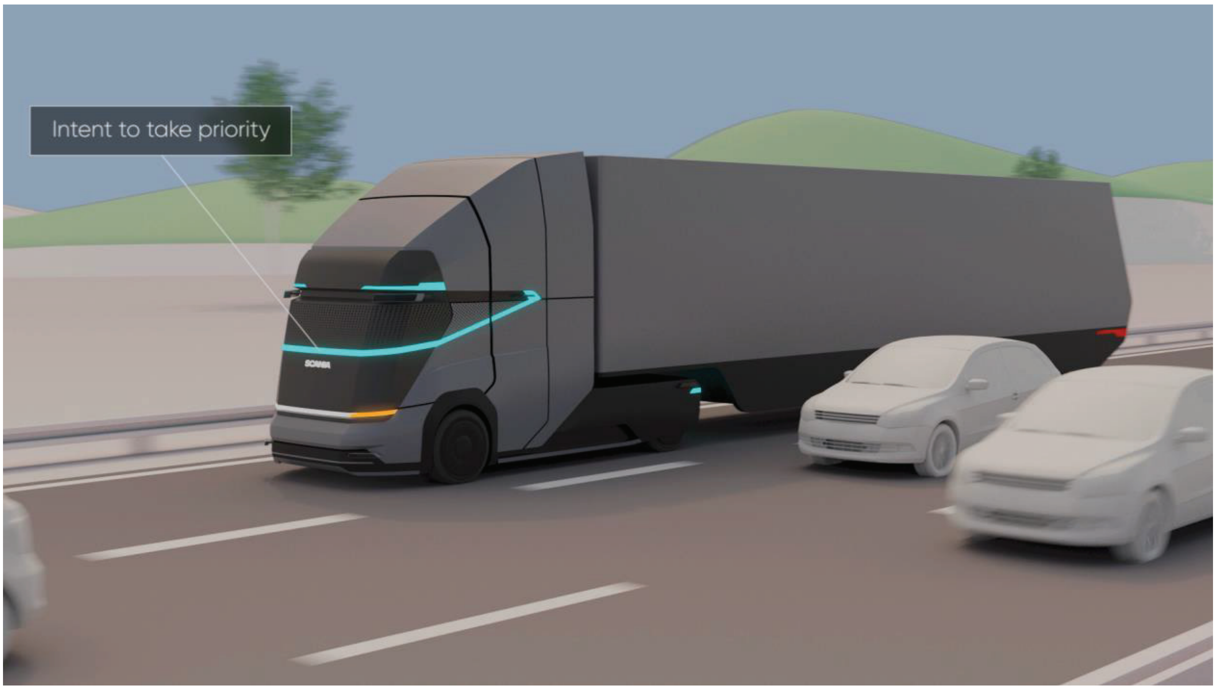
External interaction principles for creating trust in heavy automated vehicles



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Innehållsförteckning

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1 Summary

To become widely used on public roads, future automated vehicles will need to be trusted and gain social acceptance – something that will be greatly affected by the ability of such vehicles to safely, efficiently and seamlessly interact with other road users in the traffic system. While still largely limited, understanding of these interactions in the research community and industry has increased under the last 6-7 years. However, studies are mainly focused on interactions with automated passenger cars and there is a knowledge gap regarding interactions with heavy automated vehicles (HAV) such as buses and trucks. To reduce this gap, the current project investigated interactions involving HAV and other road users in their vicinity. The aim was to identify how trust and acceptance of such vehicles (SAE Level 4 with/without driver onboard) can be created and maintained.

By conducting systematic literature reviews and expert discussions, the project team created an understanding of current interactions between heavy vehicles and other road users, as well as identified scenarios in which these interactions take place. In the next step, a series of experimental studies with HAV capturing some of these scenarios (zebra crossing, loading zone, bus stop, highway merging) were conducted utilizing a mixed-methodology approach in VR, driving simulator and on a test track. A set of external human-machine interface (eHMI) concepts for HAV was designed and evaluated with the ultimate goal to explore user behavior and experience rather than designing a market-ready interface. By conducting studies both with and without additional eHMIs, the project could establish a baseline for the interactions and study what added value a given interface might have on safety, efficiency and experience – factors that are key for creating trust and acceptance.

The project results include, but are not limited to:

- Knowledge on how manually operated heavy vehicles interact with other road users in their vicinity and what implications these interactions may have for HAV.
- Mapping and understanding of traffic scenarios relevant for interactions between HAV and other road users.
- Knowledge on how HAV might interact with other road users and the role that additional eHMI might play in future.
- Several eHMI prototypes of different fidelity levels, including physical prototypes that were installed on a seemingly automated truck.
- Guidelines on design of interactions and communication between HAV and other road users.
- A mixed methodology framework for evaluation of external interactions in different settings including VR, driving simulator and test track.
- Contribution to standardization and regulation work.
- Long-term competence development: one licentiate thesis and several publications.

Given novelty of this research topic, especially when it comes to HAV, the project provides world-unique knowledge both to industry and research community. As such, the project strengthens Swedish international competitiveness and relevance, and is in line with overall FFI goals.

2 Sammanfattning på svenska

För att framtida automatiserade fordon ska kunna användas i stor utsträckning på allmänna vägar måste de få förtroende och accepteras av samhället - något som i hög grad kommer att påverkas av fordonens förmåga att interagera säkert, effektivt och smidigt med andra trafikanter i trafiksystemet. Även om kunskapen fortfarande är begränsad, har forskningen under de senaste 6-7 åren lett till ökad förståelse för dessa interaktioner både inom forskarsamhället och industrin. Studier är dock främst inriktade på interaktioner med automatiserade personbilar och det finns en kunskapslucka kring interaktioner med tunga automatiserade fordon (eng. heavy automated vehicles, HAV) som bussar och lastbilar. För att minska detta gap undersökte det aktuella projektet interaktioner mellan tunga automatiserade fordon och andra trafikanter i deras närhet. Syftet var att identifiera hur förtroende och acceptans för sådana fordon (motsvarande SAE Level 4 med/utan förare ombord) kan skapas och upprätthållas.

Genom systematiska litteraturanalyser och expertdiskussioner skapade projektgruppen en förståelse för nuvarande interaktioner mellan manuellt framförda tunga fordon och andra trafikanter samt identifierade scenarier där dessa interaktioner äger rum. I nästa steg genomfördes en rad experimentella studier med tunga automatiserade fordon som omfattade några av dessa scenarier (övergångsställe, lastzon, busshållplats, påfart till motorväg) med hjälp av olika subjektiva och objektiva metoder i virtuell verklighet (VR), körsimulator samt på en testbana. Flera externa människa-maskin-gränssnitt (eHMI) för tunga automatiserade fordon utformades och utvärderades med det främsta målet att utforska användarnas beteende och erfarenheter snarare än att utforma marknadsklara gränssnitt. Genom att genomföra studier både med och utan eHMI kunde projektet fastställa en grund för interaktionerna och studera vilket mervärde sådana gränssnitt kan ha på säkerhet, effektivitet och upplevelse – nyckelfaktorer för tillit och acceptans.

Projektets resultat omfattar, men är inte begränsade till följande:

- Kunskap om hur dagens tunga fordon interagerar med andra trafikanter i deras närhet samt innebörd av detta för interaktioner med tunga automatiserade fordon.
- Kartläggning och förståelse av trafikscenarier relevanta för interaktioner mellan tunga automatiserade fordon och andra trafikanter.
- Förståelse om hur tunga automatiserade fordon interagerar med andra trafikanter och vilken roll nya externa gränssnitt (eHMI) kan spela i framtiden.
- Flera eHMI-prototyper av olika grader av realism, inklusive fysiska prototyper som installerades på en till synes automatiserad lastbil.
- Riktlinjer för utformning av interaktioner och kommunikation mellan tunga automatiserade fordon och andra trafikanter.
- Ett ramverk med olika subjektiva och objektiva metoder för utvärdering av externa interaktioner i olika miljöer inklusive VR, körsimulator och testbana.
- Bidrag till standardiserings- och regleringsarbete.
- Långsiktig kompetensutveckling: en licentiatuppsats och flera publikationer.

