



CHALMERS
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Enhancing the User Experience in Transitions from Highly Automated to Manual Driving

Master's Thesis in Industrial Design Engineering

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Department of Industrial and Materials Science

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Master of Science Thesis

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Master of Science Thesis in the Master Program Industrial Design Engineering

In collaboration with Volvo Car Corporation

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Terminology

- AD** – Automated Driving; The driving mode when the car is driving by itself.
- ADS** – Automated Driving System; The system that makes autonomous driving achievable.
- ANC** – Active Noise Cancelling; A method for reducing unwanted sounds and frequencies.
- AP** – Autopilot; A system that enables the vehicle to drive autonomously without manual operation.
- Auditory display** – Sound communication from PC to human.
- AV** – Automated Vehicle; A vehicle that can drive autonomously without manual operation.
- CSD** – Center Stack Display; The display placed in the dashboard for navigation or NDRT.
- DDT** – Dynamic Driving Task; The functions required for driving a vehicle.
- FMT** – Function-Mean Tree; Method used to find a product’s functions and means.
- Hi-Fi** – High Fidelity; High quality.
- HMI** – Human-Machine Interface; Where interaction takes place between the driver and the vehicle.
- HTA** – Hierarchical Task Analysis; Method used to analyze a user’s tasks to reach a goal.
- HUD** – Head-Up Display; Transparent display in the windshield.
- ICD** – Instrument Cluster Display; Screen behind the steering wheel, showing speed and acceleration.
- Lo-Fi** – Low Fidelity; Low quality.
- MD** – Manual Driving; When the human (user) is driving.
- MRM** – Minimal Risk Manoeuvre; When the car pulls over and stops in AP.
- NDRT** – Non-Driving Related Task; Task not related to driving, e.g. reading.
- ODD** – Operational Design Domain; The domain where the AP operates in a safe manner.
- PA** – Pilot Assist; Assists the driver with lane assist and cruise control.
- SUI** – Sonic User Interface; The sound signals.
- TJP** – Traffic Jam Pilot; The AP in a traffic jam.
- VUI** – Voice User Interface; The voice command.
- UI** – User Interface; The space where the HMI appears.
- UX** – User Experience; The experience of using something.

Abstract

The development of automated vehicles is growing rapidly within the automotive industry. Currently there are 5 levels of automation, where the highest level is fully capable of driving with no human interaction involved. This thesis project focuses mainly on level 4 automation, where the driver is requested to take back control and drive manually in some cases. As previous solutions from Volvo Cars have received some negative feedback, the aim for this thesis is to improve the user experience regarding the transition from autopilot to manual drive.

By stripping down the system to identify different core-values, two important pieces were added to the system – Pre-notification and Post-notification. Furthermore, 106 design guidelines were created to generate different ideas using a rapid prototyping approach. Through an iterative process with brainwriting, digital user studies and expert reviews, one concept was created using both visual and auditory cues. The aim of the concept was to increase the predictability and understanding of the transition but also to increase the transparency of the interaction between the driver and the vehicle. The concept was further evaluated in VR with experts to conclude and formulate some fundamental statements.

Requirements are that the transition needs to use pedagogic information and smooth transitions between the vehicle's information channels. To avoid information overflow, information volume needs to be restricted and primary information should be placed in front of the driver. Additionally, the system was considered to benefit from implementing the Pre- and Post-notification to enhance the user experience of the transition. When evaluating the new concept with users, less stress was experienced as more time were given to prepare for the takeover. The Post-notification was also positively interpreted with less confusion as an explanation of the takeover was provided in the concept. However, further research needs to be conducted investigating the effects of the concept in a real car. Haptic cues should also be considered in future development of the concept.

Keywords: *Autonomous vehicles, Automated driving, Transition from AD to MD, User Experience, Usability, Design concepts, Information channels, Autonomous Driving Systems, After Effects, Unity, User study, Pre-notification, Takeover-sequence, Post-notification.*

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INTRODUCTION

1. Introduction

The chapter provides a background to the topic of this thesis. This chapter also explains the aim of the project, its demarcations, the structure of the report, along with an explanation of the process used in the project.

1.1 Background

The first patented engine driven vehicle was created by Carl Benz in 1886 (Diamler, 2021). Today, the automotive industry is still growing rapidly. As new innovations and technologies keep advancing in relation to our society, car manufacturers are shifting their focus towards electrification and automation. For instance, Volvo Cars have set to be fully electric by 2030 (Volvo Cars, 2021). Furthermore, estimations indicate that fully automated cars could reach the market by 2025 (GreyB, 2021). This could lead to a safer traffic environment as around 90 % of all road accidents are claimed to be caused by human error.

Currently, there are five levels of automation (LoA) where the highest level, LoA5, is fully capable of driving with no human interaction involved (Dyble, 2020). This means that the driver can engage in more Non-Driving Related Tasks (NDRT), like reading a book or watching a movie without worrying about having to drive. However, for LoA4, which is the focus of this thesis project, the driver will, in some cases be asked to take back control. This means that the HMI (Human-Machine Interface), the interaction between the driver and the vehicle, gets more complicated when communicating with the driver in a clear and proper manner, while maintaining a good UX (User Experience).

In this thesis project, UX will be referred to according to Hassenzahl's (2018) definition which states that UX is the overlap between pragmatic and hedonic attributes. The pragmatic attributes refer to more traditional usability aspects while the hedonic (non-instrumental) attributes concern the degree to which the solution is, e.g., engaging, fun, and attractive (e.g., Hassenzahl, 2005). Furthermore, Hassenzahl (2018) states that it is important to reach beyond the pragmatic attributes and to also consider the hedonic attributes when working with UX of interactive products.

Currently, there are not many car manufacturers that are investigating how to improve the UX in the transition from AD (Autonomous Drive) to MD (Manual Drive) for LoA4. Tesla, however, uses a combination of different information channels, both visual and audio signals to communicate with the driver in the vehicle. When certain conditions are no longer met, the driver will be warned through a flashing display and a beeping signal. The automated system can then be deactivated in three ways; By the driver pressing the brake pedal, by lifting the right gear stock or by turning the steering wheel. If the driver fails to deactivate the system, the system automatically turns off the Autopilot (AP) system. In a recent study, Volvo Cars used a combination of haptic, visual, and auditory signals to communicate with the driver of a concept car (Novakazi, 2020). To deactivate the automated system, buttons on the steering wheel had to be pushed. If the participants failed to deactivate the system, the car would automatically pull over and stop at the side of the road.

The common denominator between these car manufacturers is that they both use different information channels, for the input and the output of the HMI, to communicate with the driver through different human senses. It is however unknown of how these factors affect the overall user experience. An

investigation of this is therefore needed to enhance the UX of the takeover from the AP to manual drive (MD). In the study described earlier, the takeover system used in the concept car from Volvo Cars were interpreted as both intrusive and stressful by many participants. The system therefore needs to be designed to encourage the driver to take the correct actions according to the system, without resulting in any negative feelings. The communication of the HMI between driver and vehicle also needs to be explored more in depth to create a more coherent and transparent solution to support the driver's intended actions.

By enhancing the UX in the transition from AD (Autonomous Drive) to MD, the chances of improving road safety could be increased significantly. This is important as this mission correlates to the Swedish policy Vision Zero, which aims to prevent road accidents from causing any casualties or injuries from happening (Goodyear, 2014). As Volvo Cars is a company deeply rooted in safety, this is something that could bring great value for future work at Volvo Cars (Volvo Cars, 2021).

1.2 Aim

The thesis project investigated how drivers understand and experience the takeover from a highly AD to MD in automated vehicles (AVs). The aim was to enhance the user experience in the transition from AD to MD by designing concepts for the HMI. Different information channels were used in the design of the concepts, which were evaluated through user tests to find and develop a final design solution for the HMI in an AV (Automated Vehicle).

Research Question

- (How) can the user experience of the transition from AD to MD be enhanced through HMI design concepts HMI that improve the understanding and predictability of the transition?

Supplementary Questions

- How can different information channels be used to improve the user experience of the transition from AD to MD?
- How can the usability of the system be improved to support correct actions in the transition from AD to MD?

1.3 Demarcation

This thesis project did not evaluate the design concepts in real life road conditions; they were only evaluated in a simulated environment with optimal conditions. The purpose was not to design a concept that could be directly implemented in a next generation car. The concepts developed in this study mainly focused on a future scenario where AVs have advanced and reached a higher intelligence and maturity than today. The ideation process for this thesis has not been limited by technical or legislative restrictions. Furthermore, this master's thesis project has not focused too much on programming since the authors have limited competence in this area. Due to Covid-19, physical user studies have been restricted to only be performed with internal parties from Volvo Cars and Chalmers University of Technology.

