled in the game environment, including simulated Autonomous Drive (AD) mode. The simulator is normally controlled by a set of pedals and a steering wheel from Fanatec that is connected to the virtual environment. The Fanatec steering wheel provides accurate force feedback based on the driving kinematics experienced in the virtual environment. *Backend* The simulator is connected to a Middle Layer (MiLa) which consists of an MQTT server and an arbitrary number of MQTT nodes. The MQTT nodes are communicating through MiLa where data in some instances are processed and

	in others generated based on aggregated input from multiple sources. MiLa also handles orchestration of signals and the required state machines to make sure the HMI and its sub-components, such as audio playback engine, CAN-nodes (haptic seat belt), and LED lights are able to work in unison. *Composer* The composer is a tool which connects the signals from the SmartEye cameras, and allows a designer to see driver readiness in terms of visual readiness, physical readiness, and cognitive readiness. The designer can prioritize these readiness values and change the acceptance and time that these signals should be active for the sequence to be triggered in the sequencer. *Sequencer* The sequencer is a tool that was developed specifically to allow designers to be able to design and tailor sequences of multimodal HMI through a GUI, irrespective of prior coding experience or experience of the underlying communication protocol. The sequencer was also built so that it may consume data pertaining to the driver's readiness to drive from the composer software, and use that signal to tailor which sequence of HMI activations to use. This interface also allows the HMI to cease playback of certain types of feedback depending on how drivers respond to prior feedback given. I.e. if a sound is played and the driver re-orients themselves to the road environment, there is no need to continue informing them to pay attention to the road environment.
WP4 - Development of human-vehicle interaction concepts for driver re-engagement	WP4 answers RQ3.
D4.1: At least three design workshops during the project	Workshops were held within the project to develop design concepts. Two Soma-design workshops were held, one in Stockholm hosted by RISE and KTH and one at Volvo Cars (Figure 10). Several design workshops were held at Volvo Cars together with representatives from audio design, light design and visual UX design to iterate on the HMI concept to be tested in the final simulator study. Four university students have completed their thesis work within the project on the topic of design, two BSc students at RISE, and two MSc students at Volvo Cars.

	 *Figure 10: Prototype of a pneumatic shape-changing seat*
D4.2: At least three HMI concepts implemented in a WoZ vehicle	A multimodal HMI concept was designed and implemented in a simulator setting. The WoZ platform was not used in the project. The deviation from the project deliverable is motivated by the combined complexity of both the developed multimodal HMI functions and the procedure for conducting an on-road WoZ study. The exploration of activity based HMI activations entails many behavioral variables that are challenging to controlled for. It was decided that public road driving would add additional complexity and compromise the purpose of the study at the current level of maturity of the developed prototypes. Therefore, the goal of evaluating the final HMI concept as such was decided to be better accommodated and more effectively performed in the simulator environment at Open Innovation Arena at Volvo Cars. In the main simulator study two HMI concepts were implemented. One longer sequence designed for driver re-engagement and one shorter that (partially) correspond to the requirements of the UNECE ALKS legislation. In addition, HMI concepts were also implemented for the MSc and BSc theses that were performed within the project. The HMI concept was designed using an iterative procedure and focused on creating a multimodal, contextual HMI interaction model utilizing a multitude of information sources to communicate with the driver. These different modalities are outlined below. *Lights* Addressable LED strips were added to the rig in 3 layers (foot level, eye level, and overhead) on both the driver and passenger sides of the rigs. Each layer was able to be controlled separately by ESP micro-controllers using the WLED library. *Haptics* The test rig has a pre-production seat belt module attached, which allows for electronically controlled reversal of the seat belt spool. This means that MiLa may request several pre-programmed haptic profiles from the seat belt and the seat belt will actuate that request. This feature allows the HMI to draw attention to the rest of the HMI even though the driver may be visually distracted or in some way incapacitated.