Med tanke på att detta forskningsämne är relativt nytt, särskilt när det gäller tunga automatiserade fordon, ger projektet världsunik kunskap till både industrin och forskarsamhället. Därmed stärker projektet Sveriges internationella konkurrenskraft och relevans och är i linje med FFIs övergripande mål.

3 Background

By replacing human drivers, in some or in all traffic situations, automated vehicles (AVs) are expected to eliminate issues related to human drivers. Large-scale introduction of such vehicles is thus anticipated to bring many benefits to the society, including improved safety, reduced congestion, lower emissions, higher productivity, and greater access to mobility. However, to reach these benefits, AVs will need to be trusted and gain societal acceptance [1]. While trust and acceptance could be affected by a range of factors [2], one thing is sure: the ability of AVs to safely, efficiently and seamlessly interact with other entities in the traffic system will play a key role. Thus, the focus in this project has been on gaining knowledge about these parameters, or surrogates for them.

Given that AV are not widely available in traffic today, it is largely unknown how such vehicles will, for instance, be perceived and experienced by pedestrians, if drivers of conventional vehicles will be able to anticipate actions of AVs, or how first responders will interact with them. That is, future AVs may face issues related to interactions with other road users in their vicinity. For heavy automated vehicles (HAV) such as buses and trucks, these issues are expected to emerge across various traffic environments, from highways (e.g., hub-to-hub trucks), rural roads (e.g., coaches) and city traffic (e.g., vulnerable road users).

Interactions between AVs and other road users on public roads have until recently been largely unexplored as the focus in the research community has primarily been on tackling challenges associated with the interactions inside these vehicles. Under the last 7 years, however, several studies have been conducted on external interactions, but these are often of limited scope.

Current research on interactions between AVs and other entities in traffic points in two directions: one advocating that implicit communication such as motion patterns of AVs is sufficient to communicate the intent of AVs [3, 4], and the other one suggesting that interactions will be affected by the lack of explicit communication with drivers and that additional communication features may be needed [5-8]. Furthermore, our review of 70 external human-machine interface (eHMI) concepts available in the literature and media (Fig. 1) shows that only two smaller studies involve HAV – both of which are conducted by RISE and partners [9]. Lessons learned from these studies show that there are differences between interactions with HAV and passenger AVs, posing different requirements on the design of interaction features. For instance, a common design principle in the literature is to place visual elements of eHMI in the windshield of the vehicle – given the height and size of HAVs, the question is if this will be applicable to them?

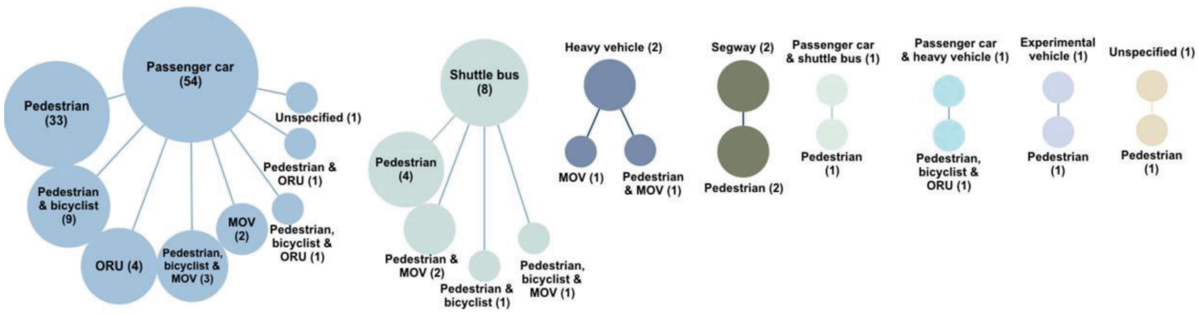

Figure 1. Majority of the external human-machine interface (eHMI) concepts are targeting passenger cars and pedestrians.

Given these contradictory findings in the literature, it is important to further investigate the nature of interactions between HAVs and other entities in the traffic system, and the question becomes: What, how, where and when should HAVs communicate to road users to deliver safe, efficient and seamless interactions?

4 Purpose, research questions and method

4.1 Purpose

The purpose of this research project was to identify how trust and acceptance of heavy AVs (SAE Level 4 with/without driver onboard) can be created and maintained via design of external interaction principles that facilitate safe, efficient and seamless interactions between heavy AVs and other road users.

4.2 Research questions

The research questions addressed within the scope of the project are:

- What can we learn from today's interactions in traffic to improve future communication and interaction with HAVs?
- Will there be new communication needs when HAVs are introduced on public roads, and how should human-automation interactions be designed to accommodate these communication needs?
- How could interactions between HAVs and other road users be evaluated?

4.3 Method

The project work was divided into 6 work packages:

- WP1: Project lead, coordination, dissemination and standardization activities.
- WP2: Selection and specification of use cases
- WP3: Understanding current and future interactions
- WP4: Design and implementation of external interaction concepts
- WP5: Development of evaluation method
- WP6: Evaluation of concepts and analysis

Work packages WP2-WP6 were largely carried out in an iterative process with three major iterations consisting of several smaller iterations, see Figure 2. The knowledge and insights generated in one iteration were transferred to the next one – a typical process in the User Centered Design. WP1 that focused on project management, dissemination and standardization activities was done over the entire project period.

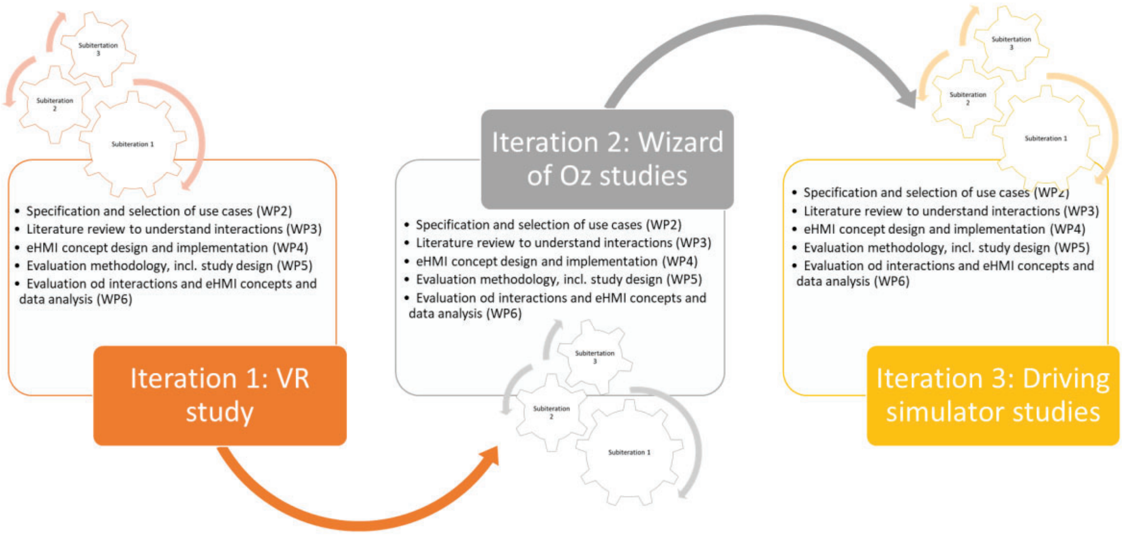

Figure 2 Schematic overview of the work process in the project showing that the project was done in three larger iterations where each iteration consisted of several sub-iterations.