1.4 Project Process

This thesis followed a 7-step design process involving one major iteration. This process was inspired by how most UX processes are carried out which stems from the 5-step design thinking process empathize, define, ideate, prototype and test (Badich, 2020). The 7-step design process for this thesis project can be seen in Figure 1.

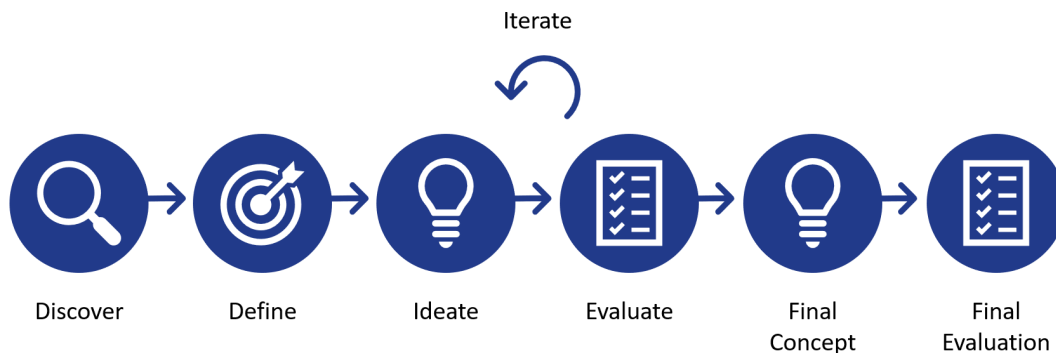


Figure 1. The 7-step design process for this thesis project

Discover

The discover-phase was conducted by gathering relevant data about the subject. First, a literature study was conducted to dig deeper into topics like the levels of automation, the transition from AD to MD, UX in automated vehicles, and HMI. This was followed by a video coding analysis of video materials from a previous user study by Volvo Cars. The purpose was to gather information to understand the problem more in depth and to design concepts that eventually would lead to an improved UX for the transition from AD to MD.

Define

The video coding analysis was completed as a thematic analysis to define the problem and to draw conclusions based on different themes. A system analysis was then conducted using an HTA (Hierarchical-Task Analysis) and a function-mean tree. By breaking down the automated system, two missing pieces were added to the system. Additionally, UX-curves were drawn from the video coding analysis to visualize the (interpretations of the) participants' experiences of the transition. Finally, design guidelines for the concept development were formulated to summarize the results from the thematic and system analysis.

Ideate

The purpose of the ideation phase was to explore the design space through different ideas and concepts. Applying a rapid prototyping approach, various methods were used like brainwriting and mood boards. Through an iterative process with sticky notes and sketches, four Lo-Fi (Low-Fidelity) concepts were animated for a Lo-Fi user study.

Evaluate

By evaluating the concepts in terms of positive, negative, and interesting aspects, impractical and incomplete concepts could be eliminated. Different concepts were also mixed and merged to form more

coherent concepts before evaluating them digitally through an expert review and a Lo-Fi user study. The purpose of the user study was to evaluate visual cues and their interpretation of the information provided in the four animated concepts.

Final Concept

A final concept was chosen and re-designed based on the results from the digital user study. The final concept was created in Unity to make it possible to test the concept in a VR (Virtual Reality) environment. The concept was evaluated internally against design guidelines to determine whether the concept fulfilled certain criteria or not.

Final Evaluation


A final evaluation was conducted in terms of an expert study where experts got to try the concept in a VR environment. The aim was to get feedback on the final concept to verify how well the concept performed in relation to the aim of this project. The final evaluation resulted in valuable feedback which determined the level of success of the concept.

1.5 Report Structure

The structure of the report is divided into the following chapters:

- Chapter 1** *Introduction*
This chapter introduces the project together with a background, aim, and description of the process used.
- Chapter 2** *Literature Study*
This chapter describes important data used in this project. Levels of automation, transition from AD to MD, UX in automated vehicles as well as the concept of HMI are explained.
- Chapter 3** *Study 1 Video Coding*
The chapter goes through an analysis of video materials from a previous user study by Volvo Cars, where people tried different features of an AV. A thematic analysis of the video materials is presented, with focus on the transition from AD to MD.
- Chapter 4** *System Analysis*
A system analysis of a prototype from Volvo Cars is presented in this chapter. The results of an HTA and a function-mean tree are presented to explain the system from a dismantled point of view. User experiences in the previous user study is also illustrated through different UX-curves created based on an interpretation of the video data.
- Chapter 5** *Design Guidelines*
This chapter presents different design guidelines for the concept development created based on the data collected in the studies described in Chapter 2, 3 and 4. The purpose of the guidelines is to create a framework for the concept development, and against which one could evaluate the final concept.

- Chapter 6** *Concept Development*
Through an iterative process with a rapid prototyping approach, different ideas were developed. In this chapter the different ideas are presented as well as the different methods used. Through an expert review, four HMI concepts were animated for further testing.
- Chapter 7** *User Study*
The chapter provides the description of four concepts and their different design elements together with the results from a user study that was conducted to determine how the concepts were perceived by users.
- Chapter 8** *Final Concept*
The chapter describes the development of and the final concept together with an internal evaluation. The process of creating the final concept with Unity and After Effects is presented.
- Chapter 9** *Final Evaluation*
This chapter describes the expert study that was conducted by presenting the final concept in a VR environment. Both qualitative and quantitative data was collected and is presented in this chapter.
- Chapter 10** *Discussion*
The chapter provides a discussion about the process in terms of the methods and their effects on the results. This chapter also covers discussions of social dilemmas like acceptance, ethical and sustainability considerations.
- Chapter 11** *Conclusion*
The chapter presents the most important conclusions based on the results from this project.



**LITERATURE
STUDY**

2. Literature Study

The literature study was conducted by gathering knowledge on subjects related to transition from AD to MD. This section presents the procedure of the literature study as well as the main take-away from interesting articles.

2.1 Method

To conduct the literature study, multiple articles were examined, most of which were gathered from experts. A selection of different articles was carried out by choosing the most relevant articles for this thesis project. Literature was also found through search engines like Chalmers Library and Google Scholar where key words like 'automated vehicles', 'UX in AV', 'Levels of automation' and 'Transition from AD to MD' were used. Some articles were also found through the reference list from other articles. Google was also used to find the international standard J3016 from the Society of Automotive Engineers.

The literature was then gathered in a software called Zotero where the articles were structured in folders and stored in the Cloud. When reading the articles, titles and keywords were first examined. The abstract and conclusion were further scanned to determine if the article was still relevant. Furthermore, tables and figures were reviewed which was followed by a scrutinized observation of the introduction, result, discussion and finally the method. The reading of the articles stopped as soon as the content was judged to provide no further value to the topic. Throughout the reading session, interesting sections were highlighted to be discussed later in the process.

2.2 Results

The main topics for the literature study were the levels of automation, the transition from AD to MD, and the HMI.

2.2.1 Level of Automation

There are five levels of driving automation according to the international standard J3016 (Shi, Gasser, Seeck, & Auerswald, 2020). The automation levels reach from 0 to 5 where level 0 does not have any automated driving system (ADS) at all, and level 5 has a fully developed vehicle autonomy. Due to legal, ethical, and technological barriers, the implementation and advancement of fully AVs is expected to develop over many years (Malik, 2020).

The levels of automation according to the international standard J3016 can be seen in Table 1.

Table 1. Level of Automation

Level 0	Level 1	Level 2	Level 3	Level 4	Level 5
No Driving Automation	Driver Assistance	Partial Driving Automation	Conditional Driving Automation	High Driving Automation	Full Driving Automation

A Level 1 vehicle normally has adaptive cruise control (ACC) which means that the vehicle has longitudinal motion control to keep distance from the car in front of it. Most cars today that are sold and operated on the roads are of Level 2 automation, which means that they have a partial driving automation often called advanced driver assistance system (ADAS), where some functions are automated, such as following a lane or keeping the distance from the surrounding traffic. In a Level 2 system the driver is responsible for when the autonomous functions are 'on' or 'off' and to intervene at any time if necessary (Shi et al., 2020). In automation Levels 3 to 5, the ADS is smart enough to drive completely on its own. For the ADS in Level 3, the user is responsible and must drive if the ADS system requests a dynamic driving task fallback (DDT fallback), which means that the ADS hands over the driving task to the driver. However, in Levels 4 and 5 the user is not obligated to respond to the hand-over request. For both Levels 3 and 4 automation the car can drive autonomously only if all required conditions are met, whereas with Level 5 automation the vehicle can drive autonomously under all conditions. The driver in a Level 3 to 5 automation vehicle can decide whether they want to activate or deactivate the ADS.

