

HaTric

HMI for Automated Driving in Traffic

Project within: FFI Traffic Safety and Automated Vehicles

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Executive summary

There is a lack in the understanding of human behaviour in automated vehicles. Research on automation in other domains has shown that new automation-related problems can be revealed that are hard to foresee. Hence, the project starting point has been that autonomy can decrease the number of accident if human behaviour is taken into consideration. Human-Machine Interaction (HMI) is an important means of supporting appropriate behaviour. This project started in what is known from other domains but was also explorative. The objective of the project has been to generate design principles, test methods and prototypes necessary to concretely understand what constitutes good HMI design for automated vehicles.

The project started with identifying the theoretical foundations and different viewpoints relevant for the scope of the project regarding *driver behaviour in automation*. A literature review focusing on what we can learn from other domain as well as what we can learn from earlier studies on Advanced Driver Assistance systems (ADAS) and Autonomous Driving (AD) was conducted. In addition, two studies focusing on an existing semi-autonomous system were conducted – an interview study and an experimental study. The learnings were gathered in a conceptual framework suitable for describing the interaction between driver and vehicle which could support the design of HMI in automated vehicles.

Poorly executed automation can be monotonous and boring proven by many examples from industry. However, to make automation successful is it not enough to try to avoid negative feelings such as boredom in monotony, frustration and sleepiness. It is necessary to also look beyond acceptance and try to create positive emotions and pleasure. This project has used several different approaches to explore *user expectations on autonomous driving*.

The projects has been explorative to its character, and has included design and test of different *HMI for autonomous driving*. A research car with the possibility to test different aspects of HMI for AD has been developed, studies on HMI based on metaphors and HMI for both urgent and non-urgent transitions have been conducted. In addition, since the car behaviour itself can convey information to the people in the car, a study exploring the behaviour of the autonomous vehicle and its impact on trust has been conducted.

The project has given fundamental knowledge in understanding what constitutes good HMI design for automated vehicles, in terms of what aspects to take into consideration in the design of HMI for AD. In addition, new innovative research methods and explorative HMI solutions have been developed.

Background

Automation of the driving task has gradually increased from very low levels 10-15 years ago, when electronic stability control systems first made their appearance in mass market vehicles, to today where both experimental and commercial vehicles exist that literally can drive themselves on regular roads under certain conditions.

The reasons for automated driving are manifold and it is assumed that automation will give many advantages. For example, since on-board computers usually are better than humans at regulating

throttle use, transportation could become more environmentally friendly. An autopilot will not fall asleep behind the wheel either, and hence the number of crashes related to driver drowsiness might decrease. Drivers might also appreciate being relieved of the driving task during longer and/or monotonous drives. Another aspect is that drivers already do things other than driving; they eat, they talk on the phone, they write text messages, they engage in social media etc. In other words, they do things that sometimes can be distracting and which potentially have a negative effect on driving performance. Automation could provide time and support for safe execution of these kinds of tasks.

Automation has existed within other domains for a long time and there is a broad scientific field that describes the experiences and lessons learned in these domains. However, driving a vehicle in road traffic is in many ways different from the types of operator control studied in these other domains. Firstly, when applying automated process control with human supervision, other domains usually have much stricter operator selection and training procedure (not everyone is cut out to be a train traffic controller or airline pilots). Secondly, the time scale on which human interventions need to happen is generally longer, compared to the vehicle domain. Hence it is not clear that knowledge from those domains is easily transferred to the domain of road traffic. However, one lesson learned in other domains with likely direct transfer is that automation of a process influences the operator in different ways. There is no reason to believe that automated driving will not affect the humans behind the wheel. Therefore, and for the reason that unanticipated difficulties often are observed in automation (Sarter, Woods and Billings, 1997). Experiences from other domains (e.g. Young, Stanton & Harris, 2007) make it reasonable to assume that when vehicles become partially automated, a new class of behaviours that can be called automation induced behaviour may make their way into the road traffic domain. Some of these have a potential negative impact on the quality of driving and handover of control, for example:

- **Mode confusion:** For example, the driver thinks the vehicle has both lateral and longitudinal control, but in reality the vehicle only has longitudinal control (Sarter & Woods, 1995).
- **Trust:** Over-trust may lead to behaviour adaptation and under-trust may lead to under-use of system and dissatisfaction. In addition, trust also relates to driver personality (Rudin-Brown & Noy, 2002; Muir, 1987).
- **Skill degeneration:** A driver who rarely drives may lose important parts of his/her driving skills (Stanton & Young, 2000).
- **Out of the loop performance problem:** Negatively affected situation awareness (Parasuraman, Sheridan & Wickens, 2008; Endsley, 1994).
- **Mental under- or overload:** Automation may create underload, which can degrade the driver's ability to retake control when required. The driving task goes from being highly operational to more of problem solving/strategic character, which may influence the capability for smooth takeovers (Stanton & Young, 2000).
- **Vigilance and boredom:** The ability to stay attentive/alert over longer periods of time is affected (Young, Birrell & Davidsson, 2011).
- **Transfer of responsibility:** From drivers to designers (Bainbridge, 1983).

The HMI challenge is to avoid the above problems. HMI can show mode clearly, teach the driver how the system act and “think” (transparency), stimulate the driver to stay alert, help to calibrate trust, monitor the driver's state and optimize mental workload. If the HMI fails to do this, the hand over will be less smooth, the user experience will be affected negatively as well as the response time and quality.