5 Results and deliverables

In this project, the focus has been on understanding the communication needs in interactions between heavy automated vehicles (HAV) and other road users, and to design and evaluate effects of external human-machine interfaces (eHMI) for HAV. Major results and deliverables are summarized in the following sections.

5.1 Knowledge on how heavy vehicles interact with other road users in their vicinity and implications for HAV

Studies on how human drivers interact with other road users in their vicinity show that these interactions are complex and affected by various factors including speed, time-to-collision (TTC), traffic density, size of the gap between vehicles, road features (such as geometry and signs), weather and light conditions, presence and behavior of other road users, drivers' demographics, driving experiences, knowledge, motivations, cognitive state as well as their expectations and feelings of safety or insecurity (see e.g.,[10]-[12]). Indeed, to avoid breakdowns and conflicts in road interactions, it is essential that road users have a similar understanding or awareness of the traffic situation [13].

To create an in-depth understanding of how heavy vehicles interact with other road users today, we conducted literature reviews targeting three broad areas: 1) Interactions with vehicle platoons on highways, 2) Interactions at merging points on highways, and 3) Interactions with Vulnerable Road Users (VRUs) in urban areas.

Literature review 1: Interactions with vehicle platoons on highways

Published in Aramrattana et al., 2021. Safety and experience of other drivers while interacting with automated vehicle platoons Transp. Res. Interdiscip. Perspect.

In busy highway traffic, platoon formations are likely to occur. This can especially be seen on two-lane highways with many heavy vehicles that are prohibited to overtake. As reported in the Netherlands, such formations may lead to several behavioral adaptations that negatively affect safety and traffic performance. For instance, there is an increased likelihood of small gaps between vehicles that typically reduce perception of the traffic conditions ahead, which in turn may increase the risk of rear-end collisions and create uncertainty in travel-time. Also, drivers in a platoon formation take more risks when changing lanes. This is because they cannot adapt their speed to that of the target lane before lane-changing. These premature lane changes may cause shock waves in the left lane that increase the risk of rear-end collisions. This can also lead to overburdening the left lane and reducing the overall highway speed below posted limits, thus negatively affecting road capacity and traffic flow. In addition, this could increase the risk of overtaking platoon formations on the right (if there are any lanes), resulting in less predictable situations and reduced traffic safety.

A conclusion is that there might be similarities between the current interactions in dense highway traffic and future interactions between drivers of manually operated vehicles and automated vehicle platoons. Studies on interactions with extra-long trucks, showing that behavioral adaptation by other drivers is likely to occur, could also be valuable. However, to truly understand how other drivers perceive and experience automated vehicle platoons, and whether they require any support, it is necessary to conduct studies addressing this topic specifically. To this end, it would be valuable to investigate drivers' mental effort and ability to understand the intent of platooning vehicles as well as drivers' perceived safety, comfort, and difficulty of merging onto the highway.
See paper

Literature review 2: Interactions at merging points on highways

Published in Aramrattana et al., 2021. Safety and experience of other drivers while interacting with automated vehicle platoons Transp. Res. Interdiscip. Perspect.

In the context of highway on-ramp merging, there are two interactive traffic streams: merging vehicles and mainline drive-through vehicles. Several studies imply that mainline drivers adopt a cooperative behavior by changing to the inner lanes or by yielding to create gaps for the merging vehicles. Similarly, drivers of the merging vehicles adjust their speeds according to the vehicles in the target lane.

While these interactions and behavioral adjustments are often smooth, there are situations in busy traffic where inefficient and unsafe behaviors might occur. For instance, if drivers of the merging vehicles perceive that there are only a few sufficient gaps in the target lane, they may choose to merge at the beginning of the acceleration lane. This, in turn, could lead to merging with a relatively low speed and hindering the traffic by causing disturbances. If the acceleration lane is about to end, merging drivers may also brake sharply in order to merge, leading to a relatively low merging speeds or a standstill at the end of the acceleration lane (or in the shoulder lane). The studies show also that the number of heavy vehicles on the target lane results in merging vehicles reducing their speed and increasing speed variation. Furthermore, drivers of merging vehicles tended to merge later when there was a truck next to their vehicle. In situations with several trucks in the target lane, merging took place at the beginning of the acceleration lane, either behind or in front of the truck that is next to the merging vehicle. Also, safety margins were smaller in such situations (the average minimum time gap and TTC were less than half that in mixed traffic).

In summary, at merging points, drivers are likely to adapt their behavior to ease the merging process. However, improper merging might still take place, with negative safety and efficiency implications.

Literature review 3: Interactions with VRUs in urban areas

Published in Fabricius et al,. 2022. Interactions Between Heavy Trucks and Vulnerable Road Users—A Systematic Review to Inform the Interactive Capabilities of Highly Automated Trucks. Frontiers in Robotics and AI.

We have conducted a systematic literature review and summarized the focuses of existing research regarding the interactive behaviors and communication cues of heavy goods vehicles (HGVs) and vulnerable road users (VRUs).

We found the following interactive behaviors and communication cues: 1) vehicle-centric (e.g., HGV as a larger vehicle, adapting trajectory, position relative to the VRU, timing of acceleration to pass the VRU, displaying information via human-machine interface), 2) driver-centric (e.g., professional driver, present inside/outside the cabin, eye-gaze behavior), and 3) VRU-centric (e.g., racer cyclist, adapting trajectory, position relative to the HGV, proximity to other VRUs, eye-gaze behavior). These cues are predominantly based on road user trajectories and movements (i.e., kinesics/proxemics nonverbal behavior) forming implicit communication, which indicates that this is the primary mechanism for HGV-VRU interactions. However, there are also reports of more explicit cues such as cyclists waving to say thanks, the use of turning indicators, or new types of external human-machine interfaces (eHMI).

Compared to corresponding scenarios with light vehicles, HGV-VRU interaction patterns are to a high extent formed by the HGV's size, shape and weight. For example, this can cause VRUs to feel less safe, drivers to seek to avoid unnecessary decelerations and accelerations, or lead to strategic behaviors due to larger blind-spots. Based on these findings, it is likely that road user trajectories and kinematic behaviors will form the basis for communication also for highly automated HGV-VRU interaction. However, it might also be beneficial to use additional eHMI to compensate for the loss of more social driver-centric cues or to signal other types of information.

5.2 Mapping and understanding of traffic scenarios relevant for interactions between HAV and other road users

To be able to systematically document traffic situations in which interactions between HAV and other road users may occur, we reviewed several existing frameworks for use case description. The framework used by the EU-project interACT was selected to enable easier comparison with the work done in that project [14]. In that framework, each use case is described on four levels: 1) Use case cluster, 2) Use case, 3) Scenario and 4) Scene(s). While the templates for the definition of the first two levels were adapted without any significant changes, the templates for the two latter levels were somewhat adopted to fit the purpose of this project.

In the next step, a literature review and expert discussion was done to identify relevant use cases involving HAV. The focus has been on Scania's two potential business cases: hub-to-hub transportation of goods and people mobility. Each of these incorporates various use cases. We mapped over 30 key use cases and selected 11 of them based on our criteria (Table 1) for further investigation (Table 2). It should also be noted that each scenario was defined in more detail (e.g., road type, speed, directions, demographics of relevant road users, etc.) than shown in the table. The selection criteria was based on the selection criteria defined in the interACT project. However, it needed to be adapted somewhat to fit our project and purposes. The parameters that were used in our selection criteria were defined on 3 levels (low, medium, and high), these are shown in Table 1.

Table 1. Parameters in our selection criteria.