2.2.2 Transition from AD to MD

The transition from AD to MD is the process from when the ADS system is deactivated, and the DDT fallback brings the DDT (dynamic driving task) back to the user for them to drive the car manually (Shi et al., 2020). There are different scenarios or use cases for the DDT fallback depending on whether the ADS system is of Level 3, Level 4 or Level 5 automation. The DDT fallbacks, also called handovers, can be divided into five types depending on what causes the handover (McCall, o.a., 2019):

- Scheduled handover
- Non-scheduled system-initiated handover
- Non-scheduled driver-initiated handover
- Non-scheduled driver initiated-emergency handover
- Non-scheduled system-initiated emergency handover

This thesis focuses mostly on the non-scheduled system-initiated handover. The non-scheduled system-initiated handover happens when the operating vehicle reaches beyond its ODD (Operational Design Domain) and functional limits, for example if the traffic situation changes suddenly (Malik, 2020). The user is thus requested to regain control of the DDT even if they are not prepared for it. Some concepts in this thesis will use ideas based on a scheduled handover, which means that the vehicle knows beforehand when the handover will take place and can thus alert the user earlier on (Malik, 2020). The emergency handovers happen due to for example ADS failure; however, it does not necessarily mean that the DDT must be discontinued. Nevertheless, the ADS will request a handover for the user to take back the DDT or put the car in a minimal risk condition if the conditions for the DDT are not met.

A vehicle with Level 4 automation has a high level of driving autonomy and can drive completely autonomous, and the driver is not responsible to be ready for a fallback when the ADS are active. However, the ADS may prompt the (now) passenger positioned in the driver's seat to start driving manually again if the conditions change so that the ADS are no longer allowed. Other examples could be if the ADS fails to perform the DDT, see Figure 2, or if it leaves the ODD, see Figure 3. If the passenger does not respond and performs the DDT fallback in time, the ADS will perform the DDT fallback and put

the car in a minimal risk condition automatically. The minimal risk condition is a stationary condition that the user or the ADS puts the vehicle in after performing the DDT fallback, to reduce the risk of a crash when the ADS cannot continue the intended trip in a safe manner (Shi et al., 2020).

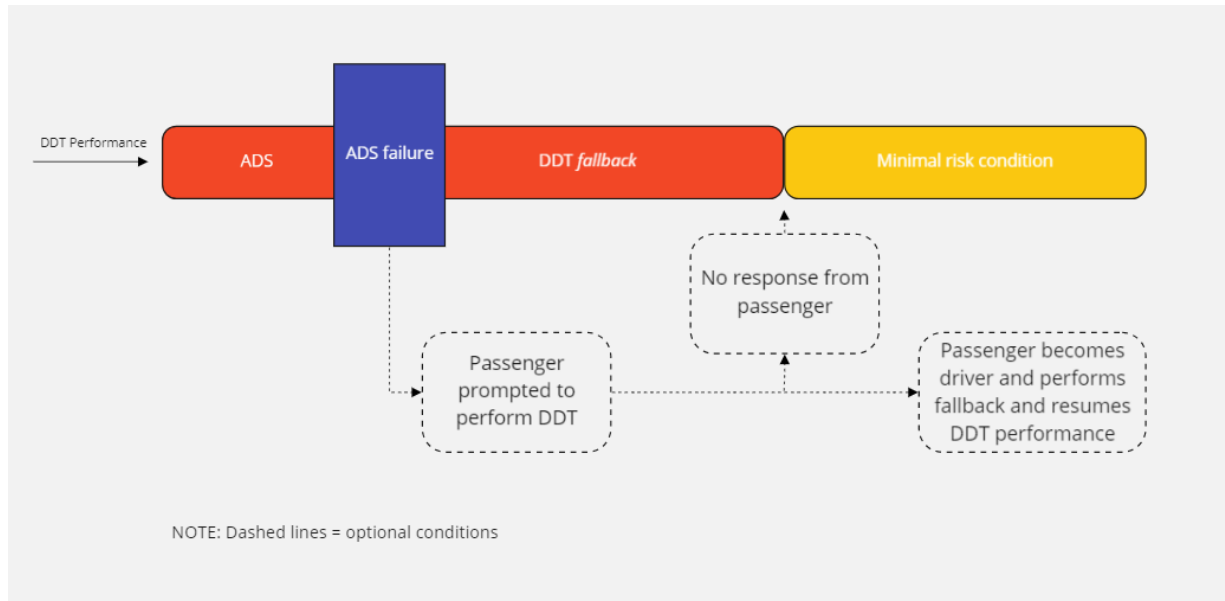


Figure 2. Explanation of a level 4 scenario where the car prompts the passenger to perform a DDT fallback because of an ADS failure. If the passenger does not respond to the prompt, the car automatically enters the minimal risk condition. The figure is inspired by an illustration from (Shi et al., 2020).

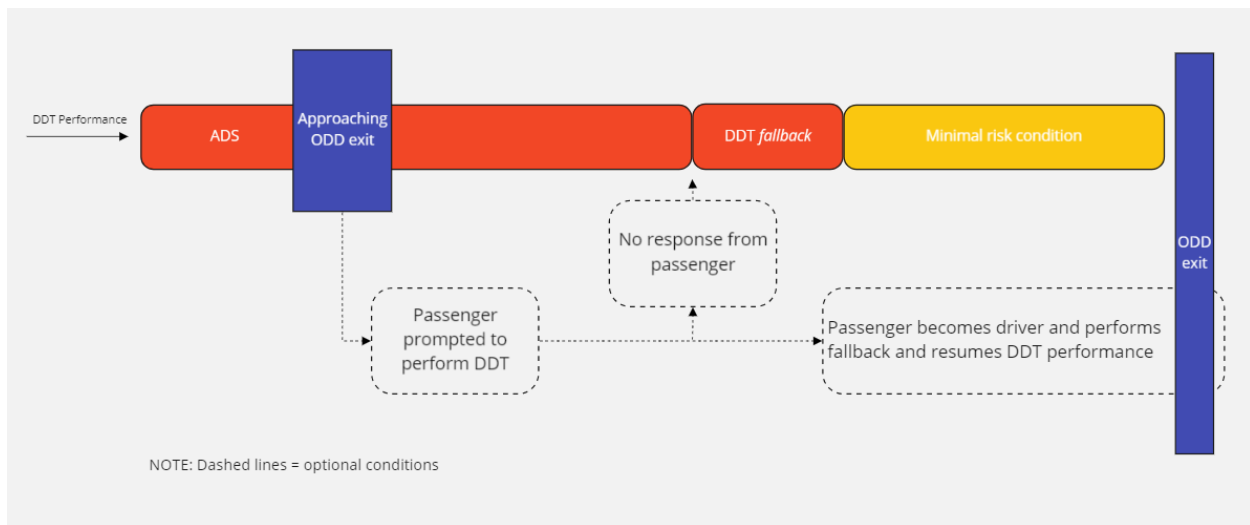


Figure 3. Explanation of a level 4 scenario where the car prompts the passenger to perform a DDT fallback because it is approaching the end of the ODD. If the passenger does not respond to the prompt, the car automatically enters the minimal risk condition. The figure is inspired by an illustration from (Shi et al., 2020).

A Level 5 system may also have the option to leave the DDT to the user and in such case the user may initiate the DDT fallback manually. A Level 5 system should function without asking the driver to

intervene if an ADS failure occurs and will in such case put the car in a minimal risk condition automatically.

2.2.3 Design of HMI

The ADS must provide sufficient information to make sure that the user trusts the automation, that they have enough situational awareness (SA), and that the timing of the hand over requests is interpreted positively (Malik, 2020). The timing of the takeover requests needs to correlate with the drivers' preferred situational driving behavior, to change the driving mode comfortably (Kutchek & Jeon, 2019).

As vehicle automation becomes more advanced, the need for new interfaces that inform the user of the automation state gets increasingly important (Muthumani, Diederichs, Galle, Schmid-Lorch, & Forsberg, 2020). As the autonomy advances, the more important it becomes to increase the transparency between the human and the vehicle. Furthermore, it is important to communicate the responsibilities and tasks for the driver in a distinct manner (Muthumani et al., 2020). The steering wheel and the area in front of the driver seem to be a good place to place visual cues of high importance. If the state and limitations of the AV are effectively communicated to the driver, the user may trust the vehicle and learn to accept new autonomous driving behaviors. However, trust and acceptance come with more driving experience, and it may therefore take some time for new AVs to be fully accepted.

