In the Hub – Interaction between Users and Driverless Vehicles in Future Transport Systems

Public report

Author Yanqing Zhang, Johan Fagerlönn
Date 2023-03-23
Diarie number: 2019-05898
Project within Efficient and connected transport systems

Content

FFI in short

FFI is a partnership between the Swedish government and automotive industry for joint funding of research, innovation and development concentrating on Climate & Environment and Safety. FFI has R&D activities worth approx. €100 million per year, of which about €40 is governmental funding.

For more information: www.vinnova.se/ffi

1. Summary

As technology for automation, artificial intelligence and connectivity develops, the role of humans in interaction with vehicles is changing. Within heavy transport, work environments are being developed where a person, or group of people, must control several driverless vehicles with a high level of automation within a hub (e.g. mine or terminal), as well as in traffic between hubs. This project explored and demonstrated how people should interact with driverless vehicles in connected transportation systems in hub contexts in the future. The goal was to investigate and design new models for interaction between human operators and driverless vehicles that contribute to efficient and safe transport within hubs. The work focused particularly on two use cases where interaction with the vehicles is assumed to be significant, and where implementation is possible at an early stage when introducing driverless heavy vehicles. For these use cases, humans have a critical role in creating “uptime” and efficiency in the transport flow. The project generated new knowledge and new models for interaction design, as well as concrete design concepts for all use cases. All major concepts were visualized and implemented in prototypes with different fidelity levels, e.g. in concept animation videos or simulator. They were also evaluated with external targeted users from relevant industries. One of the concepts have been tested and iterated twice.

The project results include, but not limited to:

- Over five HMI concepts for efficient and sustainable interaction between operators and driverless vehicles. The concepts are designed to meet the needs of professional users (e.g. mine or warehouse staff) in the project's defined user cases.
- New knowledge about user needs for interaction design found from professionals operators in a controlled transport system.
- Concrete design prototypes to demonstrate our concepts. The concepts were visualized and implemented through videos, Virtual Reality (VR) and simulator.
- All concepts were tested with targeted users from relevant industries. Three major studies were conducted. We focused on use case B (the operator is in another machine), which has been tested twice with different prototypes; we designed for use case A (the operator stands in proximity of the vehicle) as well, and conducted a test in a simulation study. A master course project focused on use case C (the operator is in a control room).
- New models for how user interfaces for driverless vehicles should be designed.
- New knowledge about how user interfaces should be designed to complement each other and together support operators with different roles in a transport system.
- Four scientific publications published at or submitted to scientific conferences.
- Two degree projects for master’s degree and one master course report.

The knowledge, design concepts, models and prototypes developed in the project have contributed to the ongoing development within Scania and can also provide guidance for the rest of the Swedish automotive industry. The project could thus contribute to the development of efficient transport systems, and that the Swedish automotive industry can strengthen its competitiveness in terms of innovative solutions for interaction design with driverless vehicles. The project was led by Scania. Other parties are RISE, Boliden and Icemakers. Together, the parties formed a strong consortium with different perspectives on the development of solutions for future vehicles and transport systems.

2. Sammanfattning på svenska

I takt med att teknik för automation, artificiell intelligens och uppkoppling utvecklas förändras människors roll vid interaktion med fordon. Inom tunga transporter utvecklas arbetsmiljöer där en person, eller grupp av människor, ska styra flera förarlösa fordon med hög automationsgrad inom en hubb (t.ex. gruva eller terminal), samt i trafik mellan hubbar. Detta projekt utforskade och demonstrerade hur människor kan interagera med förarlösa fordon i uppkopplade transportsystem i framtidens hubbar. Målet var att undersöka och designa nya modeller för interaktion mellan mänskliga operatörer och förarlösa fordon som bidrar till effektiva och säkra transporter i hubbarna. Arbetet fokuserade särskilt på två användningsfall där interaktionen med fordonen antas vara betydande, och där implementering är möjlig i ett tidigt skede vid introduktion av förarlösa tunga fordon. I dessa användningsfall har människor en avgörande roll för att främja "upptid" och effektivitet i transportflödet. Projektet genererade ny kunskap och nya modeller för interaktionsdesign, samt konkreta designkoncept för de olika användningsfallen. Huvudsakliga koncept visualiserades och implementerades i prototyper med olika nivåer realism, t.ex. i animerade videos eller simulator. De utvärderades också med externa användare från relevanta branscher. Ett av koncepten itererades och testades två gånger.

Projektresultaten inkluderar, men inte begränsat till:

- Fem designkoncept för effektiv och hållbar interaktion mellan operatörer och förarlösa fordon. Koncepten är utformade för att möta behoven hos professionella användare (t.ex. gruv- eller lagerpersonal) i projektets definierade användarfall.
- Ny kunskap om användarbehov för interaktionsdesign som finns hos professionella operatörer i ett kontrollerat transportsystem.
- Koncepten visualiserades och implementerades genom videor, Virtual Reality och simulator. Därigenom genererades konkreta designprototyper för att demonstrera våra koncept.
- Alla koncept testades med användare från relevanta branscher. Tre stora studier genomfördes. Vi fokuserade på användningsfall B (interaktion när operatören är i en annan maskin), som har testats två gånger med olika prototyper. Vi designade även för användningsfall A (interaktion när operatören står oskyddad nära

fordonet) och testade en lösning i en simulatorstudie. Inom ramen för en kurs inom ett masterprogram utvecklades en lösning för användarfall C (när operatören befinner sig i ett kontrollrum).
- Nya modeller för hur användargränssnitt för förarlösa fordon ska utformas.
- Ny kunskap om hur användargränssnitt ska utformas för att komplettera varandra och tillsammans stödja operatörer med olika roller i ett transportsystem.
- Fyra vetenskapliga publikationer som publicerats eller är inskickade till vetenskapliga konferenser.
- Två examensarbeten för masterexamen samt en masterkursrapport.

Kunskapen, designkoncepten, modellerna och prototyperna som tagits fram i projektet har bidragit till den pågående utvecklingen inom Scania och kan även ge vägledning för resten av den svenska fordonsindustrin. Projektet kan därför bidra till utvecklingen av effektiva transportsystem, och att svensk fordonsindustri kan stärka sin konkurrenskraft vad gäller innovativa lösningar för interaktionsdesign till förarlösa fordon. Scania ledde projektet. Övriga parter var RISE, Boliden och Icemakers. Tillsammans bildade parterna ett starkt konsortium med olika perspektiv på utveckling av lösningar för framtidens fordon och transportsystem.

3. Background

As technology for automation, artificial intelligence (AI) and connectivity develops, the role of humans in interaction with vehicles is changing. Within heavy transport, work environments are being developed where a person, or a group of people, must control several driverless vehicles with a high level of automation within a hub (e.g. mine or warehouses). The development of automated connected vehicles is expected to have positive effects on both transport capacity, efficiency and safety. But while the vehicles will be able to handle large parts of the driving autonomously, humans will still have an important role, both on an operational as well as on a tactical and strategic control level. This requires completely new interaction design solutions that are significantly different from the design of today's in-vehicle driver environments. In order to promote sustainable development of future transport systems, the interaction with driverless vehicles needs to be efficient, safe and inclusive. However, developing new methods of interaction is challenging. This has been researched in recent years within the mining industry, where remote control of machines is increasingly introduced. Flaws in interaction design can easily lead to reduced production efficiency, as well as increased machine wear. Thus it is important to explore how to design for such interactions in the future connected transport systems to improve efficiency, safety and inclusiveness.

3.1 Use cases

Some key use cases in the hub contexts were considered to be particularly relevant.

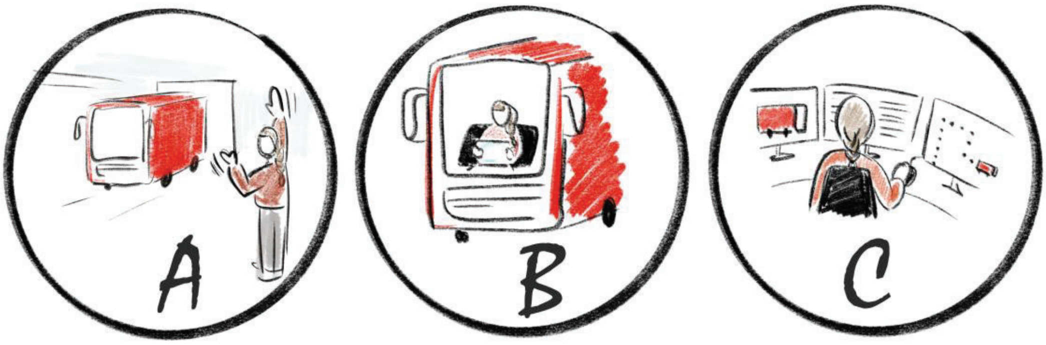

Figure 1 Illustration of major use cases explored in the project.