Selection criteria consist of several parameters (on three levels: low, medium, and high) that capture important aspects of each use case. Some of these are project specific
Relevance for safety
Relevance for experience
Relevance for efficienecy
Frequency of occurance
Duration of occurance
Time criticality
Level of interaction
Ability of AV to improve existing interactions
Challanges induced by AV
Testability (VR, test track, driving simulator)
Anticipated need for eHMI
Relevance for Scania

Table 2. Use cases that were investigated in our experimental studies.

Use case cluster	Use case	Scenario	Scenes
A high-level grouping or category of similar use cases, e.g., based on a business case.	*General description of the function for which a solution will be designed. A use case is described from the HAV perspective, and is less detailed compared to Scenario and Scenes. A use case can cover several scenarios.*	*A description of the sequences of actions and events performed by different actors over a certain amount of time. Further, the scenario specifies goals, objectives and information about the environment related to the different actors. A scenario is typically described by several scenes.*	*A scene represents a snapshot of the environment. All dynamic elements, as well as all actors and the scenery are included in this snapshot. Further the relationships among those entities are represented in the scene. A sequence of scenes represents a scenario.*
People mobility	Approaching a bus stop	An automated bus is approaching a bus stop with intention to stop there, while a pedestrian is standing at the bus stop.	1. An automated bus approaches a bus stop with speed of 50 km/h on a one lane road in an urban area with posted speed limit of 50 km/h. 2. A pedestrian is standing at the bus stop on the right hand side seen from the bus. 3. When the bus is ca 30 m from the bus stop, it starts decelerating 4. The bus comes to full stop at the bus stop.
People mobility	Picking up passengers at a bus stop	An automated bus has stopped shortly at a bus stop to pick up passenger(s).	1. An automated bus stops at a bus stop that is next to a one lane road in an urban area with posted speed limit of 50 km/h- 2. The automated bus opens its doors 3. Passenger(s) are entering and existing the bus. 4. After a while the bus prepares for closing the doors and then closes the door.
People mobility	Taking off from a bus stop	An automated bus is leaving a bus stop while a pedestrian is standing next to the road.	1. An automated bus is in stand still at the bus stop and prepears for leaving the bus stop. 2. A pedestrian is standing at a bus stop on the front right hand-side seen from the automated bus. 3. The automated bus starts slowly accelerating 4. The automated bus leaves the bus stop.
People mobility	Blocking the road at a bus stop	An automated bus is approaching a bus stop. When it stops at the bus stop, it blocks the road for the following passenger car(s).	1. A passenger car driver is following after an automated bus in the same lane driving with a speed of ca 50 km/h (there are no other lanes) 2. The automated bus starts decelerating 3. The automated bus stops at a bus stop on its right hand-side, but it is partly blocking the lane
Hub-to-hub	Letting a pedestrian cross at a zebra crossing	An automated truck is approaching a zabra crossing where it encounters a pedestrian. The truck intends to give priority (yield) to the pedestrian.	1. An automated truck drives with a speed of 30 km/h on an urban one-lane road. It is approaching a marked zebra crossing. 2. A pedestrian is approaching a zebra crossing with normal walking speed, from the left hand side seen from the automated truck. 3. At some distance from zebra crossing, the automated truck starts decelerating 4. The automated truck comes to full stop ca 4 m from the zebra crossing
Hub-to-hub	Taking off from standstill at a zebra crossing	An automated truck takes off from a zebra crossing, directly after a pedestrian has crossed the road.	1. An automated truck is in standstill at a marked zebra crossing, ca 4 m from the crossing. 2. A pedestrian crosses the road at the zebra crossing. 3. The automated truck slowly acceleretes and takes off.
Hub-to-hub	Letting two pedestrians cross at a zebra crossing	An automated truck has given way to a pedestrian at a zebra crossing, and since another pedestrian is approaching yet it needs to continue giving way (yielding).	1. An automated truck has just completed a right-hand turn and is approaching a zebra crossing with a speed of ca 10 km/h on a one-lane urban road 2. A pedestrian is approaching the zebra crossing from left seen from the automated truck. 3. The automated truck starts decelerating and comes to full stop ca 4m prior to the zebra crossing. 4. After the pedestrian has crossed the road, another pedestrian suddenly approaches the zebra crossing from the right hand side seen from the truck 5. The automated truck remins in standstill to let the second pedestrian cross the road. 6. After the second pedestrian crossed the road, the truck takes off.
Hub-to-hub	Approaching a loading zone	An automated truck is approaching a loading zone where it encounters a professional worker who is about to require access to the truck to load it.	1. An automated truck is approaching a dedicated loading zone with a speed of ca 30 km/h. 2. The truck slows down and stops in the loading zone. 3. A professional worker uses a personal device to secure access to the truck for loading purposes.
Hub-to-hub	Taking off from a loading zone	An automated truck has been loaded by a professional worker and is about to leave the loading zone.	1. An automated truck has been loaded in a dedicated loading zone by a professional worker. 2. The professional worker uses a personal device to check out from the truck 2. The truck slowly accelerates and leaves loading zone
Hub-to-hub	Giving prioroty at highway onramp	An automated truck is travelling on a highway while a passenger car is about to merge into the highway from the onramp. The truck adapts its driving behavior and gives priority to the passenger car.	1. An automated truck is travelling on a 2-lane highway, in its most right lane, with a speed of about 70 km/h. 2. A passenger car is just about to merge into the highway, from right seen from the truck perspective. 3. The truck adapts its speed and distance to let the passenger car merge infront of it.
Hub-to-hub	Taking priority at highway onrapmp	An automated truck is travelling on a highway onramp at the same time as a passenger car is travelling on the highway.The truck adapts its driving behavior to merge into the highway before the passenger car.	1. A passenger car is travelling on a 2-lane highway, in its most right lane, with a speed of about 40 km/h. There are other slow moving vehicles in the adjecent lane, as well as infront of it. The car is approaching an onramp. 2. An automated truck is travelling on the highway onramp. 3. The truck adapts its speed and merge to the highway infront of the passenger car.

5.3 Knowledge on how HAV might interact with other road users and the role that additional external interfaces might play in future

The knowledge on how HAV might interact with other road users and on the role of additional external human-machine interfaces (eHMI) might have in these interactions was mainly generated through experimental studies with limited sample of study participants. Broadly speaking, the study participants encountered a HAV both with and without eHMI. Examples of the insights that were generated include, but are not limited to the following:

- A great portion of our study participants were initially rather positive about automated vehicles and encountering them in traffic. There were, however, some participants who were somewhat skeptical.
- Generally, the situations with eHMI resulted in higher intention clarity and higher perceived safety than the corresponding situations without eHMI.
- In the highway situations, the perceived safety was somewhat higher in the situations where the study participants merged into the highway (both with and without eHMI) than in situations where the HAV merged into the highway. Intention clarity of the HAV was, however, similar in both situations, both with and without eHMI.
- Overall, the eHMI concepts conveying only that the automated driving system is active obtained low rating across the tested situations. However, ”Automated driving system active” was commonly chosen as an important type of information that HAV should communicate to other road users. One interpretation of this is that such information should be displayed as part of the concepts conveying other information.
- eHMI concepts conveying intent of HAV (to give/not give priority) were generally better rated than the eHMI concepts conveying current dynamics of HAV (accelerating/decelerating).
- The most important information to display to pedestrians in zebra crossing scenarios was: ”I’m self-driving”, followed by ”I’ve intent to yield”, ”I’m braking” and “I’ve intent to stop yielding”
- The most important information to display on highway was: ”I’m self-driving”, followed by ”I’ve intent to give priority (yield)”, ”I’ve intent to take priority”, “I’ve seen you”, “I’m braking” (visible from other sides than rear).