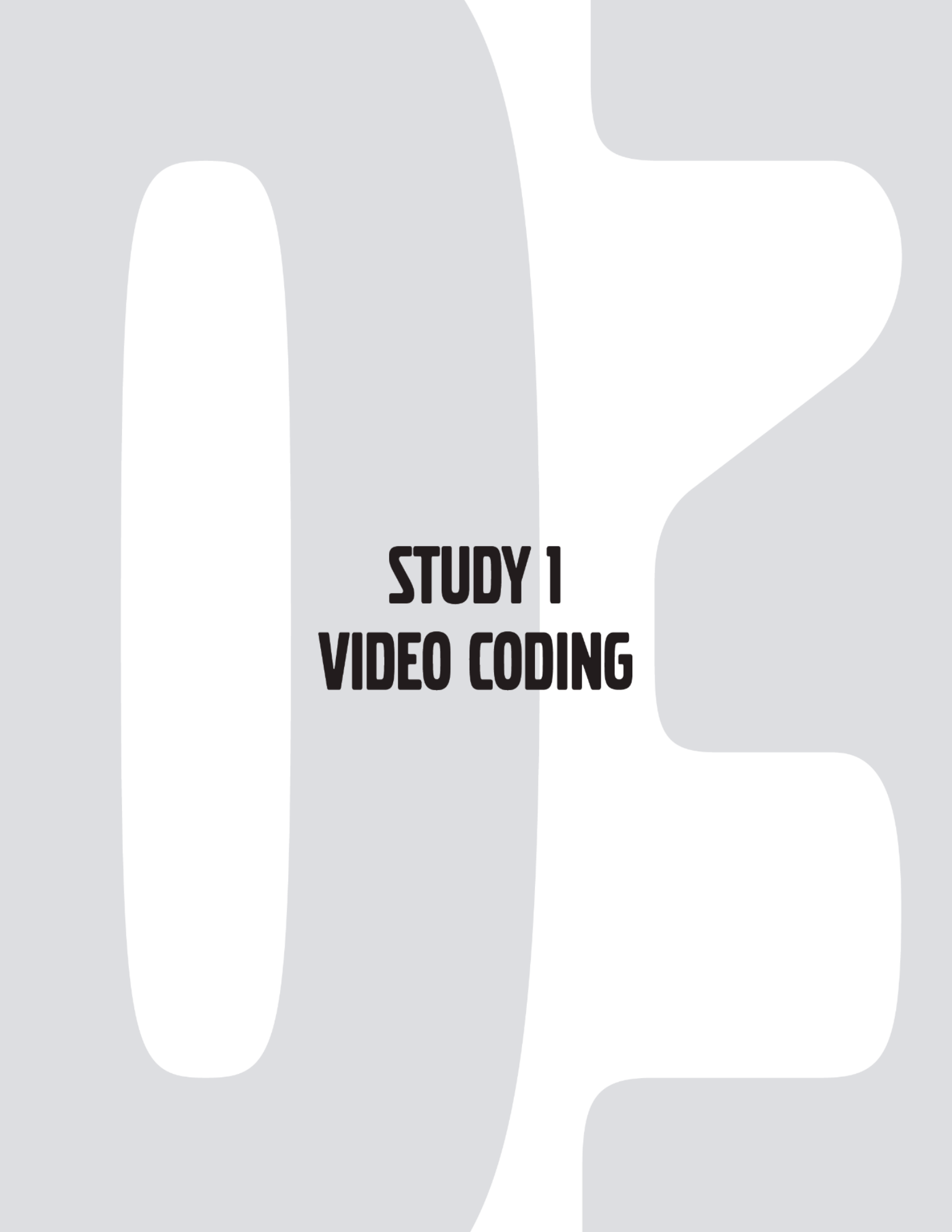
DDT fallbacks or hand-over requests currently require almost instantaneously interventions from the user (van der Heiden et al., 2017). The fallback system used in Tesla model S has a short alert and then it hands over the control to the driver. This could be stressful or lead to fatal accidents if the users do not have enough situational awareness and time to disengage from their secondary tasks while in autonomous drive (van der Heiden et al., 2017). The non-driving related tasks (NDRT) while being in autonomous mode will capture more of the user's attention as the autonomous technology matures, and as the autonomous mode can be active over longer periods of time. As the AV functionality continues to improve, users will gain more experience of the system and today's NDRT may become the primary tasks in the future. This may lead to challenging situations when users have to shift their focus back to the driving when the car asks them to take over (van der Heiden et al., 2017).

An earlier study showed that some study participants were continuously engaged in their secondary task for several seconds after they heard the auditory signal for the takeover event (Kutchek & Jeon, 2019). It could therefore be important to design auditory signals that are attention drawing and somewhat annoying for the takeover event in a high urgency situation. Short and traditional auditory display signals are effective, whereas auditory voice has been proven less effective in communicating urgent situations (Kutchek & Jeon, 2019). Aspects to consider that influence the perceived urgency can be the intensity and the frequency of the alerts (Malik, 2020).

To prevent stressful and potentially dangerous situations during the hand overs, Pre-alerts have been proven successful to use before the handover phase starts (van der Heiden, Iqbal, & Janssen, 2017). Studies show that by using Pre-alerts the users looked more at the road before the handover occurred and the users had time to disengage from the NDRT a lot earlier which led to safer handover situations (van der Heiden et al., 2017). When designing solutions for the Pre-alerts, it can be effective to mediate a sense of urgency to get the users' attention. However, users might be annoyed if too much urgency is mediated through the signals (van der Heiden et al., 2017). It could therefore be positive to use both auditory and visual signals for the Pre-alerts to inform the user about the reason why it is initiated and

what actions they have to take (van der Heiden et al., 2017). Many studies claim that using multimodal alerts are effective at getting the users' attention during the takeover request compared to only using unimodal alerts, where only one type of information channel is being used. This is important especially for users involved in NDRT content (Malik, 2020). As multimodal alerts result in faster reactions, the best type of alerts is a coordinating combination of audio, visual and haptic alerts (Malik, 2020).

Another form of Pre-alert or Pre-notification before the handover is called lead time. Lead time represents the time until the system reaches its limits, in the event of an obstacle or a collision (Malik, 2020). Studies show that a minimum of 5 seconds of lead time is needed for a successful handover. As longer lead times are beneficial, a lead time of 7 seconds increases the safety and quality of the handover compared to 5 seconds. People tend to trust in the system when a longer lead time is used compared to when 2 seconds of lead time were tested. One study recommended 10 seconds or longer for the lead time, even if it necessary did not lead to a more successful handover (Malik, 2020).

The background features a light gray field with several large, white, rounded shapes that resemble stylized letters or abstract forms. These shapes are positioned around the central text, creating a modern, minimalist aesthetic.

STUDY 1
VIDEO CODING

3. Study 1 Video Coding

Video recordings from the previous study conducted by Volvo Cars (the San Francisco Bay Study) was studied to examine how the transition from AD to MD was interpreted by the participants (drivers). The aim was to gather qualitative data from the participants that was related to the transition, such as emotions, opinions, behavior, usability, and understanding.

3.1 Method

Video recordings from the previously conducted study by Volvo Cars were analyzed in two rounds using a software called NVivo. The video coding was conducted by highlighting different timeframes with a set of pre-determined terms. First, the video coding was conducted by four people using predetermined codes. The recordings of 16 participants, 7 females and 9 males, around 90 minutes each, were analyzed. The goal was to answer the following questions: What should be changed or is missing in the HMI, to make the user experience better? What are the signals the user perceives during the transition? How do users understand and experience the cues?

The second round of analysis is called deep coding and was conducted by going through each of the video recordings again to highlight more specific parts of the videos regarding the transition itself. The aim was to determine the participants' interpretations and experiences of the transition. When both sessions were conducted, a thematic analysis was carried out to structure the codes into new and more precise subcategories. The purpose was also to find themes that would give a better overview of how the users perceived the transition.

3.1.1 The San Francisco Bay Study

The San Francisco Bay Study was part of a thesis project conducted by a group of postgraduate students from Chalmers. The study was conducted in 2019 at the San Francisco Bay Area where different participants were observed while driving in a modified XC90. While driving, the participants were offered the opportunity to try different functions such as the Level 2 Pilot Assist (PA) and the Level 4 Traffic Jam Pilot (TJP) which is an Autopilot system. During a 90-minute session that followed the route seen in Figure 4, participants were recorded while being asked different questions to investigate their understanding of the system. In total, 20 participants were involved (Novakazi, 2020).