<table>
<tr><td></td><td>Visuals
Two screens were used for the HMI, similar to the screen placement in a car. The Driver Information Module (DIM) was positioned behind the steering wheel and showed the speed from the Unity environment and information about which driving mode the test participant was in. The Centre Stack Display (CSD) was positioned in the center of the dashboard and showed the driver entertainment. Both screens allowed different notifications to be shown as part of the tests.

Sound
One speaker was situated in the footwell of the rig and was connected to the DIM to play notification sounds. Another Bluetooth speaker was placed in front of the rig to play sounds from the CSD, including the media and CSD notifications.

Figure 11: RE-ENGAGE Simulator with multimodal HMI layout</td></tr>
<tr><td>WP5 - Development of evaluation methodology</td><td>WP5 address RQ3.</td></tr>
<tr><td>D5.1: Evaluation methodology framework to be used in WP6</td><td>To answer the research questions by UX explorations and experimental testing a mixed methods methodology framework was developed and implemented. The relations between the key components are visualized in Figure 12. The iMotions platform (www.imotions.com) was used for data logging (signals and video), visualization of data streams during the experiments, and post-hoc annotation and analysis. The simulator used in OIA is built on a Unity game engine with a highway environment. The vehicle was a virtual Volvo XC40 using the Product Simulator package. This package allows for a fully functional 3D model to be controlled in the game environment, including simulated Autonomous Drive (AD) mode. The composer is a tool which connects the signals from the SmartEye cameras and allows a designer to see driver readiness in terms of visual readiness, physical readiness, and cognitive readiness. The designer can prioritize these readiness values and change the acceptance and time that these signals should be active for the sequence to be triggered in the sequencer. The sequencer is a tool that was developed specifically to allow designers to be able to design and tailor sequences of</td></tr>
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multimodal HMI through a GUI, irrespective of prior coding experience or experience of the underlying communication protocol. The sequencer was also built so that it may consume data pertaining to the driver's readiness to drive from the composer software and use that signal to tailor which sequence of HMI activations/deactivations to use. The setup also allows for a Wizard-of-Oz approach to be used, bypassing the composer and using a human observer to perform the task of readiness classification algorithm. This allows for a flexible setup and ability to create training data for future algorithm development.

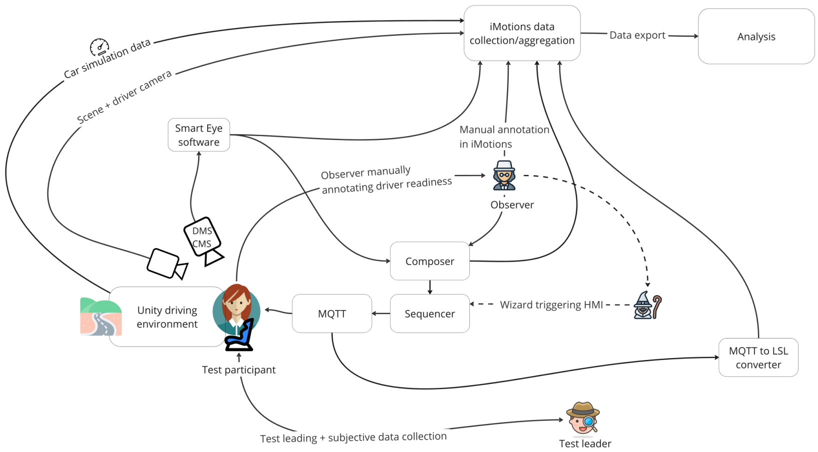

Figure 12 Evaluation methodology framework
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<td>D5.2: A list of metrics and criteria to support qualitative and quantitative evaluation</td>
<td>
Implemented quantitative metrics:

Eye-tracking metrics: eyes-on-road, cluster, center stack and other areas, driver readiness metrics (visual, physical, cognitive)
Driving behaviour metrics: collected from the driving simulator for road lane offset position, steering wheel behavior, acceleration pedal behavior

Qualitative metrics:

Participants filled out SUS form after each condition
Post test interview with participants on positive experiences, negative experiences, opinion of using self-driving technology in your own vehicle, opinion on having interior cameras, opinion about doing other things while in a self-driving car
Interview after demo of adaptive system

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<td>D5.3: A description of the tools needed to capture the metrics in Task 5.2</td>
<td>See deliverable D5.1.</td>
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<tr>
<td>D5.4: A description of the use cases to be evaluated
+
D5.5: A description of the experimental design</td>
<td>The use cases evaluated in the final simulator study was based on two plausible activities to be performed in self-driving cars, "watching a movie" and "resting with eyes closed". The driving environment was a typically Swedish road in the forest, with traffic. The speed limit was set to 80km/h, to attain a suitable speed perception in the simulator. In the study, the participants were assigned the task of watching a movie for five minutes and then resting with their eyes closed for five minutes. Each of the tasks ended with either a long or a short re-engagement sequence in a counterbalanced order where the</td>
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	drivers were prompted to take over control of the vehicle and then drive manually until the test leader asked them to activate autonomous drive again and answer the test leader's questions and perform subjective ratings. Consequently, each participant made four drives (as combinations of movie/resting task and long/short HMI sequence) with a pause for answering a rating scale and interview questions in-between. Before the test, participants were informed that they could take back manual control of the vehicle, by pressing the buttons in the steering wheel, whenever they felt it was appropriate. After the controlled experiment, the test continued with an exploratory demo session. Here, the concept adapted to their behavior was tested and the driver activities were shorter. In the demo session, the adaptivity of the long HMI sequence was explained and experienced in more detail. The demo was performed in three steps. This was done to illustrate the difference between a "driver aware" vs. "unaware" system. In the first drive, the participants were informed that the system was unaware of their activities, and they experienced the full long sequence while watching the scenery and thus being ready to drive. In the second and third drive the system was aware and the HMI was adaptive to driver activities. In the second drive the participants watched the scenery (high level of readiness) and in the third drive they were resting with their eyes closed (low level of readiness).
D5.6: Ethical approval	Ethical approval was not deemed necessary for the simulator study since the takeover after the tasks resting and watching a movie did not include any uncomfortable situations. The study was performed in accordance with the Helsinki declaration and research best practices.
WP6 - Evaluation and feasibility assessment in traffic	WP5 address RQ3.
D6.1: At least two experimental tests on public roads	Three experimental tests were done in the project, two were done within student thesis work in collaboration with Volvo Cars and RISE researchers, and a larger simulator test with 26 participants (12 males, 14 females) in collaboration between project partners. The plans of public road testing were discarded due to the need for a flexible HMI implementation and a controlled testing environment, best accommodated in a simulator setting.
D6.2: A chapter in the final report describing the results from evaluations and material for scientific publications in WP1 + **D6.3:** A synthesis of results from the evaluations and a description of the implications of these results for activity based human-vehicle interactions	Attention and driving performance • When watching movie, they are less prone to trusting the automation (more gazes on road) • With a *long* take-back gives a better driving performance (measured as road lane center offset) • Some participants were too fast to take back control Subjective ratings of ease of use (SUS) • Ease of use ratings, on average, show better ease of use for the *long* conditions compared to the *short* conditions. Participant experiences based on interviews • Participants appreciated the gradual hand-over of control of the *long* HMI sequence, allowing drivers to adjust to the transition from riding to driving. • In the *long* HMI sequence participants felt that there was enough time to take control and that the handover was smooth and easy to manage. • Additionally, the ability to relax and engage in other activities was seen as a luxury and a positive aspect of the self-driving experience.

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<td>including a roadmap of future research directions</td>
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The abruptness of the short HMI sequence - the sounds, seat movement and belt pull were perceived as too sudden by some, causing stress and alarm.
In the movie condition, there was some difficulty for the participants to become immersed in the movie due to disturbance from traffic in the peripheral vision.
Many participants were open to the idea of using self-driving technology and believed that it could be helpful in certain situations, such as long drives or commuting.
Some participants expressed concerns about the technology's ability to handle unexpected situations, such as encounters with animals or drunk drivers. They were interested in learning more about the technology's capabilities in these situations before fully embracing it.
A few participants felt that they would need time to adapt to the technology and build trust in its reliability before fully utilizing it.