5.4 Several eHMI prototypes of different fidelity levels, including physical prototypes that were installed on a seemingly automated truck

A set of external interface concepts (eHMI) have been designed and evaluated, and then refined based on the evaluation results and evaluated again. The interfaces served as an artefact, or a mediating tool, to trigger behavior of other road users when they interact with heavy AVs. That is, the ultimate goal was to explore effects of different interaction principles on road user behavior and experience rather than designing a market-ready interface. Majority of the designed concepts are based on abstract lights, however, other visual features such as text and icons have also been explored as well as sound.

We have conducted a series of workshops to discuss various topics during the concept development. We started from sharing the knowledge and summarizing lessons learned from a few internal projects at Scania. Then we continued to discuss the content and nature of the messages, which is more about what we should design for. We then discussed modalities, animations and colors of lights, timing of the signals and placement of the hardware. We also discussed the relationship between kinesthetics and eHMIs. For each study, we have generated several concepts and then selected a few following our criteria for final prototyping and evaluation, see examples in Figure 3.

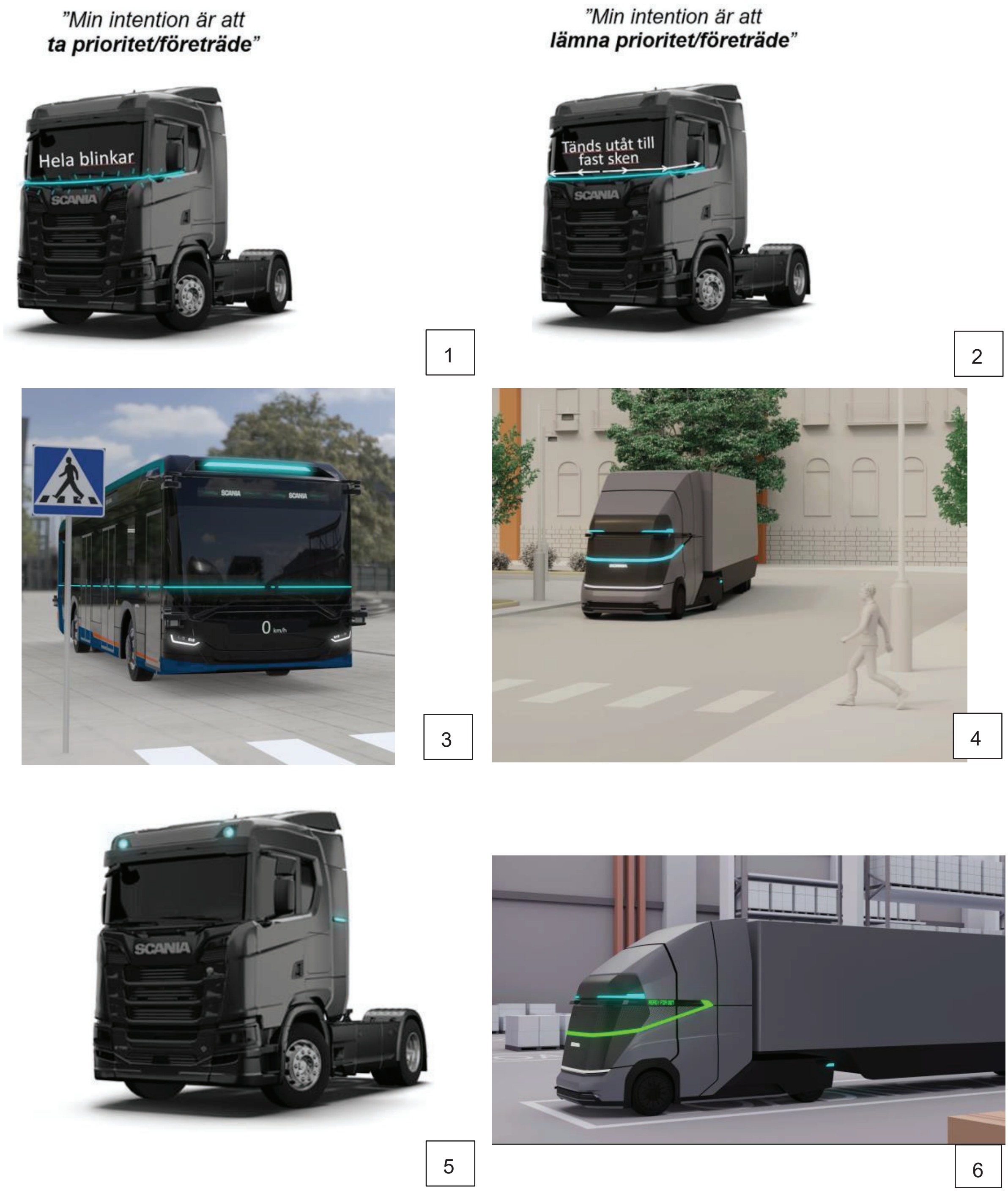

Figure 3 Examples of visual concepts that were designed and evaluated within the project. 1) My intention is to take priority; 2) My intention is to give priority; 3) Intent to give priority and speed display at bus stop; 4) Intent to give priority at pedestrian crossing; 5) Automated driving system active: cyan lamps; 6) Safe to approach in loading zone: green LED strip and display

5.5 Guidelines on design of interactions and communication between HAV and other road users

While the studies conducted within this project have extended the current state of the art, the knowledge is still rather limited. One should thus be careful when concluding how HAVs might interact with other road users, and whether additional external human-machine interfaces (eHMI) may be needed and how these should be designed. Based on our current knowledge, we suggest the following overall design guidance – many of which assume that international standardization will be in place:

- Use abstract lights as much as possible. Such lights require learning, however, they are not as much challenging as text/icons when scaling up to different cultures and contexts.
- Limit the number of messages to 2-4. It is difficult for people to learn several new messages and distinguish between them (independently of design).
- Use an unique color for automated vehicles. This will create an unified “language” for automated vehicles, as well as make it easier to distinguish such signals from other signals on vehicles and in traffic.
- Co-locate similar massages. For instance, a pedestrian approaching truck from front/side should not need to look at different places to see if the vehicle intends to give way or if the vehicle is about to take off.
- Unify signaling in confined spaces and on public roads. If this is not the case, it will be challenging for vehicles to be used both in confined spaces and on public roads.

5.6 A mixed methodology framework for evaluation of external interactions in different settings including VR, driving simulator and test track.

Highly automated vehicles are rare today, and (independent) researchers have often limited access to them. Also, developing fully functioning system prototypes is time and effort consuming. Researchers thus tend to use various approaches that are faster and less expensive, and this project was no exception. The studies were conducted under controlled conditions and were generally limited in duration.

Figure 4 The Wizard of Oz truck with eHMI prototypes on test track in one of our studies with tinted windows and windshield.

To evaluate interactions with HAV in pedestrian crossings and loading zones on a test track, the project utilized an experimental **Wizard of Oz (WOz)** methodology. It is a well-established approach for evaluating user interfaces in various domains, from 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. RISE and other stakeholders have successfully used WOz methodology in passenger AV studies, and this project extended its use to HAVs. The WOz vehicle was to a large extent developed by Scania outside this project, but it was then refined in the project to fit the specific needs of our studies. Originally, the WOz vehicle was intended to be operated by a human driver from the backseat. However, after an internal risk assessment for our studies, it was decided that it should be operated from the front seat. To create an illusion that the vehicle is operated by an automated system, its windshield and windows were tinted to avert the study participants seeing the human driver (see Figure 4). In addition, the eHMI concepts were also operated by wizard located outside the vehicle by means of an smartphone application. Overall, the WOz methodology proved to be successful, however, it required extensive training of both wizards to ensure repeatability.