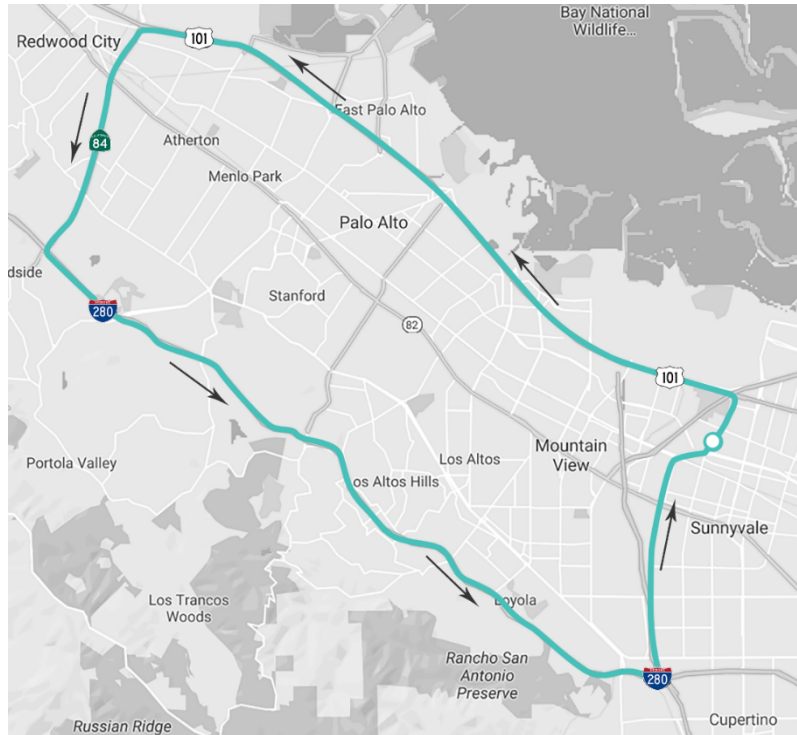


Figure 4. The Route of the Study (Novakazi, 2020).

The setup used multiple information channels to communicate information. The instrument cluster display (ICD) was placed behind the steering wheel and was used as the primary information screen during the transition. The center stack display (CSD) was placed in the middle of the dashboard and was used for secondary information and non-driving related content. The system also used audio cues, including both sounds and voice messages. Haptic feedback was also used in terms of a tugging seatbelt and physical buttons on the steering wheel which were used to activate or deactivate the system.

Figure 5 presents the different information channels used during the transition. “A” represents the visual cues during the takeover, i.e., through the ICD and the CSD. “B” represents the haptic cues used during the transition, i.e., through the seatbelt and the takeover-buttons on the steering wheel. Finally, “C” illustrates the audio signals used during the transition, i.e., voice and sound through loudspeakers.

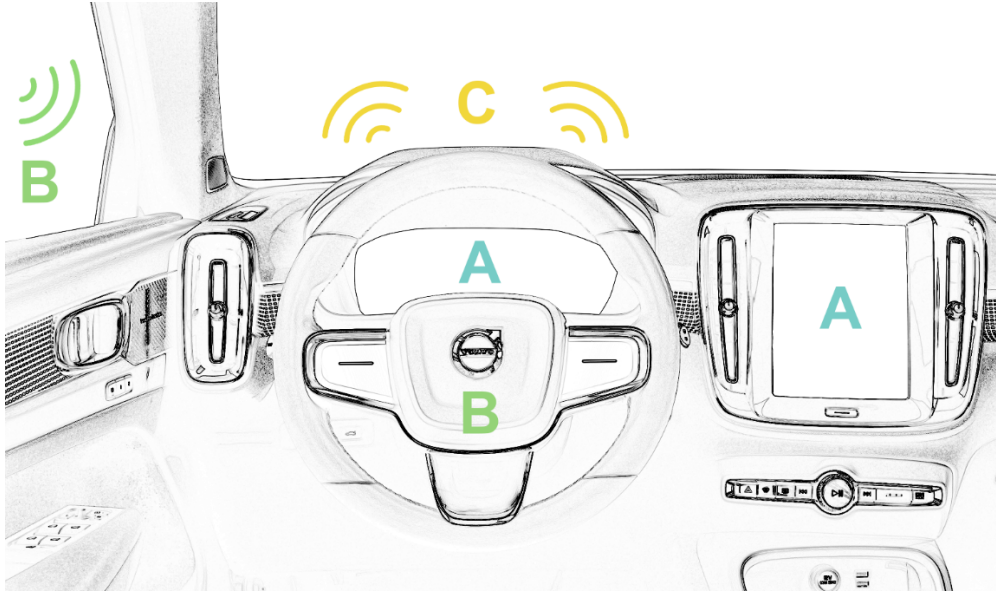


Figure 5. Information channels from the San Francisco Bay study. A represent the visual cues, B represent the haptic cues, and C represent the audio cues.

The transition from AP to MD lasted for 10 seconds and had an escalation point after a few seconds where the intensity and frequency of the signals increased. If the user failed to deactivate the system within 10 seconds, the cues would repeat until the user successfully managed to deactivate it. However, in a real AV the vehicle would perform a minimum risk maneuver (MRM), by pulling over to the side of the road.

3.1.2 Video Coding

The video coding was conducted by following a predetermined codebook which was created together with the other coders. The data coding was mostly following a deductive top-down approach where the topics for the codes were predetermined before looking at the video recordings (cf. Braun & Clarke, 2012). The coding hierarchy that was used while video coding can be seen in Figure 6.

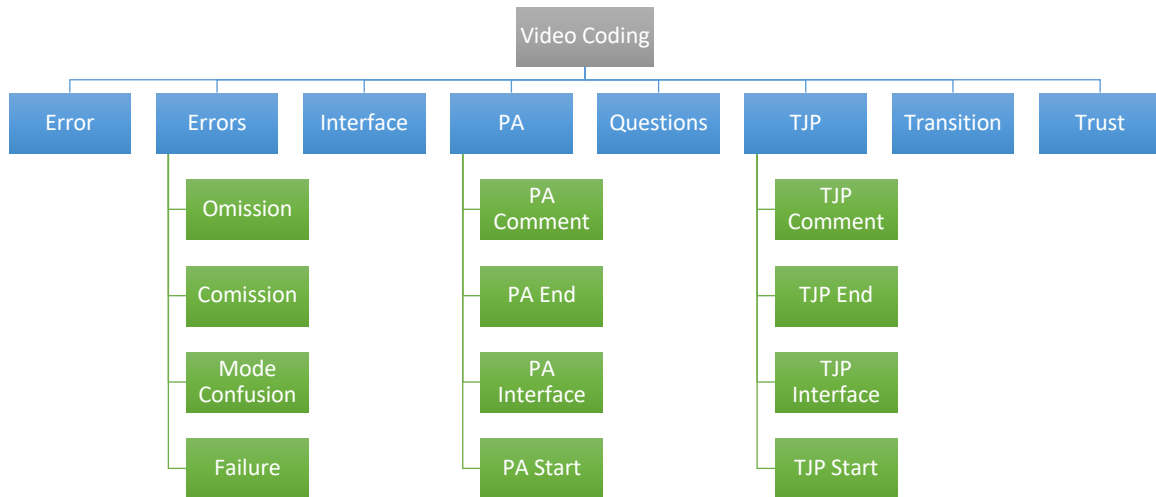


Figure 6. Coding hierarchy, explaining the coding structure for the video coding.

Sixteen of the 20 recorded video sessions from the San Francisco study were used for the video coding in the software NVivo. Four other video recordings fell out as they were either encrypted or missing. The video coding was conducted in a distributed and collaborative manner with four people including the master thesis project supervisors (Figure 6). To make sure that the codes from the codebook were used in the same manner, the first two videos were coded together (Figure 7).



Figure 7. Video coding conducted together with four people.

The coding session was then performed individually and was carried out until all 16 videos from the study were decoded. To prevent people from working on the same video material, a shared spreadsheet in Excel was created to claim and update the status of each video recording.

Accordingly, an interrelated reliability test was conducted to test the consistency of the coding between each coder. This was important to ensure that the videos had been coded in a similar manner. If this was the case, it would increase the reliability of the data collected from the videos (Lombard, Snyder-Duch, & Bracken, 2010). The procedure of the reliability test was conducted by the four coders coding the same video separately. Through an integrated calculator in NVivo, a coefficient 'Kappa' was calculated. The reason for choosing the Kappa coefficient was simply due to it being the most common coefficient for calculating the reliability of such a test (Lombard, Snyder-Duch, & Bracken, 2010). Each of the separately coded video would then be merged in NVivo before calculating the mean value of the Kappa coefficient. The mean value of the Kappa coefficient was calculated to 0.62 between all coders, with an interval between 0.61 – 0.80 which is defined as substantial reliability (McHugh, 2012). The result was therefore interpreted reliable enough to proceed with the rest of the coding. The full summary of the result from the inter-reliability test can be found in **Appendix A**.