Use case A: Natural interaction between automated vehicles and operators in proximity to the vehicles

This use case refers to the situations when human operators need to interact with the automated vehicles in close proximity. The challenge in this use case is to design intuitive ways for operators of a driverless truck to be able to interact with the vehicle when needed. The interaction focuses on operational control (e.g. for a vehicle to reverse or turn) to effectively resolve situations and optimize traffic flow in the short term. This type of interaction will probably become particularly relevant in situations where the technical systems are close to their capacity limit and there is a need for problem solving on site next to the vehicles.

User case B. Mobile control room within hub

In this use case, an operator controls one or few automated vehicles from a mobile control room (control room in a vehicle) to complete tasks together. The challenge is to develop an HMI intended for operational and tactical level control (e.g. go to a specific location for loading) as well as two way communication. The purpose of the mobile control room and the interaction is to be able to cooperate with the systems for certain tasks, optimize and streamline the flow during normal system operation, but also to act as a node for problem solving in the event of unpredictable events.

User case C. Control room within hub

In this use case, one or more operators control a large number of driverless vehicles in a hub. The work is carried out in a special control room where the production flow is planned and optimized several hours, or even days, ahead. The challenge for this use case is to develop solutions for HMI intended to optimize the traffic system at a strategic level, as well as in some cases at a tactical level to maintain a high production efficiency.

In recent years, there have been some successful projects regarding autonomous driving within hubs, the research has made the industry and researchers realize that the complexity of creating fully autonomous and efficient transport systems is higher than expected. Many situations that require detailed control of vehicles and coordination between vehicles can be identified. In these situations, humans have a critical role in creating "up-time" and efficiency in the transport flow, and it is precisely these bridgebuilding human abilities and interactions with the systems that the project intended to explore. Given the lack of drivers (about 20% globally for heavy vehicles) and the continued growing need for transport of goods (driven by e-commerce and increased globalization), the need for driverless transport will increase. This entails continued research and development needs for the new hubs that enable the introduction of early autonomy.

3.2 Natural interaction technologies

Natural user interfaces refer to interfaces that are often invisible to the user and where the interaction is done in a way that is experienced naturally by humans, e.g. via voice or gestures. Natural and intuitive interaction technologies have great potential in the interaction between people and intelligent systems. Voice Interaction (VI) has a number of advantages such as the possibility of having your hands free and not straining your vision. In the Future Industrial Voice (FIVE) project, it was demonstrated how voice interaction can improve the interaction between people and intelligent systems in the future industries. The result shows great opportunities with the interaction technology, but also identified challenges related to e.g. security and integrity.

The use of Head-up Displays (HUD) and Augmented Reality (AR) has been investigated to support operators in various domains, including the mining industry [1]. Overall, the research indicates that the technology can improve operators' productivity, confidence, and safety [2]. For instance, Wallmyr, Taufik and Sitompul [3] showed that placing information near the line of sight may reduce cognitive workload compared to using traditional "look-down" displays. AR also allows information to be placed virtually on objects in the environment, which may allow the operator to quickly access and interpret the information. Further, AR allows the operator to "see through" obstacles and potentially gain better situational awareness. Thus, a HUD solution with AR capabilities, in addition to verbal interaction, was identified as an especially interesting technology to explore. An overall challenge with HUDs and AR is that the information may obscure the real world. Thus, the placement and design of visualizations must take this into account; for instance, the use of semi-transparent AR has been suggested [4]. Another challenge is that visual information on the AR HUD may be challenging to use in bright environments. However, this makes the damped light conditions of underground mines especially interesting for AR technology.

Gesture control is used in more and more contexts such as automobile and gaming industries, but gesture interaction with professional vehicles is little explored. Through Volvo Trucks' Volvo Dynamic Steering function, a truck can be steered from the outside, freeing the driver to handle other tasks. However, control is via a hand control. Researchers from MIT and Yale have explored gesture control of aircraft driving on the ground. The gestures used were well established, but despite this, the number of misinterpretations was high. In addition to technical challenges, cultural differences regarding body language should also be taken into account.

In our project, we extended the knowledge of the state of the art of the natural technologies and explored how the above-mentioned interaction technologies can be used and combined in an effective way to facilitate efficient, safe and inclusive interactions between human operators and automated vehicles in the hubs.

4. Purpose, research questions and method

This project explored and demonstrated how professional workers in the hub contexts should interact with driverless connected vehicles by using natural interaction technologies. The goal was to investigate new models for interaction, which enable efficient and safe transport within hubs. The work focused on a number of use cases (see Figure 1) where interaction with the vehicles is assumed to be significant, and where implementation is possible at an early stage when introducing driverless heavy vehicles. Together, the use cases create a more complete overall picture of the ways people will need to interact with vehicles. In sum, the project aimed at not only providing an understanding of suitable solutions for each user case, but also examining how different interfaces should complement each other and together meet the needs of users in different roles.

The research questions were as follows:

- How should human operators interact with driverless vehicles safely, efficiently and engagingly in connected transport systems in future hubs?

Sub-questions include:

    - What are user needs in future interactions between human operators and more intelligent vehicles in key workflows?
    - Can natural modalities help facilitating safe, efficient and engaging interactions between human operators and HAVs in their daily work?
    - What are human operators' attitudes and how are their first experience with using natural interaction technologies in controlling HAVs?

- How to design for two-way communication between human operators and driverless vehicles in ATS with natural interaction technologies to enable efficient safe and inclusive experience?

  Sub-questions include:

    - What are the state of the art of such new technologies?
    - What are the design recommendations when we apply the natural technologies to improve user experience in the future hubs?

In order to answer these questions, we applied a typical user-centred design approach. As Figure 2 shows, we started from researching the needs of the potential users. We have conducted user research in both mines and logistic centers. User journeys for both contexts in current manual flows were mapped and created. Then interaction points and HMI needs were discussed and identified. Based on the user studies, we selected specific normal operational scenarios e.g. loading (which belongs to Use Case B) as well as deviation scenarios e.g. maintenance fix issues on site (which belongs to Use Case A), to focus on and concepts were created to facilitate interactions in such situations.

The concept development process involved a mixture of competence, such as interaction designers, human factor specialist, sound designers and professional workers from the industry (e.g. forklift drivers). The concepts, which involved one or more natural interaction modalities, represented our assumptions of how new interfaces could be designed. The concepts should be treated as explorative prototypes that support generating knowledge and insights through user testing, instead of final product concepts.

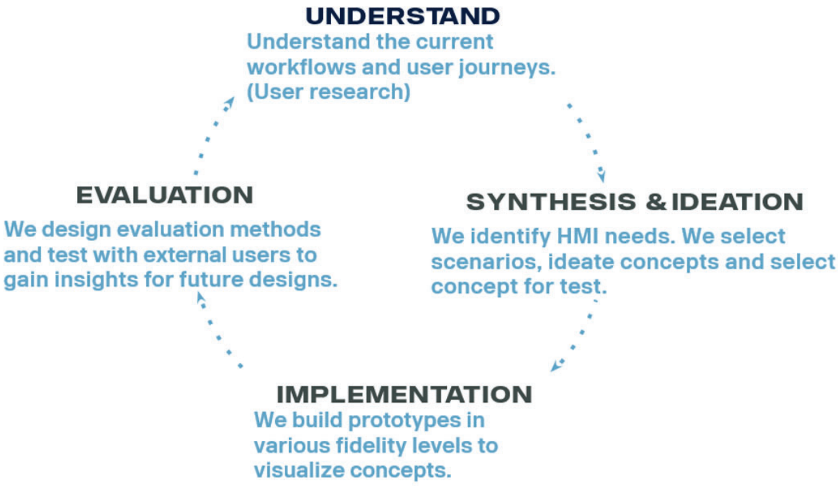

Figure 2 User centred design process in this project

The concepts were implemented into prototypes with different fidelities, such as videos, Virtual Reality (VR) and screen simulator. Videos were created to visualize the concepts of Voice Interaction (VI) and Augmented Reality (AR) in specific scenarios and shown to the targeted users remotely in an initial user study. VR was used in the second iteration of these concepts to provide a more interactive experience for evaluation. In addition, simulation with Wizard of Oz method, was applied to evaluate the gesture concept. Wizard of Oz is a well-established approach for evaluating user interfaces in various domains, e.g. robotics [5] to mobile applications [6] and automotive industry [7]. It is based on the idea of simulating a fully working technical system by a human operator – a wizard [8]. It is often used to gather data from users who believe they are interacting with an automated system.

Lastly, we tested the concepts with external users. Subjective rating was combined with qualitative interviews in all studies. For subjective rating, we have mainly used items from the User Experience Questionnaire (UEQ) [9] and the acceptance scale by Van der Laan et al. [10]. Each item consisted of seven-point rating scales between two opposite words. Each statement was answered using a scale from 1 (do not agree at all) to 7 (completely agree). Open-ended questions were asked in interviews throughout the test to gain more insights into the perceived user experience of the concepts and interaction technologies.