The project also explored what type of HMI modality make drivers take back control:

HMI interventions such as belt, sound, and text notifications increase the drivers’ attention towards the road.
Almost all participants waited for a distinct message to take-back control before going into manual mode. This was the case despite getting an explicit instruction that they could take-back whenever they wanted.
It seems like the take-back actions from the driver may change with more experience of the system and may vary with personal preference.
In this test manual driving could be activated at any time. A few participants took over control directly after resting (not ready to drive) which indicate that a future system would need to deny manual driving until the driver readiness is on the appropriate level.
Participants were worried about data being uploaded to unauthorized entities. They want assurances the data is secure and stored locally in the car. Worries were also expressed about not knowing exactly how the camera data is used and for what purposes. Participants want transparency about the data and its usage.
The major worries centered around transparency, control, and responsible use of the camera data. Participants wanted assurances that the data would only be used for the car's functions and safety, would be stored securely, and that they would have some say in when the cameras record. Without these things, privacy concerns arose for some.

Implications for adaptive HMI system development
In the demo part of the experiment participants tested different levels of system adaptivity.
Demo step 1 (long sequence – ready to drive).

Many participants felt the takeover request took too long. They felt impatient waiting for the request and were unsure if they should take over control sooner.

Demo step 2 (adaptive demo – ready to drive)

A few participants noted that the system did not need to "wake them up" since they were already attentive, hence it is clear that the system

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	should detect driver state and adapt the HMI sequence. For an attentive driver, a subtle alert is sufficient. Demo 3 (*adaptive* demo – not ready to drive, resting with eyes closed) • Several participants said the takeover sequence felt calmer and smoother when they had their eyes closed. A gentler, more gradual alert system seems most appropriate when drivers are resting or sleeping. • The sound was effective at waking some participants up. Folded seat was seen as a good feature, though some wanted the seat to move earlier. A conclusion from the demo of adaptive HMI is that the driver's experience is clearly dependent of the combination of driver activity and HMI sequence design. Another conclusion is that in the cases were HMI sequence is shortened (adapted) to activity, a majority did not notice the fact that the sequence was changed. The results show that a good classification algorithm is key since timing and content of HMI sequences is crucial for high acceptance. It became clear in the simulator study where the participants spontaneously reacted negatively to a long sequence when they were ready but gave no particular response when the HMI sequence was well adapted to their readiness. This conclusion is twofold. On one hand it shows that if the readiness classification is correct, people will accept it. However, if the readiness classification is wrong, people may take back to early when they are not ready to drive. For example, if a driver has been resting for some time and wants to take back control quickly, and the system incorrectly classifies the driver as ready to drive there may be an increased safety related risk. Future research directions, see Section 8.

7 Dissemination and publications

7.1 Dissemination of knowledge and results

Hur har/planeras projektresultatet att användas och spridas?	Markera med X	Kommentar
Öka kunskapen inom området	X	The project will publish scientific results.
Föras vidare till andra avancerade tekniska utvecklingsprojekt	X	Knowledge from the project will be used in research projects Enhanced ADAS 2, and SCREENS 2 at RISE, financed by Vinnova FFI.
Föras vidare till produktutvecklingsprojekt	X	The project is closely related to Volvo Cars and Smart Eye business activities.
Introduceras på marknaden		
Användas i utredningar/regelverk/ tillståndsärenden/ politiska beslut		

7.2 Publications

One scientific paper is accepted and under revision for journal publication.
Title: Design friction in Autonomous Drive – Exploring Friction for Safe Transitions between Autonomous and Manual Drive
Personal and Ubiquitous Computing - Theme > Issue on Engaging with Automation: understanding and designing for operation, appropriation, and behavior change.