3.1.3 Deep Coding

The second step of the analysis followed with a deep coding session. By narrowing down the scope and focusing more on the transition from AD to MD, a new codebook was created. Some codes from the previous codebook remained though to give more value for future work.

The codes that remained were the 'TJP Comment' and 'TJP End'. These codes were divided further into different categories. 'TJP Comment' was divided into 'Confusion', 'Interpreted Cues', 'Negative', 'Positive' and 'Suggestions'. Each of the different sub-codes for 'TJP Comments' were then divided into 'Auditory Display', 'Auditory Voice', 'Center Stack Display', 'Driving Behavior', 'Instrument Cluster Display', 'Seatbelt', 'Steering Wheel', 'Takeover-buttons' and 'Others'. 'TJP End' was divided into 'Errors', 'Reaction Transcript' and 'Reaction Video'. The reason for the reactions being divided into transcript and video was due to encrypted video files. The 'Errors' focused on the errors that occurred during the takeover only, and were divided into 'Commission', 'Omission', 'Failure' and 'Mode Confusion'.

Some of the video materials did not sync well with the transcript from the participants. The verbal reactions were therefore coded in the 'Reaction Transcript' while the physical reactions, like body language and non-verbal expressions, were coded in the 'Reaction Video'. Both 'Reaction Transcript' and 'Reaction Video' were coded similarly with inspirations from Plutchick's Wheel of Emotions (Arnau-Gonzál, Katsigiannis, Arevalillo-Herráe, & Ramzan, 2021).

In Plutchick's model of human affect, Plutchnik categorizes emotions in three categories: primary, secondary, and tertiary emotions. The primary emotions are anger, disgust, sadness, surprise, fear, joy, trust, and anticipation. The emotions in the new codebook were therefore 'Anger', 'Anticipation', 'Confusion', 'Disgust', 'Fear', 'Joy', 'Sadness', 'Surprise', 'Trust' and 'Other'. The purpose of having predetermined codes of emotions was to have some guidelines when analyzing the reactions from the participants. The full codebook from the deep coding session can be seen in Figure 8.

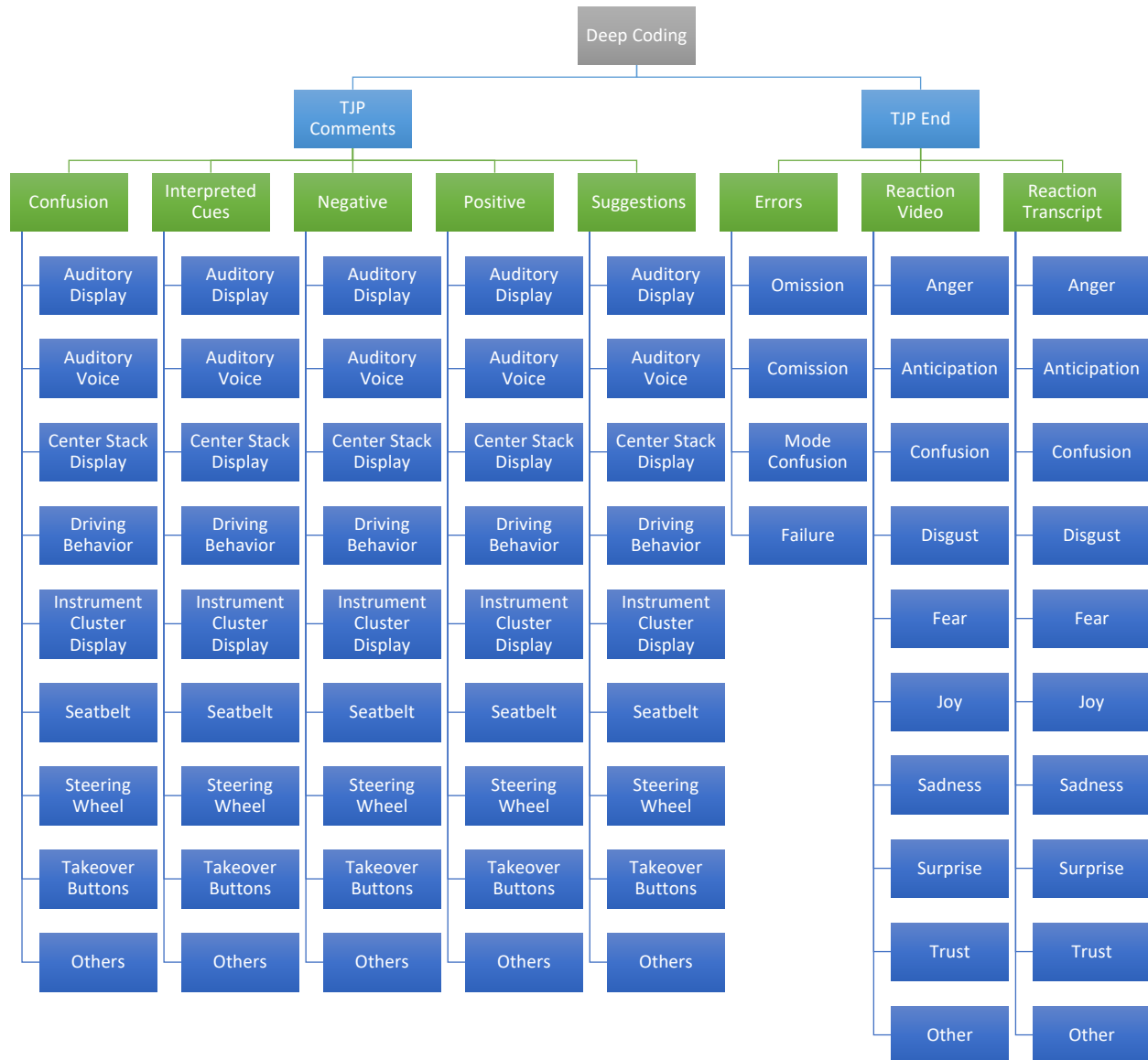


Figure 8. Coding hierarchy, explaining the coding structure used when deep coding.

3.1.4 Thematic Analysis

To analyze the comments collected from the deep coding, a thematic analysis was conducted. A thematic analysis was considered a suitable method to use to organize, identify and find insights in the data that were analyzed (Braun & Clarke, 2012). The codes were first imported to Excel and the codes that were not specifically about 'TJP End' were sorted out. When the first clustering was complete, the second step was to import the selected codes into Miro for further clustering and analyzing. The four major areas that were analyzed were the 'TJP End Comments', 'Video Reactions', 'Transcript Reactions' and 'TJP End Errors'. The thematic analysis was mostly following an inductive approach which could be compared with a bottom-up approach, i.e., the themes and clusters that were mapped were closely related and based on the empirical data (Braun & Clarke, 2012).

3.2 Results

The result from the thematic analysis is presented in this section, with explanations of the codes from the video coding. The clusters provide a representation of the experiences and user opinions about the different information channels of the automated system. The video and transcript reactions are presented together and are divided in the sub-categories 'Positive', 'Negative', and 'Mixed'. The reaction codes focused on the emotional reactions during the transition. Any errors made during the takeover are also presented in this section. The results gave valuable knowledge about the automated system and how the participants experienced the transition. The complete thematic analysis and the included codes can be found in **Appendix B**.

3.2.1 Information Channels

The codes for the Information channels in the vehicle were divided in the sub-categories 'Auditory display', 'Auditory voice', 'CSD' (Center Stack Display), 'ICD' (Instrument Cluster Display), 'Seatbelt', 'Takeover-buttons', and 'Other'. The "x" (times) in the figures in this chapter represent how many codes that were placed in the respective clusters.

Auditory Display

The Auditory display signal was proven to be very effective in getting the participants' attention. Some explained that the audio signal made them look at the visual displays. However, the signal was also interpreted as unclear, sharp, and inexplicit, and made the users not aware of what action to take after hearing the signal. Some users explained that the timing of the signal was bad, and that the volume was too low to wake someone from a sleeping state. Some suggested a higher volume of the signal in that case. The themes of the auditory display codes and their clustering structure can be seen in Figure 9.