The most recurrent control handovers will be what can be called normal or expected control handovers between driver and vehicle. These will take place when the driver asks the vehicle to take control over manoeuvring, and when the vehicle reaches its designed operational limit and no longer is allowed to control the vehicle (e.g. when the end of an automation certified stretch of road is approaching). As these two control transitions will form the basis of all interactions between drivers and partially automated vehicles, a key challenge in HMI design for partially automated vehicles is to make the transitions as simple, intuitive and non-intrusive as possible. Also, as the extent to which transitions are successful will depend on the affordances for interaction that present themselves to the driver, the underlying principles that guide and define successful transitions are as important to study and design for as the transitions themselves. The other type of control handovers that will occur can be called unexpected handovers. There can occur in two ways. The first is if the system malfunctions. Being able to drive itself does not make a vehicle exempt from technical problems (electrical failures, mechanical failures, software errors, sensor errors, etc.), which may suddenly incapacitate the automated driving function. The second is when the automated driving function reaches an operational limit in a place or time when the driver did not expect it to.

New technical solutions are adopted by users to different degrees. Fundamental prerequisites for user adoption is perceived usefulness (e.g. Davies 1989) or perceived benefits, i.e. benefits compared to the existing solutions. Additional factors include e.g. perceived ease-of-use (including learnability) and trust. The design of the HMI (including information content, interaction modality, etc.) plays an important role for drivers learning and understanding the function, understanding handovers, as well as drivers' developing trust for the information and the function.

Objective

The objective of the project has been to *generate the design principles, test methods and prototypes necessary to concretely understand what constitutes good HMI design for automated vehicles*. The focus has been on:

- Driver behaviour in automation
- User expectations on autonomous driving
- HMI for autonomous driving

Project realization

Driver behaviour in automation

This section includes this literature review focusing on what we can learn from other domain as well as what we can learn from earlier studies on ADAS and AD. It also includes two studies focusing on an existing semi-autonomous system – an interview study and an experimental study. The learnings were gathered in a conceptual framework, which is described in the last part of this section.

What can we learn from other domains

In order to find out what the project could learn from other domains, a literature study was accomplished. The literature study focused on themes addressed in scientific literature as possible consequences of automation in different context (aviation, process industry etc.) and how to remedy those. The re-occurring themes were primarily such also mentioned in the background, i.e. skill, situation awareness, trust, and mental model, such as:

- **Skill.** Long-term use of autonomous systems have been found to result in loss of skills as the operator relies on the automation (e.g. Stanton & Young, 2000). This could lead to complacency, trust and self-confidence issues as well as an insufficient ability to intervene in a situation which the automation is not able to resolve (Hoc, 2000). The problem with loss of important manual control skills has been identified as a major issue within the aviation sector leading to less cognitive and performance abilities (Saffarian, et al., 2012).
- **Situation awareness (SA).** The main problem regarding SA is when the autonomous system is in control but a sudden change occurs which will shift the control back to driver (Parasuraman, et al., 2008). Stanton and Young (2005) found, for example that the use of ACC reduced the situation awareness. The aviation industry has also acknowledged low or insufficient SA as one of the biggest issues regarding human factors in autonomous systems (Stanton & Young, 2000).
- **Trust.** Trust is frequently mentioned in relation to automation and considered to greatly influence the acceptance of automated systems (Lee & See, 2004). The main issue here is inappropriately high or low levels of trust. This could lead to misuse – where a user overly trusts the automation and uses the system in an unintended way – or disuse – where the user has lower trust for a system that is more competent than the user, causing the user not to use the system (Parasuraman & Riley, 1997; Dzindolet, et al., 2003). An appropriate level of trust is when the user's trust corresponds to the reliability of the automation. Trust can be fostered through e.g. observations of system behaviour, understanding how the system makes its decisions or understanding the purpose of the system (Lee & See, 2004).
- **Mental workload.** Mental workload is a major concern for automation. There are studies (e.g. Reinartz & Gruppe, 1993) that suggest that automated systems present cognitive demands which increase workload. Considering user/'operators' and automated system members of the same team, effective control depends upon how well the team works and communicates together. The performance of the operator can be hindered by an increase in information processing load resulting from additional task of collecting information about the system state. However, the transition from operational to supervisory control (Parasuraman, 1987) can result in overload as well as underload: reduced attention during normal operations, however difficulties increase when faced with a crisis or system failure (Norman, 1990). Mental workload needs to be optimised to prevent performance decrements.
- **Mental model.** A correct mental model is the foundation to a proper development of trust and acceptance (Kazi, et al., 2007). The mental model will also affect how users use a system. If the mental model does not match the observed behaviour of the system, this could lead to confusion regarding the capabilities of the system and who is in control (Toffetti, et al., 2009). The user should have a correct mental model to be able to create an adequate situation model and thereby selecting appropriate actions in road situations (Seppelt & Lee, 2007).

A well designed HMI could remedy some of the negative consequences. Suggestions are that:

- Providing **feedback** to make the automated systems more transparent is an import factor when designing highly automated systems. The more automated a system becomes the more feedback it needs to provide, in order to make its behavior observable (Niedrée, et al., 2012) (Christoffersen & Woods, 2000). Feedback is instrumental in skill acquisition.
- A **transparent** system will give the user an increased feeling of control since the user has a greater ability to predict the system's behavior (Verberne et al., 2012).
- Studies have shown that providing information on **system uncertainty** results a more proper level of trust in the automated systems (Helldin et al., 2013) and greater acceptance that the system is imperfect (Beller, et al., 2013). Information on automation uncertainty have been shown to increase operator-automation cooperation, to improve SA and better knowledge of fallibility, making users better prepared in takeover situations (Beller et al., 2013).
- One important design trade-off is to provide sufficient information but at the same not distracting or overloading the user (Lee & Seppelt, 2009).
- Visual information is the most commonly used information output but this could result in a data overload in the visual channel (Lu et al., 2013). It is therefore important not only to use visual feedback in order to create a good communication between the system and the user. One solution to lower the risk for data overload is **multimodal interfaces** which distributes the information across audition, vision and touch.

What we can learn from earlier studies on ADAS and AD

The literature study also investigated what could be learned from earlier studies on different Advanced Driver Assistance Systems (ADAS). Focusing on automation in vehicles, a number of studies have shown both pros and cons of advanced driver support systems (ADAS) and automated functions (AD).