To evaluate eHMI concepts for HAV in bus stop related scenarios, the project utilized **a virtual reality (VR)** approach. 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. To avoid potential issues when moving in the VR environment, we designed the study in a way that did not require the test participants to move (i.e. they were standing when acting pedestrians or sitting down when acting passenger car drivers). As the primary aim of the study was to explore the understanding of eHMI concepts, the realism of the environment was not identified as an issue. However, the VR resolution affected what elements of the concepts were visible, especially in distance.

To study interactions with HAV on highways, the project utilized a **driving simulator** where the study participants acted as passenger car drivers encountering an automated truck in a highway merging scenario. This study used "SimIV" – a high-fidelity moving-based driving simulator facility at VTI in Gothenburg (the moving-base motion was not activated in our study). Since its inauguration in 2011, the simulator has been validated and used in numerous studies. The forward field of view is about 210 degrees using 9 high resolution projectors. The simulator environment includes a passenger car cabin with two side mirrors and a rear-view mirror to allow the driver to see vehicles behind them. One challenge here was to ensure that the eHMI reflects the test participant's actions. Thus, the study was designed in a way to "nudge" the participants to drive in certain lanes and with certain speeds.

One of the commonly used approaches in early design stages incorporates **online surveys** using, for instance, online crowdsourcing markets such as Amazon MTurk that enable evaluations with large and varied test participant sample at low cost. This approach was explored in the FFI pre-study Scale-up [20], that was conducted in parallel with this project and lessons learned have been transferred to this project. In addition, we used online surveys in the design process of some eHMIs, which proved to be an efficient way of gathering first impression on what needs to be improved. In particular, presenting eHMI concepts by means of simple animations (as opposed to static images) was useful to easily demonstrate the ideas.

When it comes to data collection, our studies relied mainly on methods such as think aloud, questionnaires and semi-structured interviews. In the test track studies, some behavioral parameters of the study participants were observed from the video recordings (e.g. willingness to cross). Also, in the driving simulator study, we extracted objective data on the driving behavior of the participants (e.g., speed, acceleration, etc). While objective data provided some important information such as how long an interaction took, and whether the test participants merged in front or behind the truck, it is crucial to combine such data with subjective assessments to truly understand the reasons for certain behaviors and what impression the participants got about the eHMI concepts.

5.7 Contribution to standardization and regulation work

In parallel to the project, the international standardization organization ISO has conducted work on creating a Publicly Available Specification (PAS) titled *Road Vehicles – Ergonomic design guidance for external visual communication from automated vehicles to other road users*. The project participants have actively participated in that work and continuously incorporated lessons learned from the studies in the design guidance that will be provided in that document. The ISO discussions have to some extent also helped shaping the studies conducted in the project.

In addition, the project participants have via an the independent research group called *Human Factors in International Regulations for Automated Driving Systems" (HF-IRADS)* given input to the ongoing regulation work in the UNECE.

5.8 Long-term competence development: One licentiate thesis

The project work has also contributed to long-term competence development in Sweden. One institute PhD candidate (from RISE) has actively participated in the project and one licentiate thesis entitled

“Designing for Appropriate Road Traffic Interactions Between Highly Automated vehicles and Vulnerable Road Users” has been generated. As the title implies, the thesis is entirely focused on interactions between automated vehicles and other road users. The thesis is to be presented and published in the beginning of 2023. In addition, the project has generated two Master’s theses and a range of scientific publications.

6 Fullfilment of FFI Objectives

The project findings are anticipated to contribute to development of safe and trustworthy interactions between HAV and other road users in the traffic system, and thereby support societal acceptance of such vehicles. In addition, properly designed interactions help optimizing traffic flow and reduce energy consumption and emissions. This, in combination with the fact that heavy automated vehicles will be used for shared mobility services for both goods and people, makes the project highly in line with the overall FFI objectives. In particular, the project contributes to the following FFI objectives as follows:

- *Increasing the Swedish capacity for research and innovation, thereby ensuring competitiveness and jobs in the field of vehicle industry.* Automated vehicle technology is under development and large expectations are posed on it, however, in-depth knowledge on interactions with other entities in the traffic system is still limited. This project explored the research and innovations in this open and potential area and has as such helped Scania to increase knowledge in the field.
- *Developing internationally interconnected and competitive research and innovation environments in Sweden.* Through collaboration with Halmstad University, Umeå University and SAFER, the project has strengthen connection within Swedish research community. By common publications, workshops, and seminars the project has also strengthen collaboration on international level with, for instance, Eindhoven Uni (NL), TNO (NL), DLR (DE), Ingolstad tech. uni (DE), Leeds Uni (UK) and Stanford Uni (USA).
- *Knowledge and competence development at research institutes and companies.* RISE has an institutional PhD candidate in the field, which helps building up long-term competence development.
- *Promoting cooperation between industry, universities and higher education institutions.* By associating an institute licentiate candidate to the project, the project has ensured direct collaboration between industry, research institute and university. By conducting two master’s thesis, the project has also supported education.
- *Promoting cooperating between different OEMs.* Our ambition was to conduct common studies with Volvo Buses (within the KRABAT-project) but due to pandemics the activities could not be synchronized. The exchange with VCC and Clean Motion has been done via the parallel projects Scale-up (FFI) and GLAD (Trafikverket). The exchange with other OEMs has also been done via TRATON Group (MAN, Navistar) as well as via ISO (Ford, Toyota, GM). The project has also been associated to SAFER which as served as a platform for exchanging insights with relevant Swedish stakeholders via various presentations and communication materials.

The project addresses mainly two subareas described in the roadmap for the FFI-program *Elektronik, mjukvara och kommunikation (EMK)*:

- *Mäniska-Maskin Interaktion.* The project explored behavior and interaction of other road users in the interactions with HAV and other road users. It designed and implemented several prototypes in a) a VR environment, b) a seemingly automated vehicle (WOz vehicle), and c) a driving simulator. The proposed interaction principles lead to at least as good, or better, safety, experience and efficiency than a corresponding heavy AVs without these interaction principles. As such, the project addresses the following two goals: *The products adapt to the user, their behavior and environment and provide a caring, trusting and holistic user experience* and *Human and products are a collaborative team where their strengths complement each other and where all interaction is natural*.
- *Verification and validation.* New processes, methods and tools for design and evaluation of external interaction principles for creating trust in HAV were developed and applied. Both subjective and

objective evaluation were conducted in a) driving simulator, b) test track using Wizard-of-Oz, c) VR and d) online survey.

7 Dissemination and publications

7.1 Dissemination

Hur har/planeras projektresultatet att användas och spridas?	Markera med X	Kommentar
Öka kunskapen inom området	X	Currently, there is a knowledge gap regarding interactions between other road users and heavy automated vehicles. This project has contributed in reducing this gap. Project members have been involved in several events and workshops where need for and design of external interfaces has been discussed with other professionals, both from academia and industry. Several publications have been generated.
Föras vidare till andra avancerade tekniska utvecklingsprojekt	X	Scania has several internal activities where knowledge on design of HMI from this project has been utilized. RISE has an ongoing project with Aptiv, Clean Motion, Combitech and Halmstad University (Trv GLAD) where knowledge on evaluation methodology and eHMI design gained in this project have been utilized. RISE has an institutional PhD candidate who has been involved in the project and knowledge gained here will be utilized in his further studies.
Föras vidare till produktutvecklingsprojekt		
Introduceras på marknaden		
Användas i utredningar/regelverk/ tillståndsärenden/ politiska beslut	x	The project members have actively participated in ISO standardization activities. The project members have given input to discussions on international regulation of external HMI

The following dissemination activities have been performed the project and its results was presented:

- **Keynote presentation**: Designing mobility solutions for a diverse world: The current challenges and research gaps from an industry side. Azra Habibovic, 14th International Conference on Automotive User Interfaces and Interactive Vehicular Applications, Seoul, South Korea, 2022.
- **Workshop**: Accessible Automated Automotive Workshop Series (A3WS): International Perspective on Inclusive External Human-Machine Interfaces. In 14th International Conference on Automotive User Interfaces and Interactive Vehicular Applications, Seoul, South Korea, 2022.
- **Conference presentation.** Heavy, bold and kind: Interactions between heavy automated vehicles and other road users. Azra Habibovic. IEEE IV 2022 Workshop on Are You Happy with AV? UX in AV-Human Interaction. Online.
- **Conference presentation.** Presentation of the project to a female network, ca 20 women from different organizations within public and private sector in Sweden KITS (Kvinnor i ITS). Azra Habibovic, 2021.