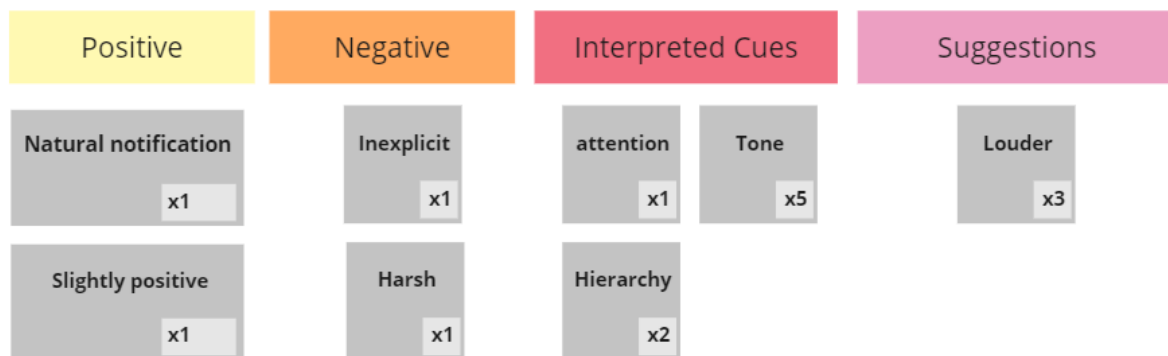


Figure 9. Results of the thematic analysis, showing the themes and clusters of the Auditory display codes.

Auditory Voice

Regarding the Auditory Voice, the voice command caught the attention of many participants. However, it was not clear if the message was understood as some participants forgot what the system told them to do (indicated with the code 'Memory Loss' in Figure 10). Some appreciated the voice command as it clarified what they were supposed to do while others thought the timing was poor and that it should be less assertive. It was also mentioned that the Auditory voice lacked a command for deactivating the automated system which may have led to some confusion of what to do. Some participants wanted it to

be clearer on which driving mode that was active and suggested the use the voice command to clarify this. The themes of the auditory voice codes and their clustering structure can be seen in Figure 10.

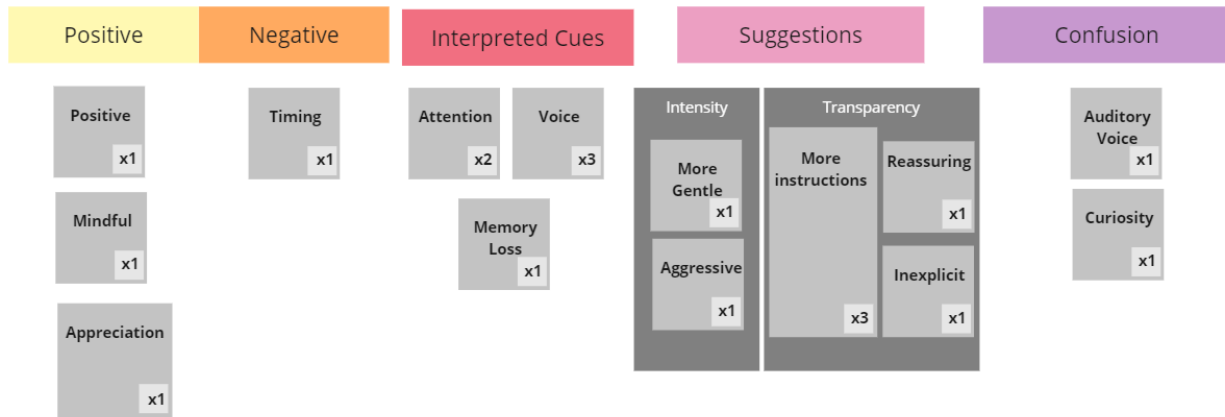


Figure 10. Results of the thematic analysis, showing the themes and clusters of the Auditory voice codes.

Center Stack Display (CSD)

There were not many comments on the CSD, although two participants mentioned that they looked at the CSD as their first reaction when they heard the audio signal, since the screen was bigger. The themes of the CSD can be seen in Figure 11.

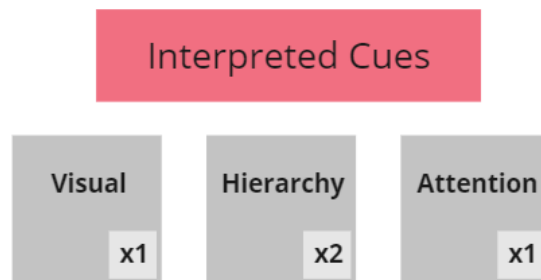


Figure 11. Results of the thematic analysis, showing the themes and clusters of the center stack display codes.

Instrument Cluster Display (ICD)

Many participants reacted strongly on the yellow color of the interface in the ICD. It is however not clear if they interpreted the signals from the ICD in a correct manner. The information in the ICD was understood first after the auditory display or the seatbelt caught their attention. It does however seem like the only information channel that explicitly clarified what to do was the ICD. The themes of the ICD codes and their clustering structure can be seen in Figure 12.

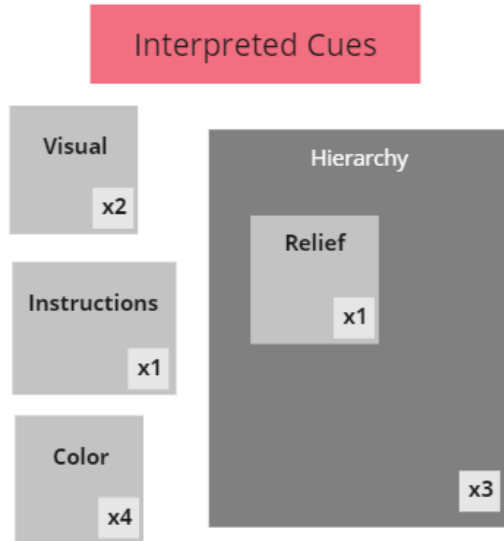


Figure 12. Results of the thematic analysis, showing the themes and clusters of the instrument cluster display codes.

Seatbelt

The seatbelt was excellent at catching the drivers' attention, but not necessarily effective at making them act in the right manner. The cue was interpreted as aggressive and was associated with danger and fear since some participants associated the signal with unpleasant experiences like hitting the brake or being in an accident. Since the users did not understand the cue and found it rather abstract, they started to question the reason why the signal was activated in the first place. Some suggested a gentler and more comfortable haptic signal for the seatbelt, like vibrations or less aggressive tugs. Some considered the seatbelt signal to be strong enough to wake someone from a deep sleep, while others thought the opposite. The themes of the seatbelt codes and their clustering structure can be seen in Figure 13.

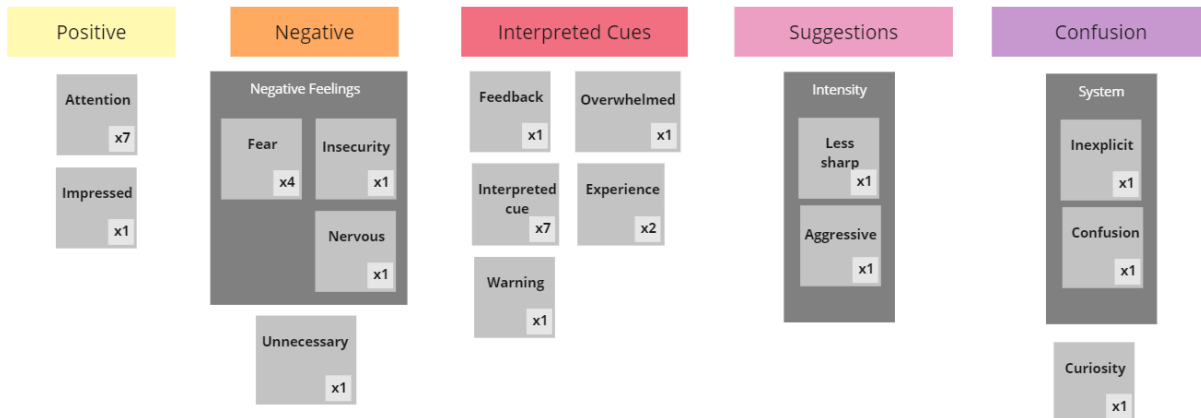


Figure 13. Results of the thematic analysis, showing the themes and clusters of the seatbelt codes.

Takeover-buttons

The Takeover-buttons were not very intuitive as some participants considered them inexplicit and confusing. Some also had the urge of hitting the brake instead of pushing the buttons when taking over,

which they were told not to do as it could potentially ruin the system. For some, the instruction for pushing the buttons was unclear and was not well presented in the ICD. The themes of the Takeover-buttons codes and their clustering structure can be seen in Figure 14.