- A number of simulator studies reported on drivers' **willingness to hand over control** to an AD vehicle. Drivers' attitude was found to be an important factor but also the choice of use cases (e.g. highway vs. city centre) influenced drivers' intention. Several studies investigated users' attitude towards the systems/functions and/or intention to use such systems/functions – even though not necessarily based on any actual use experience.
- Studies of drivers', i.e. actual end users', more long-term experience of driving with ADAS were few. Nevertheless, studies (Strand et al. 2010; Strand et al., 2014; Piccini et al. 2012) have shown that end-users are overall **satisfied** with their ADAS, in particular during longer trips, even though they had experienced functional limitations.
- Drivers' **understanding** (cf. mental model) of the systems varied, but were overall rudimentary and sometimes even wrong. Other studies have shown that ACC users, especially in the beginning, has a hard time understanding the systems limitations (Larsson, 2012).
- Some self-reported **behavioural adaptations** have also been observed (Strand et al. 2010; 2014), positive (increased speed compliance, less overtaking) as well as negative ones (increased speed, less attention to driving) depending on type of system.

Several studies have focused specifically on the **transition** between driver-vehicle in automated driving (AD). The main interest appears to be transitions from vehicle to driver and then predominantly from a performance perspective – not from a user experience perspective. Studies focusing on the transition from driver to vehicle were not found. For example, studies have been set up to determine drivers' ability to resume control from an automated vehicle where Gold et al. (2013) provide an overview of reaction times. One simulator study suggests that drivers take approximately 15 seconds to resume control and up to 40 seconds to stabilise vehicle control

(Merat et al. 2014). Other results indicate that the higher the automation level, the longer the drivers' response times.

Continuing the theme transition between driver-vehicle, a limited number of studies have evaluated **HMI** designs. In one simulator study, visual and audio-visual take-over requests were compared. The results show an advantage for multimodal requests. However, the complexity of the take-over scenario must be taken into consideration. In another simulator study which focused on the transition vehicle-driver (Walch et al., 2015) a "hand-over assistance" was introduced. The results showed that the participants preferred a combination of an alert that gives the reason for a take-over, followed by the take-over request. However, this led to longer take-over times than other combinations. Helldin et al. (2013) concluded, again based on a simulator study, that drivers provided with the uncertainty representation took control of the car faster when needed and could, to a higher degree, perform tasks other than driving without compromising with driving safety. Also, participants who were provided with the uncertainty information trusted the automated system less than those who did not receive such information.

Learning a driving assistance system of today

An interview study was conducted to investigate how drivers learn the semi-autonomous systems that are available in cars today. The aim was to understand the development of drivers' mental model over time of the Pilot Assist (PA) system provided in Volvo cars today and to address HMI implications following that description. The following research question was formulated from a driver's perspective: How is the driving automation system understood and how does this understanding develop over time? In addition the study tried to capture more specifics on the HMI and implications for HMI design.

The study used a case based approach, collecting qualitative data by using semi-structured interviews. The questions that were asked followed an interview guide that was developed based on a mental models framework distinguishing between a structural component (hard facts, context free) and a functional component (procedural knowledge, context dependent). Three participants, who were owners of a Volvo 90 series, were recruited and interviewed four times each: (1) before delivery of the car, (2) at the delivery, (3) after one week of owning the car, and (4) after three to four months of owning the car.

The results show that difficulties exist for users of automated driving systems, such as misunderstandings and mix-ups due to system complexity. Furthermore, the first encounter with the PA seems to be an important experience that provides the foundation for future use, and it is therefore important to specifically design the interaction of this first experience. From the three cases only one can be said to have reached acceptance of the system and had incorporated it in his driving, while the others after three to four months of access to the system had not started using it in their driving. This suggests that the PA is a low prioritized feature in the car but due to potential safety benefits of the system, the user should perhaps be nudged towards prioritization of such a system. Next steps of this study are to follow up after an additional time period to see if/when an adoption decision has been made, but also to investigate how the first experience could be designed (e.g. in-vehicle tutor systems, scenarios in driving simulators, etc.)

Drivers' behaviour when using a driving assistance system in real traffic

As shown in different studies (e.g. Carsten et al. 2012; Jamson, Merat, Carsten, & Lai, 2013; Llaneras, Salinger, & Green, 2013) automated driving increases driver proneness to engage in

other tasks. In fact, the general public expects such proneness to increase as higher levels of automation reach the market (Kyriakidis et al. 2015). Studies on level 1 and, particularly on level 3, have shown that, in fact, performing other tasks while driving automated will be easier for drivers (de Winter et al. 2014). However, little attention has been given level 2 automation, where drivers will still be responsible for monitoring the environment (e.g. traffic signs, hazards, etc.). Given that this task may be a rather demanding task, it is possible that drivers still need to display cognitive and behavioural strategies to integrate additional tasks to driving, particularly visual tasks that require drivers to time-share visual resources. Different factors like, prior experience with the same system, may modulate the level of demand experienced by the drivers and the different strategies used to handle these multitasking situations.

An on-road study was conducted on a highway. Two groups of drivers were recruited. The “automation-novice” group consisted of 12 participants with no prior experience with automated vehicles. The “automation-experienced” group consisted of 9 drivers with naturally acquired experience with a Level 2 vehicle. A Volvo S90 equipped with the Pilot Assist Generation 2 (PA2) was used as test vehicle. The vehicle was instrumented with different cameras and GPS systems to continuously register traffic environment and vehicle speed and position. Drivers’ task was to drive safely while performing a visuomotor task presented on a tablet. A modified version of the arrows task used in the EU project HASTE was used (Östlund et al. 2004). The drivers had to detect by pressing a button on the tablet when an arrow pointed downwards in a 4 x 4 matrix where the other arrows pointed upwards. In half of the condition, the task included an “on-off” button that allowed drivers to switch off the task when they deemed the overall demand would affect its execution. This way, the additional task performance would not be affected. The participants drove the same stretch of highway (15 km) four times, two of them automated and two manually. Also, in half of the conditions, the additional task was system-paced (non-interruptible) or self-paced (interruptible). The drivers’ glance behaviour was registered by using head mounted eye trackers. Different dependent variables were collected from the driving task (e.g. average speed, number of overtakings, % time with the PA2 on, etc.), the additional task (% correct/misses/errors, % time with task on, number of trials completed, etc.) and the glance behaviour (% time looking and number of glances to the front, additional task, dashboard, etc.). Additionally, after each driving condition, the drivers filled the NASA-TLX to collect their perceived MWL for such specific condition.