The project work was divided into 10 work packages:
WP 0 Project Management
WP 1 Identify user needs
WP 2 Mapping of interaction design and technology
WP 3 Concept development
WP 4 UI Prototype implementation
WP 5 Integration
WP 6 Evaluation
WP 7 Publishing
WP 8 Demonstration
WP 9 Dissemination of results

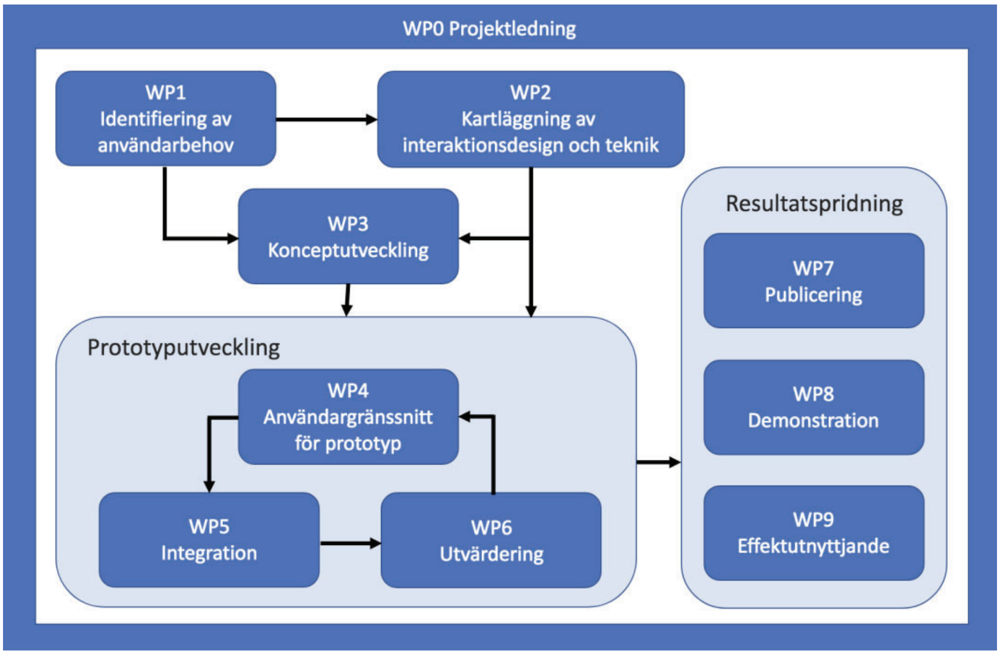

Figure 3 An overview of all the work packages and their major purposes

WP 1 and 2 belong to the **Understand** phase, as seen in Figure 2. They were to gather existing knowledge on natural technologies and identify user needs. WP3 was about concept development, which belongs to the **Synthesis and Ideation** phase. It needs to gather all knowledge from pre-studies and generate new ideas based on the learnings. WP 4 and 5 turned concepts into prototypes of various types. This was about **Implementation**. WP 6 was about **evaluating** the concepts, where the insights would be able to be used in future designs. WP0, 7, 8 and 9 that focused on project management, publications and dissemination were done over the entire project period.

5. Fullfilment of FFI Objective

The project partners comprised a mix of organizations, including a vehicle supplier (Scania), a research institute (RISE), a vehicle customer and end user (Boliden), and an SME specializing in vehicle testing (Icemakers). This combination allowed for the collection of different perspectives from various actors and competences, creating a conducive innovation environment. The project facilitated collaboration between small and large businesses, and between industry and research institutes. The formed consortium creates new opportunities to continue the work in future innovation projects following the present project.

Effective and safe interaction between unmanned, automated vehicles and professional human operators is an important factor for the successful market introduction of autonomous transport systems. This project has generated new knowledge and design solutions for how users can interact with the vehicles in ways that enable safe, effective, and pleasant collaborations. The results of this project can help accelerate the implementation of autonomous transport systems and allow Swedish industry to compete with international actors in the development area. Additionally, the results will contribute to the fulfilment of the zero vision for road safety. Thoughtful interaction between automated heavy vehicles and professional operators who work in proximity of the vehicles is essential for safety, and the interaction models and concepts developed for such situations can guide development and serve as a starting point for further evaluations.

The project has especially generated knowledge related to the needs that the EUTS roadmap addresses under Section 5.6, Humans in the changed system. Overall, the project has created a better understanding of how collaboration between human operators (with different roles in a hub) and future automated systems can be designed. The work has, for instance, provided insights on (1) how people's needs and behaviors change when automated unmanned vehicles are introduced in hubs, (2) how the vehicles can be designed to facilitate trust in the system, and (3) how systems need to be designed so that operators can understand the intentions of the vehicles.

The results provide new input for the requirements of future digital infrastructure in transport systems (see EUTS Roadmap Section 5.3). Considering the high potential of natural interaction technologies (e.g., gesture interaction), it is likely that future digital infrastructure must be able to handle solutions proposed in the present project, in terms of, for example, bandwidth, types of information, and data analysis. The results also give insights into the design and requirements for future vehicle and mobility services mentioned in EUTS Roadmap Section 5.2. The project has contributed to a better understanding of how human operators can communicate and provide input to the system to facilitate transport efficiency and uptime in connected transportation services.

6. Results and deliverables

In this project, the focus has been on understanding the interactions between human operators and heavy automated vehicles in the hubs, and how to design for such interactions with new interaction modalities. Major results and deliverables are summarized in the following sections.

6.1 Knowledge about the workflows, user interactions and environment in current transport systems in the hubs.

We conducted user research in Boliden mines and Scania's internal logistic centers. RISE researchers investigated current workflows for mining. The study was carried out during pandemic, so even though the researchers could visit the company, they could not visit the mines and observe how people work. Instead, they did interviews in the offices with many staff in different roles from several Boliden mines. The outcomes included a report summarizing how workers today perform their jobs and how they view autonomation in general; how collaborations among roles and interactions with technology take place today, as well as three user journeys which visualize the current manual workflows for different scenarios, see below:

1) Truck loads waste rocks/ore from loading area to crusher, unload in a hole (see Figure).

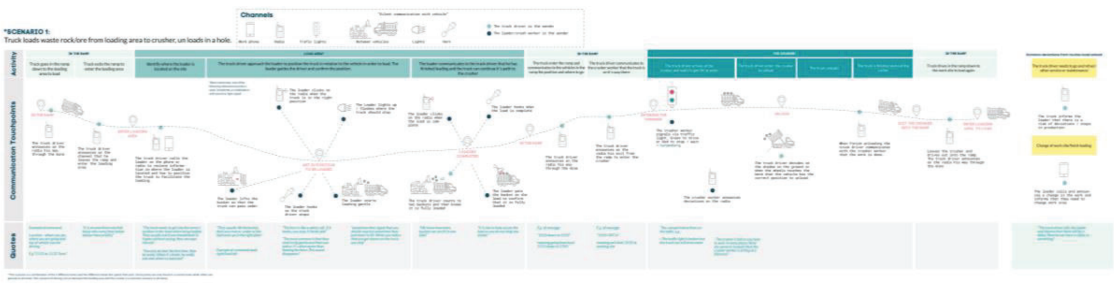

Figure 4 A major workflow for manual transport system in a underground mine: Scenario 1 Truck loads waste rocks/ore from loading area to crusher, unload in a hole

2) Supervisor in light vehicle drives down the ramp on the way to visit staff that loads in a loading area

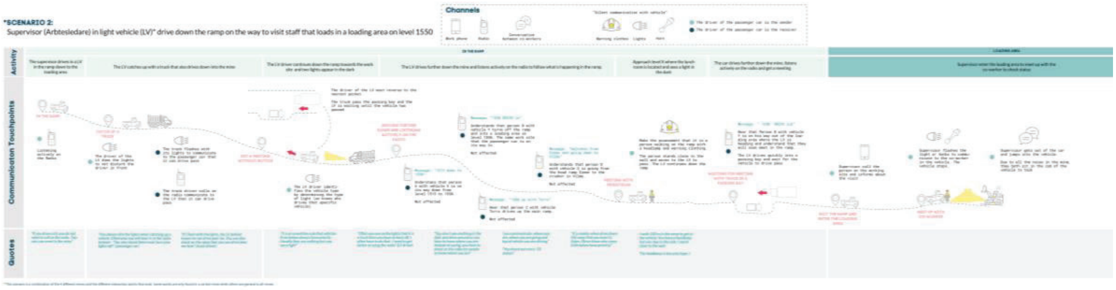

Figure 5 A workflow for manual transport system in a underground mine: Scenario 2 Supervisor in light vehicle drives down the ramp on the way to visit staff that loads in a loading area

3) Communication between Mine Operation Control(MOC) and production in the mine

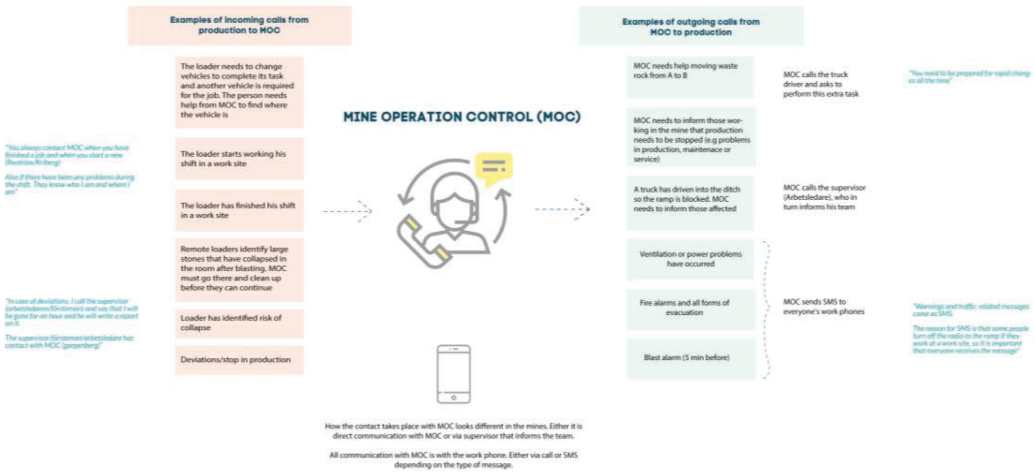

Figure 6 A workflow for manual transport system in a underground mine: Scenario 2 Communication between Mine Operation Control(MOC) and production in the mine

Researchers from Scania focused on understanding the current transport system in warehouses. Interviews and visits were conducted in internal logistic center. The results were also summarized in a written report for internal use. Similarly, we also mapped user journeys for terminals, forestry and factory.