Bachelor of Science thesis report:
E. Johansson and S. Börjesson, “DRIVER ENGAGEMENT User experience of static & dynamic interaction and engagement in Non-Driving Related Activities in Automated Vehicles - An experimental study,” Göteborg Universitet, 2023.
Available: https://gupea.ub.gu.se/handle/2077/76555

Master of Science thesis report:
J. Bley and L. Johansson, “Autonomous to Manual Drive with a Smooth Take-Over Sequence, A design study exploring how to create a dynamic takeover for non-urgent situations”, Chalmers, 2022.

W. Ju, B. Pfleging, and A. Riener, “Radical Innovation and Design for Connected and Automated Vehicles (Dagstuhl Seminar 22222),” *Dagstuhl Reports*, vol. 12, no. 5, pp. 188–230, 2022, doi: 10.4230/DagRep.12.5.188.

SAFER Pre-study on embodied cognition in the automated vehicle domain:
H. Svensson., Exploring the impact of embodied cognition on automated driving design. SAFER. https://www.saferresearch.com/library/final-report-exploring-impact-embodied-cognition-automated-driving-design

There are three additional publications planned to be submitted. One paper on the main experiment, one on method and how to define driver readiness metrics, and one method paper on the composer/sequencer tool.

8 Conclusions and future research

- Drivers are less likely to become immersed and trust the automation when watching a movie as compared to resting with their eyes closed since the peripheral vision is active, resulting in more gazes on the road.
- Results indicate that longer take-back sequences result in better driving performance and are perceived as easier to use.
- Participants appreciate the gradual handover of control in longer HMI sequences, allowing for a smoother transition from riding to driving.
- HMI interventions, such as seatbelt tap, sound, and text notifications, effectively increase drivers' attention towards the road. However, personal preferences and experience with the system may influence take-back actions.
- Data privacy and transparency are real concerns for participants; they seek assurances that their data will be used responsibly and stored securely when being monitored in the car.
- In terms of adaptive HMI system development:
    - Driver state detection is crucial for adapting the HMI sequence to the needs of attentive or resting drivers.
    - Shorter takeover request times are preferred when drivers are already attentive.
    - Gentler, more gradual alerts are appropriate when drivers are resting.

The directions for future research entails human-machine interaction as well as methods.
HMI design:

- HMI for re-engagement in autonomous vehicles – the RE-ENGAGE project has only scratched the surface on multimodal interaction and exploring other types of designs and combinations of modalities is a natural way forward.
- The detection of readiness to drive is also a key component for re-engagement systems. Future research should entail not only detection of readiness, but also how to design active driver interactions and responses that can help the system to ensure driver readiness (e.g. ask the driver to respond to requests to ensure readiness).
- A limited number of scenarios were tested in the project. The variety of scenarios should be expanded in future research.

- Current research focus mainly on driver readiness detection and corresponding HMI for take-overs. Less attention is given to interaction for scenarios when the driver wants to take over but is not ready, i.e. if the driver wants to take over but the system determines the driver to not be sufficiently ready to drive. The scenario needs more research since it is a new type of safety critical situation.
- The Soma design methodology proved valuable as a systematic approach for creating new concepts based on bodily engagement. Soma design has previously not been used in the automotive domain and provides an avenue for new explorations. However, development of high fidelity prototypes that is mature for testing beyond exploratory design work needs a seat supplier onboard. This is an opportunity for future research and development.

Methods

- Task and activity classification is a core component for activity based HMI. Creating classification algorithms that can cope with a wide range of human behaviors in the new context of in-vehicle activities needs continuous development.
- Emotion recognition was briefly explored in the project and some parameters from the emotional detection system showed potential for use as driver readiness indicators. This area needs more research.
- The project chose to not pursue the original intention to perform on-road data collection. Nevertheless, on-road studies are important to understand real world driving and should be pursued in future projects.
- Personalization of classification models and HMI sequences is an interesting use case for future AI applications in vehicles. New types of AI models that can handle multimodal input and output has potential to disrupt in-vehicle UX design.

9 Project partners and contact persons

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