The scores on the NASA-TLX revealed that, the self-paced task was perceived as less mentally demanding than when system-paced, and the automated driving as less effortful than the manual driving. Moreover, automation-novice drivers scored higher in the frustration sub-scale than the experienced drivers. As for the additional task, those drivers with level 2 experience kept the task on for longer periods than the automation-novice group in the self-paced conditions. This was observed regardless the automation level. In addition, a lower and a greater percentage of correct and misses responses, respectively, were observed in the automated than in the manual conditions. Regarding the driving variables, compared to the automation-novice drivers, the experienced drivers performed more overtakings, used the PA2 for a greater percentage of time and spent more time in the left lane. Furthermore, glance analyses showed that, during the automated driving conditions the percentage of time looking to the front and left mirror decreased, whereas the number of glances and the percentage of time looking to the dashboard (where the PA2 system was presented) increased significantly. Moreover, an interaction effect reported that the automation-experienced drivers directed more and longer glances to the tablet in the automated than in the manual conditions, while no differences were seen for the novice group. Regardless the level of automation, the automation-experienced group spent more time looking at

the additional task and looked less to the inside mirror. During the self-paced conditions, drivers looked more and glanced from frequently to the additional task than in the system-paced condition. Finally, when the task was self-paced, the automation-experienced drivers spent less time looking to the front than the novice drivers.

Our findings indicate that it might not be easier to perform other visuo-motor tasks in a level 2 automated vehicle than when driving manually, but rather the opposite may occur. Moreover, prior experience with level 2 automation does not seem to mitigate this effect. These results may be somewhat surprising given prior research on levels 1 and 3. Probably, the additional task used in this study interfered more with the monitoring demands placed by the system than with the demands stemming from the manual control of the vehicle position. But other effects, like cognitive underload could also have influenced. Our results highlight the importance for automation designers to analyse the nature of the tasks that are automated and to anticipate the effects on driver performance via theoretical models and empirical testing. We encourage future studies to continue investigating the effects of performing other tasks while driving with Level 2 automation, and its implications for safety.

Conceptual framework supporting the development of HMI for automated driving

An important part of the project has been to define a framework suitable for describing the interaction between driver and vehicle which could support the design of HMI in automated vehicles. The task was accomplished in several stages.

The initial literature study (described earlier) formed the basis. In addition, personal interviews were conducted with in-house staff at Volvo Cars representing different departments (user experience and safety) and with researchers with an expertise in automation in other areas than automotive, such as aerospace, health care, and process industry. A series of seminars/workshops was then run with the overall purpose to reach consensus regarding a framework that can provide a common theoretical basis for the HATric project. In the first workshop project partners as well as other competences from different areas participated. During this workshop a summary of the interview results and different theories of relevance for the area of automation were presented and discussed. It became clear that a common terminology and definitions (for instance regarding what is meant by HMI and automation levels) was needed in order to be able to move forward. In addition, in order to be able to evaluate the relevance of different theories concrete use cases were necessary. In the three remaining workshops, in which participated project partners only, key terms were defined and four use cases were developed and discussed.

An important basis was that in designing the HMI for AD, **all interfaces** that interact with the driver are to be considered, i.e. not only the information cluster, but also steering wheel, gear stick, pedals, car seat, as well as the car per se (i.e. its behaviour in terms of, e.g. acceleration and braking patterns, etc.). Furthermore, the HMI must support the driver/user during different types of driver-vehicle and vehicle-driver transitions. The following definitions were proposed for different types of transitions:

- **Handover:** A driver initiated transfer of control from the driver to the vehicle in the driver-vehicle system.
- **Reclaim:** A driver initiated reclaim of control from the vehicle to the driver in the driver-vehicle system.
- **'Pass back':** A vehicle initiated pass-back of control from the vehicle to the driver in the driver-vehicle system. The vehicle "wants" the driver to reclaim control.

- **Take over:** A vehicle initiated take-over of control from the driver, i.e. there is no initiation from the driver.

Rather than defining transitions as critical or uncritical, the decision was to differentiate between urgent and non-urgent transitions:

- **Urgent transitions** are necessary in order to maintain safe and efficient performance of the driver-vehicle system. Urgent transitions have a time dimension which can be longer or shorter.
- By **non-urgent transitions** are meant transitions that are planned and/or anticipated by driver or vehicle due to delimitations of the AD system.

Furthermore, the transitions from non-automated to automated driving (or from levels of lower automation to higher automation) and vice versa are not ‘on-off’ events but a process including different phases during which the driver needs different types of support. The different stages in each transition as well as stages between pose different requirements for the HMI. Fundamental guidelines for how to design human-machine interaction must be applied and relevant theories and models for example on human information processing, mental models, and trust must be taken into consideration.

In addition, a tentative model has been developed which describes the interdependency between the driver (human agent), the vehicle (autonomous agent) and the role of the “interface” in this dynamic human-vehicle system. The notion that all interfaces that interact with the driver are to be considered formed the basis. The defined goal for the joint system is to “move forward in a safe, efficient and enjoyable manner”. The framework describes the processing and basic information flows necessary to accomplish this goal. A special focus is on the two agents’ communication through the “interface”, regarded as a mediating tool in the process.