- **Conference presentation.** Presentation of the project to a group of 15-20 professionals from different countries from PIARC, Azra Habibovic, 2021.
- **Vision zero course.** An online lecture in the course on vision zero (organized by Swe-India collaboration platform SITIS). Brief description of the area and the project to ca 130 Indian safety professionals. Azra Habibovic, 2021.
- **Conference presentation.** HMI forum organized by Innovation Center China to participants from industry and academia. Yanqing Zhang, 2021.
- **Video:** We have created a 4 mins' video introducing the project and also demonstrating the key concepts in hub-to-hub context. The video will be published online together with a press release.
- **Visual materials:** We have created images and short videos for the key concepts and concept combinations generated for test. These could be used to demonstrate our eHMI concepts in presentations.
- **Master thesis presentation**: "Designing eHMI for trucks: How to convey the truck's automated driving mode to pedestrians.", Darban Dauti, 2021/07.
- **Master's thesis presentation**: "Communicating the stopping intent of an autonomous truck: The interplay between content size, timing and truck speed.", Sam Zadeh Darrehshourian, 2021/07
- **Newsletter notice**: "External interaction principles for creating trust in heavy automated vehicles", Daban Rizgary, Zhang Yanqing, Azra Habibovic, 2021/12. Link: https://omad.tech/guldkorn-fran-svensk-forskning-2021/
- **Newsletter notice**: "Studie om lastbil-VRU interaktioner inom FFI-projekt", Daban Rizgary, Zhang Yanqing, Azra Habibovic, 2022/07. Link: https://omad.tech/guldkorn-fran-svensk-forskning-2/
- **Workshop**: "Prosocial Behaviour in Future Mixed Traffic", Sahin et al, 2021/09.
- **Workshop**: "WeCARe: Workshop on inclusive communication between Automated Vehicles and Vulnerable Road Users", Andreas Löcken, Mark Colley, Andrii Matviienko, Kai Holländer, Debargha Dey, Azra Habibovic, Andrew L Kun, Susanne Boll, and Andreas Riener, 2020/10.
- **SAFER presentation.** Project was presented to the SAFER research group on road user behavior, 2020/04.
- **SAFER web.** Project introduction on SAFER web, Linda Meiby, Azra Habibovic, 2020/04. https://www.saferresearch.com/projects/ehmi
- **SAFER news**. Linda Meiby, Azra Habibovic, 2020/04. Link: https://www.saferresearch.com/news/how-should-automated-heavy-vehicle-interact-its-surroundings
- **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-automated-vehicles---phase-1/
- **RISE web**. Project overview. Daban Rizgary. Link: https://www.ri.se/en/what-we-do/projects/external-interaction-principles-for-creating-trust-in-hav

7.2 Publications

Master's thesis:

- **Dardan Dauti**. Designing eHMI for trucks: How to convey the truck's automated driving mode to pedestrians. Master's Thesis. Umeå University, 2021.
- **Sam Zadeh Darrehshourian**. Communicating the stopping intent of an autonomous truck: The interplay between content size, timing and truck speed. Master's Thesis. Umeå University, 2021.

Workshop papers:

- A. Löcken, A. Matviienko, M. Colley, D. Dey, **A. Habibovic**, Y.M. Lee, A. Riener. Accessible Automated Automotive Workshop Series (A3WS): International Perspective on Inclusive External Human-Machine Interfaces. In In 14th International Conference on Automotive User Interfaces and Interactive Vehicular Applications, Seoul, South Korea, 2022.
- Hatice Sahin, Heiko Mueller, Shadan Sadeghian, Debargha Dey, Andreas Löcken, Andrii Matviienko, Mark Colley, **Azra Habibovic**, and Philipp Wintersberger. 2021. Workshop on Prosocial Behavior in Future Mixed Traffic. 13th International Conference on Automotive User Interfaces and

Interactive Vehicular Applications. Association for Computing Machinery, New York, NY, USA, 167–170. DOI: https://doi.org/10.1145/3473682.3477438

- Andreas Löcken, Mark Colley, Andrii Matviienko, Kai Holländer, Debargha Dey, **Azra Habibovic**, Andrew L Kun, Susanne Boll, and Andreas Riener. WeCARe: Workshop on Inclusive Communication between Automated Vehicles and Vulnerable Road Users. Workshop Paper. In conjunction with MobileHCI 2020, October 5-9, 2020.
- **Frida Eriksson, Angelos Malikoutis, Adeliina Aho Tarkka, Pontus Unger, Pedram Nayeri, Anders Bäckman, Maria Kougioumoutzi, Julia Söderberg, Karolina Ingre, Stas, S, Krupenia**. External HMI for Autonomous Buses. Results of the IQ Mobility project in preparation for Project Qatar Mobility. Workshop paper. Workshop on Inclusive Communication between Automated Vehicles and Vulnerable Road Users (WeCARe). In conjunction with MobileHCI 2020, October 5-9, 2020.
- **Victor Malmsten Lundgren**. Insights from a series of projects related to accessibility in an AV mobility landscape. Workshop paper. Workshop on Inclusive Communication between Automated Vehicles and Vulnerable Road Users (WeCARe). In conjunction with MobileHCI 2020, October 5-9, 2020.

Journal and conference papers:

- Dey, D., **Habibovic, A.**, Berger, M., Martens, M. Investigating the Need for Explicit Communication of Non-Yielding Intent through eHMIs in AV-Pedestrian Interaction. In 14th International Conference on Automotive User Interfaces and Interactive Vehicular Applications, Seoul, South Korea, 2022.
- **Fabricius, V., Habibovic, A., Rizgary, D., Andersson, J.,** and **Wärneståål, P**. Interactions between heavy trucks and vulnerable road users: a systematic review to inform the interactive capabilities of highly automated trucks. Frontiers in robotics and AI: Human-robot interaction, 2022.
- Maytheewat Aramrattana, **Azra Habibovic**, **Cristofer Englund.** Safety and experience of other drivers while interacting with automated vehicle platoons, Transportation Research Interdisciplinary Perspectives, Volume 10, 2021, https://doi.org/10.1016/j.trip.2021.100381.
- Wilbert Tabone, Joost de Winter, Claudia Ackermann, Jonas Bärgman, Martin Baumann, Shuchisnigdha Deb, Colleen Emmenegger, **Azra Habibovic**, Marjan Hagenzieker, P.A. Hancock, Riender Happee, Josef Krems, John D. Lee, Marieke Martens, Natasha Merat, Don Norman, Thomas B. Sheridan, Neville A. Stanton, Vulnerable road users and the coming wave of automated vehicles: Expert perspectives, Transportation Research Interdisciplinary Perspectives, Volume 9, 2021, https://doi.org/10.1016/j.trip.2020.100293.
- Debargha Dey, **Azra Habibovic**, Andreas Löcken, Philipp Wintersberger, Bastian Pfleging, Andreas Riener, Marieke Martens, and Jacques Terken. 2020. Taming the eHMI jungle: A classification taxonomy to guide, compare, and assess the design principles of automated vehicles' external human-machine interfaces. Transportation Research Interdisciplinary Perspectives 7 (2020). https://doi.org/10.1016/j.trip.2020.100174

Planned publications:

- **Licentiate thesis**: Fabricius Victor. Designing for Appropriate Road Traffic Interactions Between Highly Automated vehicles and Vulnerable Road Users, 2023.
- **Journal paper**: Exploring Light-Based Interfaces to Support Crossing Encounters Between Pedestrians and Heavy Automated Trucks, 2023.
- **Journal paper**: Exploring External Interfaces to Support On-Ramp Encounters Between Motorists and Heavy Automated Trucks, 2023.
- **Journal paper.** Development and application of a scale for assessing pro-social behavior of automated vehicles in traffic., 2023.
- **Conference paper**: Interactions between other road users and automated buses at bus stops.
- **Conference paper**: Utilizing Wizard of Oz methodology to evaluate light based interfaces: intent vs deceleration, 2023.
- **Press release,** incl video, 2023.