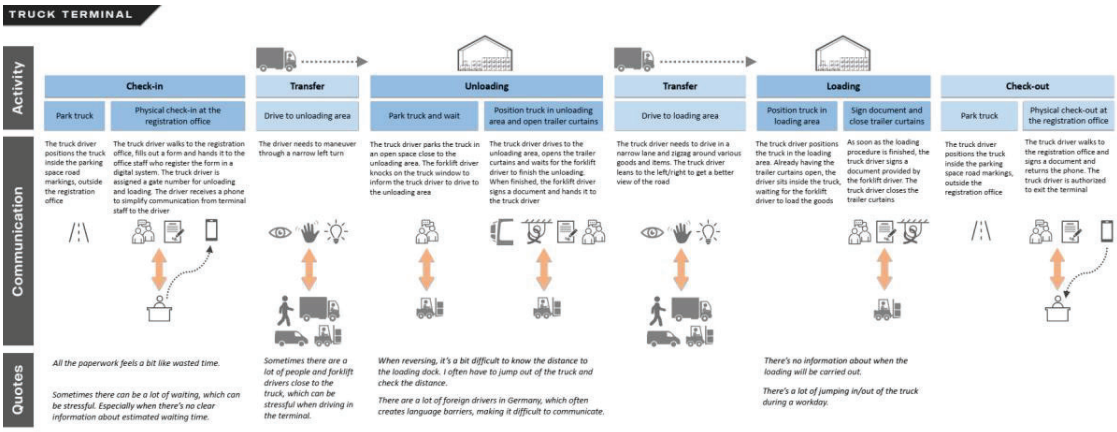

Figure 7 A major workflow for terminals

The project team studied all the results from the user studies and then synthesized HMI touchpoints and needs for normal flows. Based on these discussions and syntheses, we narrowed down to the loading scenarios to create concrete design ideas. The main reasons were that firstly, loading is one of the most important activities in the operations of hubs; secondly, loading is likely to be a major scenario where human beings are still involved in an autonomous transport system of the future (perhaps in ten years), hence keeping such interactions safe and efficient is of great importance. This scenario falls into Use case B from the original plan. From the user research, we also got to know the environment of the human operators and the different roles in the hubs. These knowledge had inspired us and formed the basis for the next major concept developed in the project, which was gesture controlling HAVs in underground mines. The scenarios for this study fall into Use case A. We did not study much on Use case C, except for one master course study focused on designing interfaces for control room, not only because we found other scenarios interesting from our user research, but also because there was another research project called "HAVOC" ongoing focusing specifically on remote control in control room. In order to avoid double work, we decided to move on to other use cases while waiting for the information from that project.

In sum, the knowledge gained from the user research contributes to the goals of understanding the users' needs from current workflows in the hubs. Sorting out what is going on today allows us to improve our knowledge about the needs of targeted users and their working environments. The knowledge also helped us identifying important scenarios for further investigation.

6.2 Summary of "the State of the Art" of natural interaction technologies

This project aimed to investigate how to design for new interactions in the future transport system with natural interaction technologies. In order to better use such emerging technologies, we need to equip us with more knowledge about the features of these different modalities, the current applications and development of them. We summarized the state of the art for the key natural interaction modalities: Voice interaction (VI), Augmented reality (AR) and gesture control.

6.2.1. Voice interaction

Previous research suggests that verbal communication may facilitate interactions between automated vehicles and humans. However, the work has mainly focused on users inside cars and pedestrians near vehicles. A possible advantage of verbal interaction is that the operator can interact with the system while keeping their hands and eyes free. Also, assigning human-like features to the system (anthropomorphism) may increase likeability and trust toward the system.

In the car industry, there are already designs that integrate existing voice interaction assistants to enable verbal interactions with the intelligent systems in cars. For instance, Volvo integrated Google Assistant, Siri or Alexa in some of their models to support drivers getting information and giving commands in voice [11]. The major and more established functions of VI in cars include:

- controlling car telematics features while not in the car such as locks, climate and ignition;
- controlling traditional in-car features while driving such as climate, windows, navigation and entertainment
- accessing or creating personal information such as calendar entries, messages and contacts
- accessing general knowledge such as weather, news, or other questions that may come to mind
- controlling smart home devices while driving
- making voice purchases while driving

In recent years, more companies started to investigate more intelligent solutions. For instance, Nuance focuses on VI solutions and they have combined Artificial intelligence to make the voice interaction smarter and more adaptable. They claimed that the new solution could implement voice biometrics that automatically identifies the driver and personalizes the car settings to their preferences. This will also personalize results from the learning system to the specific driver. Toyota and Audi integrated one of their services “Dragon drive” in their products [12].

6.2.2. Augmented reality

Visual system information in work machines is typically presented on screens and tablets. However, looking at screens while manually operating a machine may pose a safety risk. The use of augmented reality (AR) has been investigated to support operators in various work contexts, including mines. Research has indicated that technology can improve operators' productivity, confidence, and safety [2]. AR also allows information to be placed virtually in the environment, which may allow the operator to easily perceive and interpret the information. AR also offers possibilities to "see through" obstacles (e.g., walls), which offers new possibilities for increasing situational awareness.

In the industry, it was forecasted that AR and VR would be one of the major trends that would change the logistic industry a few years ago [13]. AR has been integrated into more and more industrial development in recent ten years. For example, Skoda uses augmented reality to support logistics staff. As part of a large-scale trial, video mapping projections assist staff when loading sets of components onto pallets. Laser projections indicate the correct position for a part and text, images and video provide information on how to optimally secure and protect the components. The system also notices when a part has been placed incorrectly and helps workers correct this [14].

6.2.3 Gesture control

Gesture control is the ability to recognize and interpret movements of the human body in order to interact with and control a computer system without direct physical contact. The term "natural user interface" is becoming commonly used to describe these interface systems, reflecting the general lack of any intermediate devices between the user and the system.

In academic, research on gesture control has focused on both technical development and user experience for hand gestures. Many of the user studies were conducted in home environment, where gesture is used to control home electronics. For example, Li et al. argue that while gesture control put more mental stress and cognitive load on users, it could improve the overall experience, especially in terms of unrestraint and efficiency, compared to remote control [15]. There are also studies attempting to generate design guidelines and establish a language system for various gestures [16]. Although a few, there are studies that examine the possibilities of using gestures to control more safety critical machines or devices. For example, Montebaur et al. investigated gestures control of automated drones for Special Operations Forces during operation [17].

In industrial application, gesture control has been widely used in consumer electronics (e.g. smart TV, smart home device), healthcare and automobile (e.g. for infotainment systems). The market has been growing fast. For example, it is said to reach 30.6 billion USD for various industries that apply gesture controls in China [18].

In sum, the development of natural interaction technologies, such as Voice interaction, Augmented reality and gesture control have been growing fast and attracted attentions from academic. However, little is known about how these emerging technologies can be used and combined to facilitate collaboration between humans and self-driving vehicles.

6.3 Better understanding and new knowledge on efficient, safe and inclusive interaction between human operators and automated heavy vehicles (by using natural interaction technologies)

We have gained knowledge on the interactions between human operators and automated heavy vehicles and what effects natural interaction technologies could bring to the interactions. Based on the insights from user research, we created concepts for future with our own assumptions and tested them with potential users in relevant professions to gain more knowledge about the future interactions.

The roles of interacting with heavy automated vehicles closely in the hubs do not exist today. Today, the interactions and communications in the hubs are mostly done among human workers, by using traditional devices such as radios and phone calls. Until everything becomes fully autonomous and well synchronized in the future hubs, there will probably be a phase where humans need to work with intelligent self-driving vehicles together. Forklift drivers and mine loaders are such groups of workers that could potentially work with heavy automated vehicles closely on site in the hubs. For the voice interaction concepts, we focused on the loading scenario and created concepts for these groups of users. Today, they collaborate with truck drivers to load and unload goods or rock materials. Truck drivers do more tasks than driving the truck. For instance, in logistic centers, the truck drivers need to secure the loads in logistic centers, and they may be a witness when something wrong happens on the goods that are needed to load into the trailer. They drive the truck to specific loading zones in a warehouse. In mines, especially underground mines, the loaders often guide and lead truck drivers to where the loading should be carried out and the location is often flexible.