User expectations on autonomous driving

Poorly executed automation can be monotonous and boring proven by many examples from industry. However, to make automation successful is it not enough to try to avoid negative feelings such as boredom in monotony, frustration and sleepiness. It is necessary to also look beyond acceptance and try to create positive emotions and pleasure. This project has used several different approaches to address user expectations on autonomous driving which are described in this section: exploring future scenarios, participatory innovation and strategic planning.

Exploring future scenarios

In order to design autonomous cars that are adopted by users, it is of great importance to develop an understanding of what expectations people have of autonomous cars, how they expect them to behave and function. A study was undertaken in order to address the following questions: (i) What are the drivers’ reactions/attitudes and why?; (ii) What behavioural consequences do they think that further automation will lead to?; (iii) What are the important prerequisites for drivers’ acceptance and adoption of further automation?; (iv) What are the important requirements for the future HMI?

Altogether 14 participants (Ps) (13 men and 1 women) were possible to recruit. They were all car users, i.e. their main mode of transport was their car, and two defined themselves as “early adopters”. The method used was “staging” as described by Pettersson (2014). This meant that the

Ps were invited to an interview session where a physical context was arranged, consisting of chairs arranged as in a car on a big paper with a car outline drawn on it. During the interviews, the Ps were encouraged to act out future use, rearrange chairs, and make drawings and comment on the paper, etc. Each session was individual and typically lasted about an hour.

The findings show that the Ps were curious about but most had at the same time difficulties imagining what an autonomous car could be like. Most Ps based their assumptions on existing ADAS and similar concepts. They provided little input as to the design of a future HMI, i.e. the level of detail was quite low, even though they included for example suggestions re how to redesign of steering wheel, the design of HUDs and voice recognition. However, the early adopters differed as to how they imagined AD as well as the design of the HMI. Ps claimed that they would use of AD on highways and rural roads – but at the same time this is the type of driving they liked - and could not imagine autonomous driving to work in rush hour city traffic – i.e. the type of traffic they claimed to dislike. However, Ps with experience of more advanced systems were more confident about the functionality.

In summary, the Ps envisioned positive consequences of but had also some concerns about future AD. The main benefits of AD according to Ps were that it would be fun and/or exciting and that one would be able to do “... *other things than drive*”, the anticipated tasks depending upon how and for what purpose they used the car. However, there were also those who were concerned that they would not be allowed to be the driver anymore, referring to the pleasure they associated with certain types of driving. Ps also mentioned increased safety and positive consequences for the environment. They thought that automated vehicles could lead to less stressful traffic and an overall better traffic flow. The main worries associated with AD according to the Ps were technical failures in that the technology would fail, that infrastructure (WiFi/5G/etc) would not be available and that the system could be exposed to hacker attacks. There were also those that worried about functional limitations, such as that the system would not cope with emergency braking (even though this is probably what the systems are best at) and that it would not be able to “read” more complex traffic situations. Furthermore there were issues re responsibilities raised along with cost to buy and maintain the AD vehicles.

Participatory innovation

A participatory innovation study for AD was conducted within the project to understand user perspectives, i.e. developing understandings of how cars and automation fit into people’s lives today and in the future. A team went to Stockholm to meet and interview “lead users”. Before the interview occasion the lead users made photo diaries of their daily commute trips. The team made journey mappings based on the diaries and brought them to the interview occasion. They spent 90 minutes with each of the nine lead users included in the study at a location of their choice in Stockholm. Future journey mapping and a tangible future scenario was created together with the lead users. At a later occasion a workshop was held at Volvo Cars with stakeholders within the area of AD, supporting them to understand, appreciate and incorporate user knowledge and perspectives in their own efforts. The gathered information was also included in the strategic planning described below.

Strategic planning

Impact mapping is a strategic planning technique that is used to explore, evaluate and discuss a product, service or technology and is used to make sure that solution is based on impact, not features (<http://www.inuse.se/blogg/evolution-impact-mapping/>). An impact map for HMI for

autonomous vehicles was developed within this project and served as a tool when designing and evaluating the interfaces for AD.

The building blocks in an impact map is why, how and what. **Why** – is the impact on business, why the solution is meaningful to invest in. Why should we develop this AD technology? It includes metrics that is used to measure success, and they state what the solution need to meet and to what degree. **How** – is the impact on use. It includes user behaviours, attitudes and needs and it describes how users think and behave in situations where the solution is active. The needs descriptions give guidance for validating the design. **What** – is the actual solution.

HMI for autonomous driving

This section includes activities within the project related to the design and test of HMI for autonomous driving. At first, a research car with the possibility to test different aspects of HMI related to the autonomous car is described. Then studies on metaphors as the basis for designing human-vehicle interaction and studies on HMI for both urgent and non-urgent transitions is described. The car behaviour itself can also convey information to the people in the car and the last study describes the behaviour of the autonomous vehicle and its impact on trust.

Method development – the AD research car (also known as “Wizard-of-Oz car”)

In the project an AD research car was developed. In the setting the test participants in the driver's seat can give control to the car and interact with the HMI and they believe it is all real, but the car and the HMI are partly operated by a human being. In the setting a safety driver positioned in the rear seat continuously monitors the car and intervenes with it which makes it possible to test different driving styles and traffic situations. In addition, different HMI solutions can be tested in a “real” setting. This makes it possible to test the trust in the AD car under different circumstances and before such car exists. The car has been used in several studies within the project.

Metaphors as the basis for designing human-vehicle interaction

Using metaphors in design can help shape perceptions and actions without the user noticing them by linking new ideas to well understood objects and processes (Bruemmer et al., 2007). The suggestion to use metaphors in the design of automated vehicles was made by Flemisch and colleagues (2003) as it can help create a uniting vision for the design team, as well as help the user create an initial mental model of the system. It does so by giving concrete properties to abstract ideas (like that of the character of a relationship), and should help clarify the division of control and responsibility, communicate intentions and goals, and set the tone of relationship (Bruemmer et al., 2007). A few different metaphors have been suggested as a guiding principle for designing interaction with highly automated vehicles, such as the relationship between a horse and rider, the vehicle and driver as team players, or as a married couple. However, there is (as yet) no consensus on which metaphor should be chosen.