8 Conclusion and future research

The purpose of this research project was to identify how trust and acceptance of heavy automated vehicles (HAV, corresponding to SAE Level 4 with/without driver onboard) can be created and maintained to ensure safe, efficient and seamless interactions with other road users. In particular, we explored the role and design of additional external human-machine interfaces (eHMI). The work has relied on literature review as well as experimental studies where interactions with/without such interfaces have been explored under controlled conditions (VR, test track, driving simulator, survey). The focus has been on traffic situations relevant for Scania's business cases hub-to-hub goods transportation and people mobility, i.e. traffic situations involving pedestrians, professional workers and drivers of passenger cars. In this section, we present our major conclusions related to the research questions that were addressed in the project as well as our ideas for future work in this field.

What can we learn from today's interactions in traffic to improve future communication and interaction with HAVs?

Studies on how human drivers interact with other road users in their vicinity show that these interactions are complex and affected by various factors. Indeed, to avoid breakdowns and conflicts in road interactions, it is essential that road users have a similar understanding or awareness of the traffic situation. To achieve this, road users need to communicate with each other. Our literature reviews reveal the following three broad interactive behaviors and communication cues: 1) vehicle-centric, 2) driver-centric, and 3) other road user-centric. These cues are predominantly based on road user trajectories and movements forming implicit communication, which indicates that this is the primary mechanism for interactions. However, there are also reports of more explicit cues such as cyclists waving to say thanks, the use of turning indicators, etc. Another generic, yet important, conclusion is that road users adapt their behaviors over time as well as adapt their behavior to accommodate smooth interaction with each other. Compared to corresponding interactions with light vehicles, interactions involving heavy vehicles are to a high extent formed by the their size, shape and weight. For example, this can cause pedestrians to feel less safe, drivers to seek to avoid unnecessary decelerations and accelerations, or lead to strategic behaviors due to larger blind-spots.

Will there be new communication needs when HAVs are introduced on public roads, and how should human-automation interactions be designed to accommodate these communication needs?

The conclusions of the studies in this project ought to be used carefully since further research is still needed. Our findings from experimental studies indicate that other road users may expect, and benefit from, additional communication from HAV in the traffic situations that were investigated. In particular, information on the operation mode of the vehicle (i.e. whether automated driving system is active) as well as information regarding the intent of HAV to give priority or take priority was found to be valuable. It is, however, crucial that such information is in synchronization with the kinematics of HAV. When it comes to the design of eHMI, one insight is that such interfaces need to be possible to scale up and deploy across different vehicle models and markets. To this end, using abstract light signals (as opposite to text and icons) is to prefer.

While our studies have not revealed negative effects of eHMI, it is reasonable to assume that such interfaces could, depending on the design, lead to distraction, confusion, overreliance, light pollution etc. In addition, we find it important to highlight that the potential benefits are likely to be more diverse than to replace "eye-contact" with the human driver, which is often the only benefit emphasized in the literature. More specifically, if being properly designed, eHMI could:

- Replace information that other road users obtain from human drivers (especially relevant in situations where negotiations take place).

- Provide other road users with information that eliminates the need of seeking contact with human driver (especially relevant for vehicles that can be operated in both manual and automated mode).
- Improve the overall impression and acceptability of automated vehicles in society.
- Help other road users distinguish if a vehicle is operated in manual or automated mode (to keep the positive effect of observing human driver and avoid dangerous situations due to a mismatch between the human driver's and automated vehicle's behavior).
- Make intentions and planned actions of the vehicle more noticeable to other road users, and thereby increase the efficiency of interactions.
- Clarify situations that are unclear and challenging today.

How could interactions between HAVs and other road users be evaluated?

Currently, one of the major challenges when it comes to evaluations in this context is lack of standardized procedures to enable systematic evaluation and comparison of different design variants of eHMIs with each other and with interactions without eHMIs. While our project did not focus on formulating a standardized evaluation procedure, we recognize the importance of standardizing such procedures both for researchers and practitioners. At the same time, our experiences from this project show that the evaluation methodology often needs to be tailored to suit the specific research question and practical conditions in a given study. One should thus carefully consider what needs to be standardized and to which degree.

Another insight from our project is that a research approach that combines different data types contributes to deeper insights and knowledge of user experience and trust. Furthermore, the project has shown that both qualitative and quantitative methods add to the understanding of how users behave and experience HAV. When it comes to selection of evaluation tools, we believe that various evaluation tools should be used depending on the research question and maturity level of the eHMI concepts. For instance, online surveys and VR are good tools for obtaining a first impression about a concept or interaction principle. However, if the goal is to capture safety and efficiency aspects of an eHMI concept one should consider conducting experiments under more realistic conditions (in our case on a test track using Wizard of Oz techniques and in a driving simulator).

Selection of study participants in this context is often a neglected issue, that has significant implications for insights. To start with, the type of study participants is typically limited, both in number and diversity of background. Our project is no exception when it comes to such aspects. All our studies have been conducted under controlled conditions and involved a limited number of study participants, mainly from Sweden. It is thus difficult to say whether our findings and insights are transferable to other conditions, and one should be careful when generalizing. In several of our studies, we recruited the study participants via a recruitment company, which proved to be an efficient way to ensuring fulfilment of certain requirements (e.g. gender, age, previous experience).

Another generic, yet important, insight is that study participants have generally no experience of interacting with automated vehicles, which makes it crucial to explain the technology in advance as well as to repeatedly expose them to encounters with automated vehicles during the study.

Future research

The research on interactions between automated vehicles and other road users has been increasingly growing the last 6-7 years. However, our general impression is that the field has reached a level where it is not advancing; the studies that are published are similar to each other, include simplistic scenarios (interaction between one passenger car and one pedestrian at a (zebra) crossing) and metrics. To make a significant advancement in the field, we suggest the following research steps:

- Establish more in-depth knowledge on interactions between HAV and other road users.

- Conduct longitudinal (uncontrolled) studies in realistic environments (as opposite to the current trend where majority of studies are done under controlled conditions and last for about 20-30 minutes only).
- Explore in more detail what information needs to be communicated from automated vehicles, and when it needs to be communicated.
- Examine combination of implicit (driving behavior) and explicit (eHMI signals) communication from HAV.
- Investigate other communication modalities and find out how these could co-exist with current communication systems such as AVAS.
- Investigate effect of eHMI in more complex and dynamic situations (as opposite to zebra crossings which is currently default in the literature)
- Scale up evaluations and include a broader group of participants in studies (cultures, demographics, etc.)
- Figure out what are suitable metrics (KPIs) for eHMI (researchers today tend to use a very limited number of metrics).

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