Based on the user studies of current workflows in hubs, we created some concepts using VI and AR to support two-way communication between human operators and heavy automated vehicles in loading tasks in both logistic centers and mines. The test results have given us many insights on how the interaction could be in the future. Figure 8 shows an overview of the results we gained from one of the user tests. The results cover a holistic view of our HMI concepts, including not only the experience of the concepts, but also where such interactions will happen (environment), general attitudes from the end users towards automated vehicles and potential changes of personnel (skills and roles) etc.

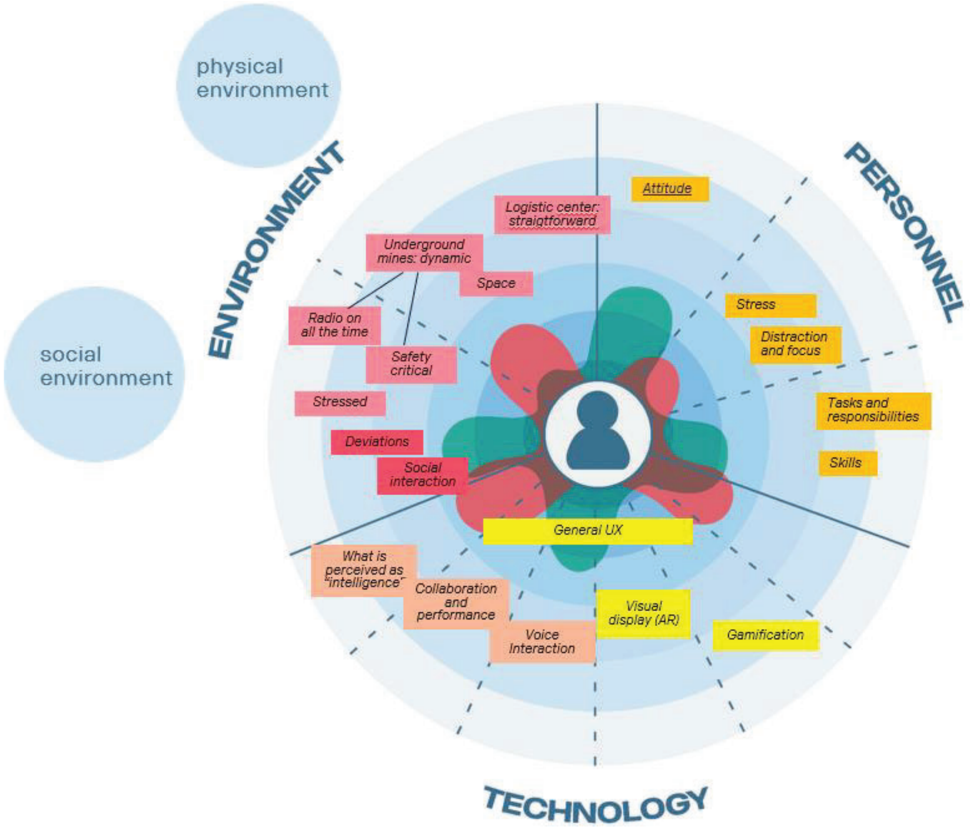

Figure 8 An overview of the insights from one user test for the VI and AR concepts we developed in the project

The test participants, who were real users in logistic centers and mines, helped us understand what would be the consequences, pros and cons if truck drivers were removed from the workflows in the future and how they experienced the voice interaction and augmented reality in loading tasks. On the one hand, the test participants showed positive attitudes towards this new technology and new ways of working, saying that working with automated vehicles will be more efficient and simple in many ways; on the other hand, they also raised the questions like who would secure the loads, and who would clean up the trailer if needed? Some of these tasks seem to be hard to be handled by AVs. If these tasks should be switched to forklift drivers or mine loaders, how should we prepare the existing workforce for new tasks? How much more tasks could they handle except for existing ones? We did not have the answers for these questions, but the results show that these potential human factor issues will have an impact on the interactions between new technology and human users in operations. It is not simply about changing to a different vehicle to work with, but also about a bigger eco-system, such as the trust of the new technology, personnel skills and role changes and new working environment.

The above insights concern general autonomous transport systems. We have also generated many insights directly linked to the user experience (UX) of the concepts. Some key insights are:

- Natural interaction modalities, such as voice interaction, augmented reality and gesture, have high acceptance among end users in the hubs in terms of usefulness, satisfaction and efficiency.

Our first experience tests showed that natural interaction modalities were considered to make the interaction with heavy automated vehicles easier and more intuitive, hence creating more efficiency in the workflow. Regarding specific interaction modalities, AR scored somewhat higher in general, indicating that AR could be especially useful for future implementations. There were also various opinions about talking to a computer. Some expressed it could become boring, or it can make people feel insecure. But some expressed that it would be less misunderstandings due to the fact that there is no human driver involved in the communication. However, our results also showed that many participants considered it beneficial to have a combination of VI and AR, for example if verbal response options could also be displayed in text on the AR screen. Similarly, we have got high acceptance for the gesture control concepts for mine workers, though there are concerns about technical implementation in harsh environment in underground mines.

- It is of great importance to adapt future implementations to the needs and desires of specific users in specific contexts.

For the concepts of VI and AR, we have conducted studies with both logistic staffs and mine workers to compare more social conversation with intelligent systems with basic verbal interactions, like voice command. Our interviews with forklift operators supported that successful implementation of social interaction could increase the operator's trust in the automated vehicle and acceptance of the interaction. However, rock-loading operators tended to prefer simple voice commands. This indicates that within confined areas in hubs, there are different and unique needs for different end users, thus it is crucial to study what their needs are. The interaction will not be the same for hubs.

- There is high dependency on the technical capabilities for the interactions enabled by natural interaction technologies. Technology needs to be developed to a level that can provide reliable functions so that users confidence in such interactions will be assured.

Although natural technologies have got high acceptance, some of the end users also believed that the solution belongs to the future rather than the present, as some development is still required to make it work well. For instance, in our VR study, we have implemented basic voice interaction into a VR headset using the simplest method available today. Eight subjects (44%) had difficulties to communicate without any interference using VI, e.g., they needed to repeat a message or rephrase it at least once. Thus comments on the technical development for such interactions were mentioned. This indicates that it is of great importance to develop VI solutions that can accurately interpret the voice messages, and support users to recognize, diagnose, and recover from errors. Otherwise, it will easily lead to frustration and stress in the interaction.

6.4 Several concepts visualized in different prototypes with different fidelity levels

In this project, we have created over five concepts using different natural interaction modalities. These concepts were implemented into several prototypes with different fidelity levels. The project was conducted during pandemic, which caused more difficulties to conduct experiments with users in person. Due to many practical limitations, we had to revise the prototyping and testing methods to adapt to new situations in the project. For instance, the testing truck which was rebuilt by Scania to test HMI concepts for automation, was not possible to use due to malfunctions during the period when we wanted to build physical prototypes to test our concepts. In that case, we had to go for other methods, to create simulation instead. Nevertheless, we managed to make the best use of what we had as resource within limited time frame, and still applied a variety of methods to test the concepts, including videos, Virtual reality and simulation.

Video prototyping

The process of designing concepts involved a team of interaction designers, 3D animators, researchers, a forklift operator, and people from a mining company. The process resulted in two concept variants for each user context: natural voice interaction (NVI) and basic voice interaction (BVI). Below is a table summarizing the differences between the two concepts.

Table 1. Comparison between Concept A Natural Voice Interaction and Concept B Basic Voice Interaction

	Concept A Natural Voice Interaction	Concep B Basic Voice Interaction
Key features	Complex voice interaction between operators and AI (social characteristics, situational) Swedish Simple clear icons to display information in HUD Time and progress indication in HUD Visual guidance in loading Gamification elements for loading correctly Error warning in loading	Simple voice interaction between operators and AI. Swedish Simple clear icons and texts to display information in HUD Time and progress indication in HUD Visual guidance in loading Gamification elements for loading correctly Error warning in loading
Interaction models	AI-enabled VI, AR HUD	AI-enabled VI, AR HUD
Contexts	Logistic center; underground mine	Logistic center; underground mine

AR was used in both variants to provide visual guidance and information to perform the loading (see Figure 1). The AR consisted of 2D and 3D elements. The concepts were implemented in approximately three-minute-long animated movies, showing the loading being performed by the operator from a first-person perspective. The videos showing the scenarios and the concepts are accessible online.