To explore the usefulness of metaphors, a series of four workshops was organised at scientific conferences and universities (NordiCHI'16 in Göteborg, at Safer in Göteborg, at the design research centre at Stanford, and at DIS'17 in Edinburgh). At each workshop, participants were asked to choose a metaphor and design an interaction design concept for an autonomous vehicle with "high automation" (by the SAE organization described as a "level 4" system). Participants

were a mix of academics and practitioners in interaction design, automation and vehicle development.

Cross-analysis of the workshops showed that the metaphors did help a multi-disciplinary group come together over a uniting vision, as the range of metaphors available forced participants to question their own assumptions and explore the full design space and relationship dimensions. When combined with enactment methods, the metaphors could also help guide more detailed design. However, many participants started to feel restricted by the metaphor and stepped away from its restrictions in terms of, for example modalities or intelligence. Different metaphors appear to have worked differently well, as fuzzier metaphors that were not equally well-known by participants did not work to create a uniting vision, and too limited metaphors could not cover the complex human-vehicle interaction.

To investigate further how the metaphors could work as design guides four interaction designs conveying relationships between human and machine (i.e. AD vehicle) were designed. The four designs, based on the metaphors ‘elevator’, ‘chauffeur’, ‘horse’, and ‘team player’, were evaluated by 28 participants in a Usability Laboratory setting. The results showed very small differences between the concepts regarding, for example, perceived control and involvement. There were differences in perceived appropriateness related to individual differences in general perception and situation-based differences in critical situation, i.e. situations that can lead to harmful consequences, either for the participant or for vulnerable road-user (pedestrian or bicyclist). A main conclusion is that people want to be in control, but don’t want to make decisions, except for strategic and preferential decisions.

Normal control handovers

Several studies have been conducted within the project that have tested HMI solutions for mode understanding (manual, semi-autonomous and autonomous mode) and different solutions for initiating hand-overs, e.g. buttons, paddles and gear shifter for initiating handovers.

Unpredicted, urgent but non-critical control handovers

The experiments below targeted unpredicted and urgent, yet non-critical pass backs. A key property of these events is that because the vehicle must leave AD mode immediately, it will start a Minimum Risk Manoeuvre at the same time as the request to resume manual control is issued (typically a speed reduction to zero in a controlled manner).

Experiment 1

The first experiment aimed to study which is the most effective, yet least intrusive, hand-over cue that can be designed for unpredicted, urgent, non-critical pass backs. The study used the Volvo Cars Dynamic driving simulator, which is a simulator with a motion platform. 30 participants were recruited from a base of Volvo Cars employees (excluding anyone involved in AD development). The driving environment consisted of a three lane motorway with a speed limit of 120 kph. Participants were told to drive along this road, and when instructed to do so, engage the autonomous mode. They were told to stick to 80 kph also in manual driving, and disregard the posted speed limits. During driving, there was oncoming traffic and traffic in the same direction. The latter was controlled in such a manner that all surrounding vehicles automatically kept a minimum longitudinal and lateral margin to the test participant vehicle. Hence the test participant did not need to do anything to negotiate same lane traffic. When drivers had engaged autonomous mode, they were asked to play the game Dots, which was provided on an Ipad placed in the

simulator (handheld, not fixed mounted). The game idea is to connect dots of like colour to remove them from the board and rack up as many points as you can during the 60 seconds allowed for each run. After 4-5 minutes in autonomous mode, the car issued a request to resume manual control. When drivers had resumed manual control and driven in manual mode for 1-2 minutes, they were again asked to engage autonomous mode. Each driver experienced 4 epochs in autonomous mode where each ended with a request to resume manual control. The whole drive ended after approximately 25-30 minutes.

Autonomous mode was engaged by simultaneously pulling on the right and left steering wheel stalks during minimum 2.0 s. AD engagement was indicated by a blue ring of LEDs around the Driver Information Module (DIM). When the driver switched to manual driving, these LEDs turn red to indicate manual mode.

Each driver got four requests to resume manual control. Every time, the same auditory voice prompt was used, which consisted of a voice saying “please resume manual control now”. In addition to the voice prompt, each request contained the following:

- Every time:
 - One of two brake profiles (pulse vs linear, for characteristics). This brake profile condition was between group variable, i.e. stayed the same over all repetitions for any particular driver.
- Every second time:
 - An additional ambient light cueing in combination with the voice prompt and brake profile. The ambient light cue was a within group variable and counterbalanced across exposure, i.e. for half of participants it occurred at exposures 1 and 3, and for the others at exposures 2 and 4.
 - Furthermore (and important for the analysis outcome below), all the cues were synchronised in time, i.e. started simultaneously.

The terms effective and least intrusive were given the following operational definitions:

- Effective (objective measures):
 - Deactivation time – time from requesting manual control resumption until manual control had been resumed
 - Speed loss – reduction of vehicle speed in the interval from requesting manual control resumption until manual control had been resumed
- Least intrusive (subjective measure):
 - As reported by participants in post drive feedback interview

In experiment 1, all cues were equally effective. The average deactivation time was around 5.5 seconds, regardless of which cue combination that the driver experienced. For speed loss, the Pulse brake profile showed a significant advantage over the Linear brake profile. The speed loss distribution is also smaller for the pulse mode, indicating a more uniform behaviour compared to the linear braking mode. The latter can be explained by the fact that when doing linear braking, speed reduction is quite rapid despite the limited braking applied (0.2G in this case), so variability in response times will lead to a corresponding variability in speed loss. Unexpectedly, all cue combinations were perceived as intrusive by the drivers. Furthermore, Intrusiveness was not limited to the first exposure, it persisted over the four exposures. The post drive interviews suggest that this partly is coupled to the general observation above, i.e. that someone truly engaged in a secondary task also has completely disengaged from driving. Many reported the cueing to resume manual control as being very “sudden”, “loud” or “alarming”, despite the fact

that voice, light and deceleration levels were at most moderate. Another contributing factor is likely that the cues were synchronised in time. Humans are extra sensitive to multimodal cues when synchronised in time; it triggers a startle effect. In the current study, the synchronised cueing, combined with a (for many) truly engaging secondary task, literally made drivers jump. Another interesting observation was that very few could recall differences between cue combinations. The few that said there was a difference consistently said the voice prompt sometimes was louder, while in reality what differed was whether they got the ambient light cue or not. In summary, all cues provided in Experiment 1 were effective, but they were also all intrusive.