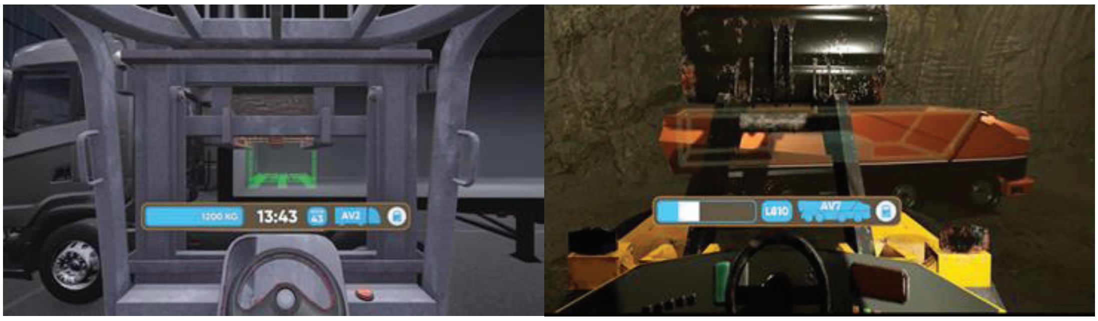

Figure 9. AR display in the logistic center (left) and mine (right).

Virtual Reality

Based on the first study using concept videos, we decided to go for one of the concepts for logistic center and implemented it in a more interactive prototype in a second round of iteration. We improved the concept, especially the AR user interface; and implemented the concept in a VR environment.

The screen was projected on the windscreen of the forklift in the VR environment and contains both 2D and 3D elements, see Figure 10. The VI consisted of information and questions provided by the truck. To make it as easy as possible to interact with the truck, the language of the operator's area of operation was used (Swedish). A female voice was used to represent the truck. Initially, the truck greeted the operator and provides information about the position of the vehicle in the logistic center, total load capacity and time to departure. The truck asked questions, e.g. if the operator is ready to start the loading, if it should lock itself (to prevent other operators from controlling the truck), and if it should open the compartment. When the load capacity was reached, the truck informed the operator and asked if it should close the compartment and unlock itself. The operator can reply to the questions using either simple answers (e.g., "yes") or a bit more complex answers (e.g., "please do that"). The concepts and virtual environment were created using the Unreal Engine software (Epic Games Inc, USA). VI was integrated using Google API [13], as it is one of the most reliable APIs and it facilitates the development for this particular case. In addition, we also summarized the existing potential technical solutions or platforms to implement more social conversations in a report for future use.

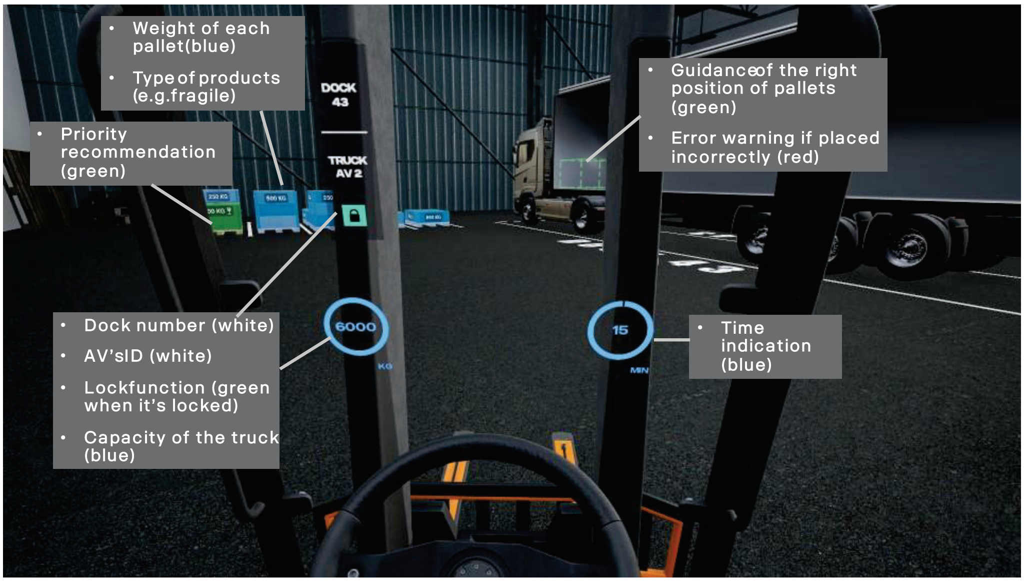

Figure 10. AR display in the logistic center (left) and mine (right).

Wizard of Oz simulation

We used a Wizard of Oz simulation method to test the gesture concepts created for the mining contexts. The concepts consisted of gestures and external Human Machine Interfaces (eHMI) which provided feedbacks on the heavy AV. The eHMI were LED light strips showing different behaviors in reaction to different gestures.

A projector was set up to project a simulated underground mining environment into a cloth display. The visual context was created using Unreal engine. The AV's movement was controlled manually by a Wizard person sitting in an adjacent room and was invisible to the test participants. He observed participants' gestures and make reactions of the AV accordingly at the right time. Each session included doing predefined gestures for three scenarios: Stop an AV; Adjust position of a standing still AV; Navigate around (guide an AV to pass a big obstacle). Table 2 describes the predefined gestures.

Table 2. Description of the gesture concepts and their features

Scenarios	Stop	Adjust position	Navigate around

Gesture concepts	 Stretch your arm in front of your chest Palm faces towards the vehicle.	 Arm bends on one side and one palm faces towards the vehicle. Hand goes down and the arm stretches straight.	 Arm waves toward the direction that you would like the AV to continuously move in.
Features	Semaphoric		
	Static	Single stroke	Dynamic

Each test participant experienced two rounds: one with external HMI and one without eHMI. We created a short video to show all the gesture concepts and eHMI and how they should be combined in the selected scenarios. We also investigated a bit on the technical implementation of gesture detection in simulation studies and summarized them into a written report to provide insights for the future tests.

Figure 11. The cab-less automated vehicle with eHMI to signal vehicle's intentions in the underground mine simulation.

6.5 Design implications

Through concept development with multiple competence in the project and several user tests with real targeted users in the hub contexts, we have gained insights for designing two way communication between professional workers and heavy automated vehicles by using natural interaction technologies. Key design implications are listed as follows:

General implications

- Designing for efficiency is of great importance for hub workers. It is important that designs enable a proper flow in the collaboration between heavy automated vehicles and professional workers in daily tasks.
- Multi-modal interactions are recommended in order to provide maximal efficient and safe experience.
- Designs should adapt to the needs of specific user groups to gain high acceptance and productivity. There is no single solution for all hub contexts. Different needs could include different personalities as well as different workload/stress and working environment.
- Design should support users to recognize, diagnose and recover from errors from the system as well as to handle deviations in operations.
- Attitudes towards gamification are individual. People have different needs in playing games (different preferences, purposes) e.g. 5 types of players. More studies and tests are needed to investigate into how to use gamification to motivate professional users.

Voice interaction

- Design of Voice interaction should enable flexibility. This means that the same command can be given in different ways. Designing such interfaces need to study natural conversations in real world. The system should be able to recognize various possible ways of speaking/giving commands from the users as input, instead of only one way.
- Design of Voice interaction should show the system status. The start and end of the speech interaction must be obvious.
- Design of VI and AR should keep information simple.

HUD Augmented Reality

- Show key information at the right time.
- Design of HUD AR should not obscure visibility. This requires a good understanding of the users needs in specific contexts.
- It may be good to provide customization possibility to set the position of the information and style of UI.
- It might need AR to display information in HUD and on the sides, to provide the best visibility and maximize the display of important information

- Design of HUD AR should use colors carefully.

Gesture

- How many times of the gesture the user should do may need to be predefined. This is also related to technical capabilities, such as what the hardware could recognize in terms of gestures.
- If the gesture is to make AV stop or standstill in a certain way, static or stroke gesture is recommended; If the gesture is to make an AV move or guide an AV's movement, dynamic gesture is recommended, or at least it could be a major part of a series of gesture.
- Gesture needs to be detected in a distance, not to be too close.
- Gesture needs to deliver clear messages.
- For different messages, gesture should be distinguished enough, to avoid confusion
- Gesture control should be combined with immediate feedback, 1) to confirm that the system has taken the command or recognized the gestures; 2) to inform users of which actions it is about to take.
- The feedback could be shown through external Human Machine Interfaces. They should be straightforward and simple.
- Light is a good modality to provide feedback to gesture control.

However, we also want to emphasize that these insights were merely based on all studies within "In the hub" project, including major concepts developed together by Scania, RISE and Boliden as well as master thesis. Three of them were related to VI and AR, and two were on gesture control. More research and tests are needed to understand how to design with these technologies, especially gesture control, in the future.

6.6 A mixed method frame work to evaluate our concepts in different settings, including video test, VR and Wizard of Oz simulation

In this project, we attempted to use mixed methodologies to evaluate the concepts in different hub settings and managed to do two iterations for one concept. In the first study, we used concept videos to communicate our ideas. Video prototyping is a good way to tell a story about a design concept in an early phase of product development. Video prototyping allows end users to connect with the design as they would in a seemingly real life. It shows the entire experience in a context through a narrative.