Experiment 2

After reviewing the results of Experiment 1, it became clear that intrusiveness could be addressed in two ways; lowering modality intensity or de-synchronization. Since the modalities in Experiment 1 already were low in intensity, experiment 2 was designed to look into effectiveness and intrusiveness when de-synchronising the cues. Everything in the second study was set up exactly as in the first. The only difference was that 2.0 s prior to the voice prompt and brake onset, drivers received a pre-cue, consisting of either a melodic sound or the ambient light cue described above. The pre-cue type was a within group variable counterbalanced across exposure. This effectively gave drivers a mono-modal stimuli 2.0 s prior to receiving the multimodal control resumption request.

Similar to Experiment 1, there was no difference among cue types and combinations in terms of effectiveness. The average deactivation time was around 6.5 seconds from onset of first cue element (i.e. the pre-cue), regardless of which pre-cue or brake profile the driver experienced. For speed loss, the results of Experiment 2 corroborated those of Experiment 1, i.e. the pulse brake profile showed a significant advantage over the Linear brake profile. Also, similar to Experiment 1, the speed loss distribution was much smaller for the pulse mode compared to the linear braking mode. The subjectively reported intrusiveness was much lower for study 2, compared to study 1. Quite simply put, the pre-cue eliminated the element of surprise inherent in the synchronized cueing, and thus drivers were not as startled or alarmed by the cueing in Experiment 2.

The price paid for this lower perceived intrusiveness is extended deactivation times. While drivers in Experiment 2 were slightly faster to deactivate the AD condition in relative terms (i.e. counting from onset of the voice requesting resumption of manual control), they were slower in absolute terms (i.e. counting from the onset of the pre-cue). As in other domains, there thus seems to exist an inherent trade-off between effectiveness and intrusiveness also for AD deactivation. What is new from the current studies is perhaps that compared to manual driving, the thresholds for perceived intrusiveness are much lower someone truly engaged in a secondary task in AD mode; startle effects thus comes easier. Alert modality intensities and timing thus may need a different tuning when in AD mode, as compared to manual driving.

The behaviour of the autonomous vehicle and its impact on trust

Previous studies have indicated that the design of graphical user interface of autonomous vehicles affects trust. To test this hypothesis, an initial study on anthropomorphism in user interfaces was conducted. Ten participants tested three versions of user interfaces in a Wizard-of-Oz car and rated experienced level of trust. The results showed no significant difference in levels of trust between the user interfaces and, further that the participants' trust in the vehicle depended primarily on how the vehicle behaved.

A baseline study was therefore set up to investigate how car behaviour affects drivers'/users' trust. Two behaviours, defined as "eco-mode" and "sport-mode", were compared. Altogether 18 participants (Ps) between 20 and 55 years (50/50 male/female) took part in the study. They rode together with test leader in Wizard-of-Oz car on the Asta Zero test track and rated trust and comfort in predetermined situations. No graphical user interface and no secondary task were included.

The results indicate that the predictability of the automation is of importance for how much trust the Ps felt, several of the Ps wanted to be in the "information-loop" regarding the intentions of the automated vehicle. Eco-mode was in general perceived as more trustworthy, since this behaviour showed the car's intentions earlier as well as in a calmer manner. The results also indicate that the perceived intelligence of the automation depended on the situations. In critical situations, eco-mode was preferred since it more clearly showed the intention(s) of the car (e.g., early slow down for pedestrian). In non-critical situations, the sporty-mode was preferred since it was perceived as more effective (e.g., narrow turn in roundabout). Regarding the relationship between trust and comfort, there seems to be a correlation. However the Ps had different definitions of comfort, some Ps focused more on physical comfort (i.e. softness of seat etc.) whilst others described comfort as a more holistic term including feelings of satisfaction as well as anxiety. In summary, the study showed that the driving behaviour of the automated vehicle affected the Ps' trust but also that people experienced the autonomous car as 'a whole'. Hence, vehicle dynamics and driving patterns need to be considered as an essential part of the user interface of the car to create trust as well as comfort (holistic term) – the entire autonomous car is the AD interface to the driver/passenger.

Results and deliverables

The project has contributed to the overall FFI targets:

- Increase research and innovation capacity in Sweden. The work has contributed to knowledge regarding human behaviour in partially and highly automated vehicles. The work has helped Volvo Cars in designing interfaces that can optimize handover of control between vehicle and driver, embodied and tested in prototype form, which is a competitive advantage. Chalmers and VTI will utilize the competence gained in this project to remain competent partners in research within this area. Participation in forward thinking research projects is vital for Chalmers and VTIs ability to attract and retain talented researchers.
- Develop competitive and internationally connected research and innovation clusters in Sweden.
- Promote cooperation between industry, universities and institutes. In addition, the project has contributed to the establishment of new international collaborations.

The project has supported several of the areas of research in the FFI collaboration program "Traffic Safety and Automated Vehicles", such as:

- Insights of the essentials of human behaviour in automated and semi-automated cars, with regards to automation induced behaviours, handover of control and value and pleasure.
- Methods for data collection: the project has included development of tools and processes for evaluation, which have already been successfully applied in other ongoing research

and development projects.