In the second study, we selected one concept for logistic center to improve. It was implemented in a VR headset to provide a more immersive experience. VR has been a common tool in the automotive sector to design, develop and evaluate interfaces in early development stages since the 1990s. Using VR reduces development time and cost but also comes with new challenges to build real-world-like scenarios. In our study, the study participants were equipped with a commercial VR headset that allowed them to get a

360-degree view of the environment around them. The subjects sat in a chair which was adjusted to the participants height so they could comfortably use the steering wheel pedals when driving the forklift in the VR environment. A script was followed during the sessions, so all participants got the same information, and everything presented in the same order. A brief warm-up session was performed, without the VI and AR elements, before the real test to allow the subject to familiarize with the controls and VR environment. The loading scenario was around 8 min long and subjects typically performed the scenario in VR two times.

In the final study, we used a Wizard of Oz simulation method to allow the test participants to interact with the vehicle in a virtually simulated environment. Our research questions for the test focused on human factor issues, e.g. users' general attitudes and experience of using this modality to control a big vehicle, thus we did not require a simulation prototype with real gesture control functions, which also would probably limit the gestures that we could test. Using Wizard of Oz, instead, allowed us to build a simulation prototype within less timeframe, and test more gestures in different scenarios. Wizard of Oz is a well-established approach for evaluating user interfaces in various domains, e.g. robotics [15] to mobile applications [16] and automotive industry [17, 18]. It is based on the idea of simulating a fully working technical system by a human operator – a wizard [19]. It is often used to gather data from users who believe they are interacting with an automated system. In our experiment, the Wizard, who was controlling the vehicle movements, sat in an adjacent room and was invisible to the test participants. He needed to observe test participants' gestures and make reactions of the AV accordingly and at the right time. Each trial included two rounds: one with eHMI and one without eHMI. The controlling gestures were the same in both rounds, and the subjects conducted the rounds in a counter-balanced order. A video presented specific gestures for each scenario, and the participants followed along accordingly. After each round, they answered questions and statements related to acceptance and efficiency of the interaction, and other aspects of their user experience. Video data was collected.

6.7 Long-term competence development: two master thesis

The project work has also contributed to long-term competence development in Sweden. It has generated two Master's theses entitled "Investigating User Accepted Interaction Concepts for Autonomous Mining Vehicles: A Design Process for Developing and Validating a Human-Machine Interaction Concept based on User Needs" and "Investigating a gesture based interaction model, controlling a truck with the help of gestures"; as well as one master course report. In addition, we have generated a range of scientific publications.

7. Dissemination and publications

7.1 Dissemination

How are the project results planned to be used and disseminated?	Mark with X	Comment
Increase knowledge in the field	x	Currently, there is a knowledge gap regarding interactions between professional users and heavy automated vehicles, as well as how natural interaction technologies could be used in such interactions. This project has contributed to these areas. Project members have been involved in several events internally and externally where the need for and design of external interfaces has been discussed with other professionals, both from academia and industry. Several publications have been generated.
Be passed on to other advanced technological development projects		
Be passed on to product development projects	x	Scania has some new product development for 2030s where knowledge on design of HMI from this project could be utilized.
Introduced on the market		
Used in investigations / regulatory / licensing / political decisions		

The following dissemination activities have been performed in the project and its results was presented:
• Master course report presentation: David Bejlum , Sofia Johansson, Hanna Mattsson, LTU. "UI design for control room in the hub". Jan. 15, 2021

• Master thesis presentation: Niclas Brynolfsson, Umeå University, “Investigating a gesture based interaction model, controlling a truck with the help of gestures”. Niclas presented his master thesis work on the gesture control of heavy auto vehicles when the operator is close by. Apr. 20, 2021.
• Master thesis presentation: Johan Rindborg, and Johanna Engström, “Investigating User Accepted Interaction Concepts for Autonomous Mining Vehicles: A Design Process for Developing and Validating a Human-Machine Interaction Concept based on User Needs.” Linkoping University. Jun. 8, 2021. Niclas presented his master thesis work on the gesture control of heavy auto vehicles when the operator is close by.
• Conference demo: Johan Fagerlönn, “Designing Collaboration between Human Beings and Self-driving Heavy Vehicles with Emerging Interaction Technologies”, AutoUI 2021
• Conference presentation: Johan Fagerlönn, “Facilitating Collaboration between Humans and Unmanned Heavy Vehicles using Verbal Interaction and Augmented Reality”, AHFE 2022. New York.
• Conference presentation: Hamed Yahyaei, “Design complexity for future customer co-creation”. In the hub was presented as a case where we involve future customers in the concept development. Car HMI Europe 2022, Amsterdam. Jun. 20, 2022.
• Conference demo: Johan Fagerlönn, “Collaboration with Highly Automated Vehicles via Voice and Augmented Reality”, In Companion of the 2023 ACM/IEEE International Conference on Human-Robot Interaction (HRI ’23 Companion), Mar. 13–16, 2023, Stockholm, Sweden.
• Internal events: Yanqing Zhang, “User experience of future HMI concepts for automated Hubs” online seminar during the Scania Innovation Day, Oct. 13, 2022. Audiences were Scania employees and guests from the Traton group.
• SAFER presentation. Project was presented to the SAFER lunch seminar, Dec. 9, 2022.
• Seminar: Johan Fagerlönn, “Smarta fordon och framtidens mobilitet”, Luleå Science Park, Jan. 24, 2023. Link: https://projekthandson.se/2023/01/25/handson-bjod-in-till-lunchseminarium-pa-lulea-science-park/
• Demo: Johan Fagerlönn. RISE 40-year anniversary in Skellefteå. Demonstration of project results to wood industry stakeholders. Feb. 24, 2023.
• Videos: the concept videos for Voice interaction and Augmented reality are online for public views. https://vimeo.com/user141709666
• VINNOVA web. Project overview, Linda Meiby, Azra Habibovic, 2020/04. Link: https://www.vinnova.se/en/p/external-interaction-principles-for-creating-trust-in-heavy-automatedvehicles---phase-1/
• RISE web. Project overview. https://www.ri.se/en/what-we-do/projects/in-the-hub

Upcoming:
• Conference presentation: Johan Fagerlönn, “Interaction with Automated Heavy Vehicles Using Gestures and External Interfaces in Underground Mines”, in 25th International Conference on Human-Computer Interaction, Jul. 23-28, 2023

7.2 Publications

Master thesis:

Rindborg, J., & Engström, J. (2021). Investigating User Accepted Interaction Concepts for Autonomous Mining Vehicles: A Design Process for Developing and Validating a Human-Machine Interaction Concept based on User Needs.

Brynolfsson, N. (2021). Investigating a gesture based interaction model, controlling a truck with the help of gestures. (Dissertation). Retrieved from http://urn.kb.se/resolve?urn=urn:nbn:se:umu:diva-191598

Conference papers

Fagerlönn, J., Sirkka, A., Orrell, L., Zhang, Y., Larsson, S., Tybring, E. and Rönntoft, H. (2021). Designing Collaboration between Human Beings and Self-driving Heavy Vehicles with Emerging Interaction Technologies.(Automotive UI '21 Adjunct). Association for Computing Machinery, New York, NY, USA, 123–127. https://doi.org/10.1145/3473682.3480278

Fagerlönn, J., Zhang, Y., Orrell, L., Rönntoft, H. (2022). Facilitating Collaboration between Humans and Unmanned Heavy Vehicles using Verbal Interaction and Augmented Reality. In: AHFE (2022) International Conference. AHFE Open Access, vol. 57. http://doi.org/10.54941/ahfe1002310

Fagerlönn, J., Zhang, Y., Orrell, L. and Rönntoft, H. (2023). Collaboration with Highly Automated Vehicles via Voice and Augmented Reality. In Companion of the 2023 ACM/IEEE International Conference on Human-Robot Interaction (HRI '23 Companion), March 13–16, 2023, Stockholm, Sweden. ACM, New York, NY, USA, 5 pages. https://doi.org/10.1145/3568294.3580143

Others

Zhang, Y. "In the hub project", Posters for In the hub project. Scania Innovation Day, 2021. Published internally on the website of the event.

Zhang, Y., "Design for collaboration between human operators and av in the hub", Posters for In the hub project. Scania Innovation Day, 2022. Published internally on the website of the event.

Upcoming publications

Johan Fagerlönn, Yanqing Zhang, Lina Orrell, Hanna Rönntoft, Interaction with Automated Heavy Vehicles Using Gestures and External Interfaces in Underground Mines, in HCII proceedings, 2023, Submission accepted and full paper submitted.

8. Conclusions and future research

In this project, we aimed to investigate new models for interaction, which enable efficient and safe transport within and between hubs. The work focused on a number of use cases (see figure 1) where interaction with the vehicles is assumed to be significant, and where implementation is possible at an early stage when introducing driverless heavy vehicles. Based on our user research, we focused on Use case A and B in the concept development. Overall, the project provided an understanding of possible solutions for each user case, and how new interfaces could be used and combined together to meet the needs of users in different roles.

How could human operators interact with driverless vehicles in connected transport systems in future hubs?
Today, the communication in the hubs is mostly done among human workers, by using traditional devices such as radios and phone calls. To replace some of the roles with intelligent systems in the future, we need to understand the interactions and investigate how to make the transition from interacting with human workers to interacting with new systems. The concepts developed in the project were used as prototypes to gain insights and understand future interactions. Our test results show that natural interaction technologies has great potential to improve efficiency, perceived safety and satisfaction in the work experience of professional workers where interactions with heavy automated vehicles are needed. Using natural interaction modalities to interact with automated vehicles mimics the interactions with colleagues today. It is easy and familiar for the users, contributing to building trust in a new system. Intelligent systems could also avoid human errors in many ways and provide good information at the right time, which improves the efficiency.

In addition, some industries are concerned that they would encounter workforce challenges in the future when autonomous transport systems are more mature and become the mainstream, for example, the mining industry. How to attract young talented people will be one of biggest challenges for them. To attract young generation who take user-friendly interactions for granted, as well as to transform old workforce to fit in new roles, easy user interfaces will be one of the key issues in the development of intelligent systems. Using natural interaction modalities has clear benefits in this, since they do not require much learning. They can help preparing the existing workforce for system transformation in the future. The end users do not need to have a degree in technology to be able to work closely with these intelligent systems in the future. Moreover, with easy to use interfaces and possibilities to adapt to different needs, natural interaction technologies (empowered by AI) may contribute to more job satisfaction among professional workers in hubs.

How to design for two-way communication between human operators and driverless vehicles in ATS with natural interaction technologies to enable efficient safe and inclusive experience?

Through concept development which often involved multiple competence, including potential end users, we created several concepts using VI, AR and gesture control. The concepts provided concrete examples of how we could apply these natural interaction modalities and how we could combine some of them to improve the whole experience. We tested the concepts with real professional workers in hub contexts today, e.g. forklift drivers and mine workers. The test results provided input and implications for designing two-way communication between human operators and driverless vehicles in hubs. VI and AR were combined in concepts and tested for two rounds. Gesture was combined with external signals on AVs in the concept and tested in one simulation study. Therefore, we have gained knowledge in how VI and AR could be combined for specific scenarios, but not in how gesture could be combined with other natural modalities. The following table shows the features of these different modalities and what information types would be good to use for each specific interaction modality.

Table 3. Communication models and information types for different natural interaction tecchnologies

	Voice interaction	**AR-HUD**	**Gesture**
Communication model	Two way: User's voice as Input, system's voice as output	One way: system display information as output	Two way: user's gesture as input, AV's action (perhaps also eHMI) as output
Information type	- provide the info that is useful right now, and to highlight important information - give feedback for users' voice command - give reminders or warnings (Be careful that giving warnings by speaking may increase stress upon users) - social conversations (if advanced voice interaction is preferred)	-visual guidance/recommendation - more complex info to help understand products and environment better - work memory support (e.g. the name of the truck or remaining capacity). - Give reminders and warnings	Users give input to the system in specific and urgent situations (e.g. when urgent take over in proximity to the AV is needed)

Future research

This project has gained valuable insights on how to design for interactions with heavy automated vehicles in the hubs by using natural interaction technologies. It demonstrated that these new technologies have great potential for future development and integration into ATS, but still more research is needed, for example in the following areas:

- Further investigation could be on when should we use which modalities (including all possible interaction modalities) to make the best use to fit users' needs and human capabilities in external interactions with AVs. For instance, when should we use gesture and when to use voice interaction?

- We mainly used VR and simulation for user tests. The results show that natural interaction technologies may provide great value for future ATS development. However, virtual environment and testing in labs are not the same as if the users interact with a real heavy vehicle in relevant contexts. It will be beneficial to test concepts in real vehicles to compare the results.
- In this project, we focused on several use cases in the hubs. We assume that natural interaction modalities could be useful in more use cases, which could be further investigated into, such as control room, or hub-to-hub. For instance, voice interactions in control room one interesting scenario will be if gestures could help communicating with traffic police on the public roads.
- Natural interactions depend much on cultural background and social norms. All our studies were conducted in Sweden. Future studies could look into the cultural differences of using natural interactions, e.g. voice and gestures. How do people with different cultural backgrounds use the same natural interaction modalities to interact with intelligent systems? This will be important for global companies like Scania to study, since they need to develop future services and products for different markets.

9. Participating parties and contact persons

SCANIA	Scania CV AB Granparksvägen 10 SE-151 48 Södertälje, Sweden Contact: Yanqing Zhang yanqing.zhang@scania.com
RI. SE	RISE Research Institutes of Sweden, Kunskapsallén 14, SE- 94163, Piteå, Sweden Contact: Johan Fagerlönn johan.fagerlonn@ri.se
NEW BOLIDEN	Boliden Mines Technology Finnforsvägen 4 SE-936 81 Boliden, Sweden Contact: Peter J. Burman peter.j.burman@boliden.com

10. References

[1] Jacobs J., Webber-Youngman R. C. W., and Van Wyk E. (2016). Potential Augmented Reality Applications in the Mining Industry. ResearchGate. https://doi:10.13140/RG.2.2.27751.44961

[2] Sitompul T. A., Wallmyr M. (2019). Using augmented reality to improve productivity and safety for heavy machinery operators: State of the art. In The 17th International Conference on Virtual-Reality Continuum and Its Applications in Industry, ACM, New York, NY, 8:1–8:9. https://doi.org/10.1145/3359997.3365689

[3] Wallmyr M., Sitompul T. A., Holstein t., and Lindell, R. (2019). Evaluating mixed reality notifications to support excavator operator awareness. In IFIP Conference on Human-Computer Interaction. Springer, Cham, pp. 743-762.

[4] Sarupuri B., Lee G. A. and Billinghurst M. (2016). Using augmented reality to assist forklift operation. In Proceedings of the 28th Australian Conference on Computer-Human Interaction. ACM, Launceston, Australia, 16-24. https://doi.org/10.1145/3010915.3010952

[5] Hoffman G, Ju W (2014). Designing Robots With Movement in Mind. Journal of Human- Robot Interaction, 3(1), 89-122.

[6] Carter S, Mankoff J (2005). Momento: Early-Stage Prototyping and Evaluation for Mobile Applications. Retrieved: https://www.eecs.berkeley.edu/Pubs/TechRpts/2005/5224.html

[7] Habibovic A, Andersson J, Nilsson M, Lundgren Malmsten V, Nilsson J (2016). Evaluating interactions with non-existing automated vehicles: three Wizard of Oz approaches. In the Intelligent Vehicles Symposium (IV), 2016 IEEE. http://doi.org/10.1109/IVS.2016.7535360

[8] Steinfeld A, Jenkins O C, Scassellati B (2009). The oz of wizard: simulating the human for interaction research. The 4th ACM/IEEE international conference on Human Robot Interaction, pp.101–107. http://doi.org/10.1145/1514095.1514115

[9] Schrepp M. (2015). User experience questionnaire handbook: All you need to know to apply the ueq successfully in your projects URL http://www.ueq.online.org.

[10] Van Der Laan, J.D., Heino, A. and De Waard, D., 1997. A simple procedure for the assessment of acceptance of advanced transport telematics. Transportation Research Part C: Emerging Technologies, 5(1), pp. 1–10.

[11] See https://www.volvocars.com/uk/support/topics/car-systems/volvo-on-call/volvo-on-call-app-about-voice-control-with-google-assistant-amazon-alexa-and-siri. Accessed 10 October, 2022.

[12] See https://voicebot.ai/2018/01/17/dragon-drive-nuance-provides-automakers-voice-interaction-edge/. Accessed 01 March, 2022.

[13] Glockner H., Jannek K., Mahn J., Theis B. (2014) Augmented reality in logistics: Changing the way we see logistics- A DHL perspective, DHL Trend Research. Retrieved https://www.dhl.com/discover/content/dam/dhl/downloads/interim/full/dhl-csi-augmented-reality-report.pdf

[14] See https://www.skoda-storyboard.com/en/press-releases/skoda-auto-tests-video-mapping-augmented-reality-helps-when-loading-pallets-in-logistics/attachment/190315-skoda-testuje-videomapping/ Accessed 17 May 2021

[15] Li X., Guan D., Zhou M., Zhang J., Liu X., and Li S. (2019). Comparison on user experience of mid-air gesture interaction and traditional remotes control. In Proceedings of the Seventh International Symposium of Chinese CHI (Chinese CHI '19). Association for Computing Machinery, New York, NY, USA, 16–22. https://doi.org/10.1145/3332169.3333570

[16] Aigner, R., Wigdor, D., Benko, H., Haller, M., Lindbauer, D., Ion, A. & Koh, J. T. K. V. (2012). Understanding mid-air hand gestures: A study of human preferences in usage of gesture types for HCI. Microsoft Research TechReport MSR-TR-2012-111, 2, 30.

[17] Montebaur M., Wilhelm M., Hessler A., and Albayrak, S. (2020). A Gesture Control System for Drones Used with Special Operations Forces. In Companion of the 2020 ACM/IEEE International Conference on Human-Robot Interaction (HRI ’20). Association for Computing Machinery, New York, NY, USA, 77. https://doi.org/10.1145/3371382.3378206

[18] See https://nexocode.com/blog/posts/gestures-recognition-challenges-and-opportunities. Accessed 15 March. 2022.