Dissemination and publications

Knowledge and results dissemination

Seminars, workshops and test drives have been held among the project partners with the aim of enabling for discussions, knowledge transfer, as well as concept and study ideation. Presentations of thesis work have invited parties outside the project. In addition, the following activities involving external parties have been conducted:

- Presentations of the work made within the project were held at the public HaTric and AIMMIT Joint Results Conference, October 25 2017 at Volvo Cars (<https://www.saferesearch.com/events/results-conference-hatric-and-aimmit-safer-associated-projects>)
- Workshop arranged at the conference DIS'17. Title: Setting the Stage with Metaphors for Interaction - Researching Methodological Approaches for Interaction Design of Autonomous Vehicles
- Presentation made at a VTI-seminar with prof. Simone Pettigrew, Curtin University, Australia, 19th of Dec 2017
- Presentation at the seminar “New approaches for future mobility”, 4th International Electric Vehicle Expo (IEVE), Jeju, Korea, 2017
- Presentation at the conference NordiCHI 2016. Title: The Drive for New Driving Interfaces: Researching a Driver Interface from Design Intent to End-User Experience.
- Workshop arranged at the conference NordiCHI 2016. Title: Living Room on the Move: Autonomous Vehicles and Social Experiences
- Ekman, F., Johansson, M., & Sochor, J.L. (2016): Creating trust in automated vehicles using a HMI-based framework. Presentation at the 5th Swedish National Conference on Transport Research, Lund, Sweden, October 18-19, 2016
- Presentation at Transportation Research Board Conference, Washington, D.C. January 10-14, 2016

Publications

Reports and papers

- Aremyr, E. & Jönsson, M. & Strömberg, H. (forthcoming): Anthropomorphism: An investigation of its effect on trust in human-machine interfaces for highly automated vehicles. *Abstract submitted to IEA 2018*.
- Strömberg, H. & Bligård, L-O. (forthcoming): A theoretical framework for human - autonomous vehicle interaction. Paper to be submitted to Theoretical Issues in Ergonomics.
- Ekman, F., & Johansson, M., Strömberg, H., Bligård, L-O & Karlsson, I.C.M. (forthcoming): Investigating the impact of vehicle behaviour on users' trust in and experience of autonomous driving. Paper to be submitted to Transport Research Part F.

- Johansson, M., Ekman, F., Bligård, L-O, Strömberg, H. & Karlsson, I.C.M. (forthcoming): Talking AD - An investigation of users' understanding of an autonomous vehicle. Paper to be submitted.
- Ekman, F., Johansson, M., & Sochor, J.L. (2017): Creating Appropriate Trust in Automated Vehicle Systems: A Framework for HMI Design. *IEEE Transactions on Human-Machine Systems* 2168-2291.
- Ekman, F., Johansson, M., & Sochor, J.L. (2016): To See or Not To See – The Effect of Object Recognition on Users' Trust for Automated Vehicles. *Proceedings of the 9th Nordic Conference on Human-Computer Interaction – NordiCHI'16, Gothenburg, October 23-27, 2016*
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- Johansson, M. & Karlsson, M. (2016): Literature review. Report. Design & Human Factors, Product and Production Development, Chalmers University of Technology, Göteborg.
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- Strömberg, H., Bligård, L-O., Ekman, F., & Johansson, M. (forthcoming): Designing with metaphors - A tentative framework. *To be submitted*.
- Strömberg, H., Ekman, F., & Johansson, M., Bligård, L-O (forthcoming): Designing with metaphors - An empirical study of applying metaphors in autonomous vehicle interface design. *To be submitted*.
- Strömberg, H., Bligård, L-O. & Karlsson I.C.M. (forthcoming): HMI of autonomous vehicles - more than meets the eye. *Abstract submitted to IEA 2018*.
- Strömberg, H., Pettersson, I., Nolhage, J., Ju, W., Martelaro, N. (2017) Setting the Stage with Metaphors for Interaction - Researching Methodological Approaches for Interaction Design of Autonomous Vehicles. DIS '17 Companion *Proceedings of the 2017 ACM Conference Companion Publication on Designing Interactive Systems*
- Strömberg, H. Pettersson, I., Ju, W. (forthcoming): Horse, butler or elevator? Metaphors and enactment as a catalyst for exploring interaction with autonomous technology. *Submitted to DRS2018*
- Strömberg, H. Pettersson I., Andersson, J., Rydström, A., Klingegård, M. Forlizzi, J., Dey, D. (forthcoming): Designing for Social Experiences with and within Autonomous Vehicles - Exploring methodological directions. *Submitted to Design Science*.
- Wallgren, P. & Rexfelt, O. (2017). A qualitative study on car drivers' attitudes towards and expectations of automated cars. Working paper. Design & Human Factors, Product and Production Development, Chalmers University of Technology, Göteborg.

Master Theses

- Aremyr, E. & Jönsson, M. (2017): AVID - Autonomous vehicles interaction with drivers. An investigation of the embodiment of vehicle-driver communication and development of an HMI concept. Master Thesis, Design & Human Factors, Product and Production Development, Chalmers University of Technology, Göteborg

- Ekman, F. & Johansson, M. (2015): Creating Appropriate Trust for Autonomous Vehicles – a framework from HMI design. Master Thesis, Design & Human Factors, Product and Production Development, Chalmers University of Technology, Göteborg

Conclusions and future research

The objective of the project has been to *generate the design principles, test methods and prototypes necessary to concretely understand what constitutes good HMI design for automated vehicles*. The project has given fundamental knowledge in understanding what constitutes good HMI design for automated vehicles, in terms of what aspects to take into consideration in the design of HMI for AD. In addition, new innovative research methods and explorative HMI solutions have been developed.

Work within the area will be continued in, for instance, FFI HEAD (Human Expectations and Experiences of Autonomous Driving) and FFI TIC (Trust in Intelligent Cars).

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