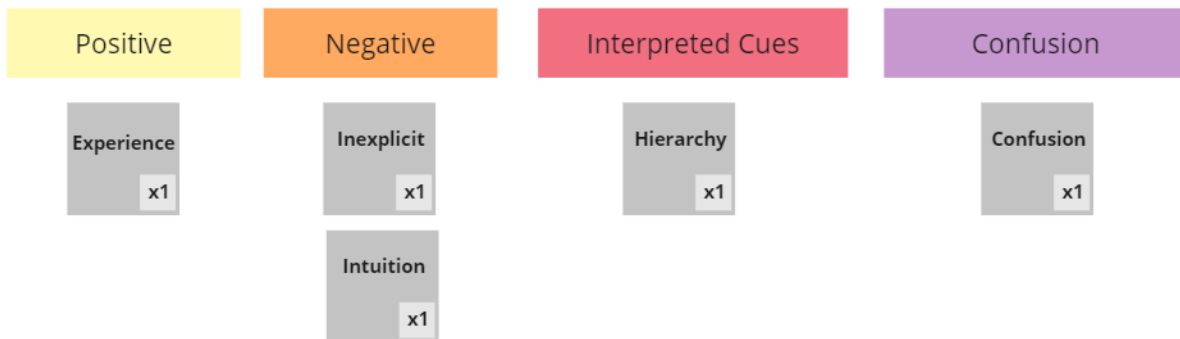


Figure 14. Results of the thematic analysis, showing themes and clusters of the Takeover-button codes.

Other

The Other category includes a mix of different comments. They did not fit the other categories but were still considered important for the transition, see Figure 15.

According to the participants, the transition was interpreted as smooth and they did not feel like it was too cumbersome, like having to stop the car to deactivate the system. The communication of the system was interpreted as unclear, and some wanted more transparency and intuitive instructions on how to act. The participants did not know what to expect from the system and felt that more experience with the system would be needed to be able to trust it and feel more comfortable with the transition. Many felt stressed as the transition procedure felt rushed. More time would therefore have been appreciated to feel more prepared. Since the users did not know when a transition would occur, some expressed that they felt paranoid or self-conscious and that the transition felt random. Furthermore, some participants wondered if the system knew something they were not aware of themselves. One person did not feel like pushing the buttons as (s)he felt distracted while focusing on the road when driving. (S)he therefore suggested a pre-notification and a countdown to deactivate AP.

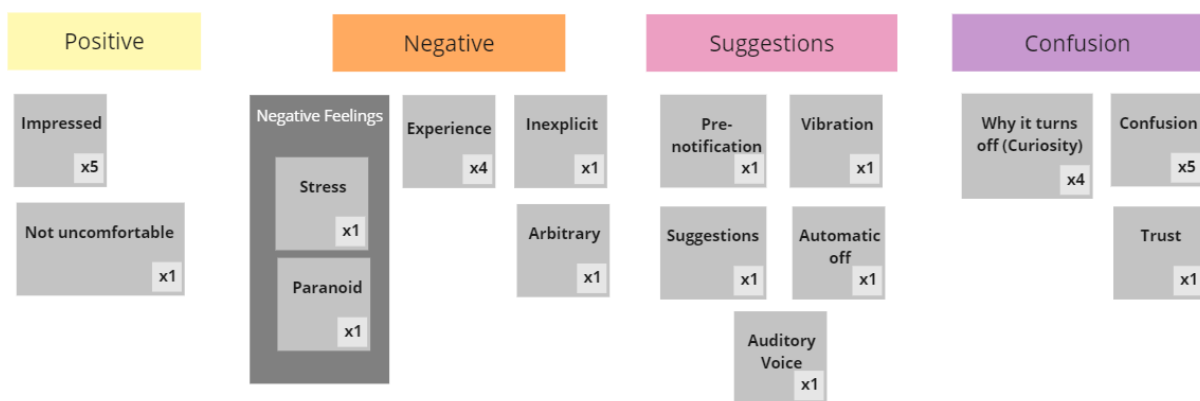


Figure 15. Results of the thematic analysis, showing the themes and clusters of the other codes.

3.2.2 Reactions

The video and transcript reactions during the transition are presented here. The reactions are presented with the sub-categories 'Positive', 'Negative', and 'Mixed'. The reactions were divided in 'Reaction Transcript' and 'Reaction Video'. 'Reaction Transcript' included codes extracted from verbal expressions while the 'Reaction Video' included codes based on the participants' body language and non-verbal expressions.

Positive

The positive reactions extracted from the transcript were few and were mainly based on an overall impression of how good the system performed; some described the system as cool, easy, and well-functioning, see Figure 16. Other positive reactions were noted regarding safety, where some were surprised of how safe they felt and that there was no anxiety involved – except for when they did not understand the system.

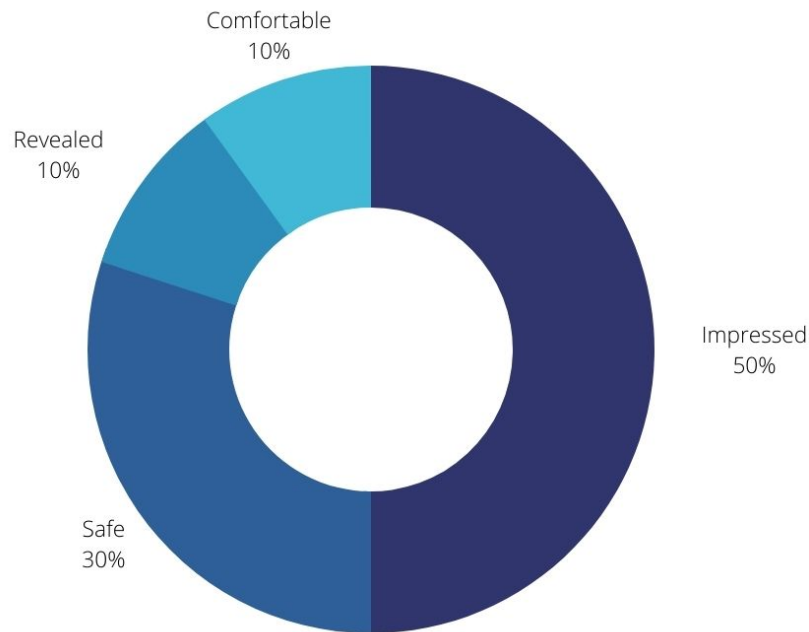


Figure 16. Results of the thematic analysis, showing the themes and clusters that had a positive impact on the experience, based on the codes from the reaction transcript.

Negative

Most of the reactions regarding the takeover involved negative feelings, such as confusion, stress, and fear, see Figure 17. Many expressed that they did not understand how to act when they heard the signal from the auditory display or felt the tugging from the seatbelt. This resulted in incorrect actions such as pushing only one steering wheel button instead of two and holding the steering wheel while expecting the car to take over by itself. Some also expressed a sense of paranoia as they did not know when to expect a signal, which in turn scared them.

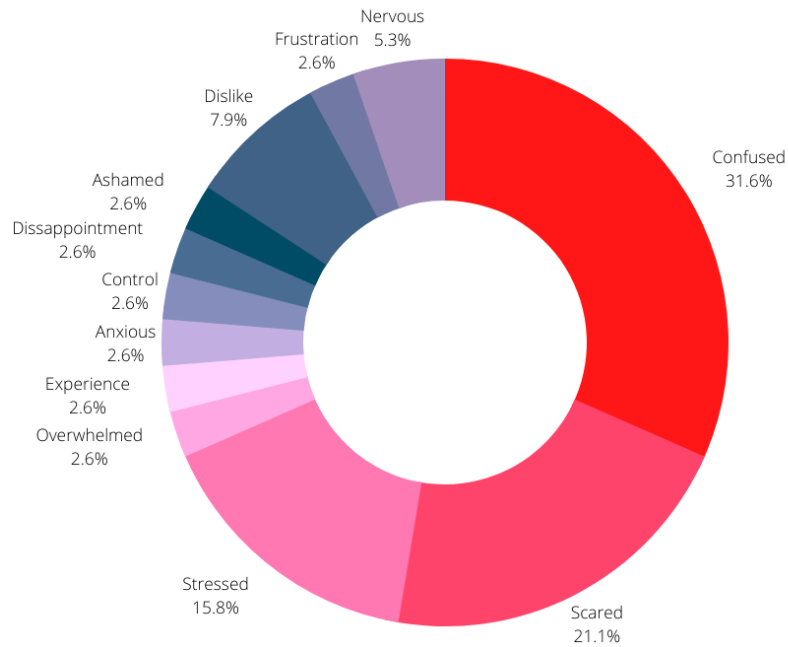


Figure 17. Results of the thematic analysis, showing the themes and clusters that had a negative impact on the experience, based on the codes from the reaction transcript.

Mixed

Overall, many expressed a sense of curiosity of the system. They wondered whether they were the reason for the car to deactivate the AP, whether the traffic caused it, or simply if the supervisors in the vehicle triggered it for them. Some questioned the level of trust that could be put into the system, while others claimed that they needed to familiarize themselves with the system to gain more experience of confidence in the system. Some suggested that the system should be further improved by extending the timespan for taking back control from AP. Others expressed that the transition should be more intuitive. The themes and clusters of the reaction transcript codes that were sorted into the category Mixed can be seen in Figure 18.

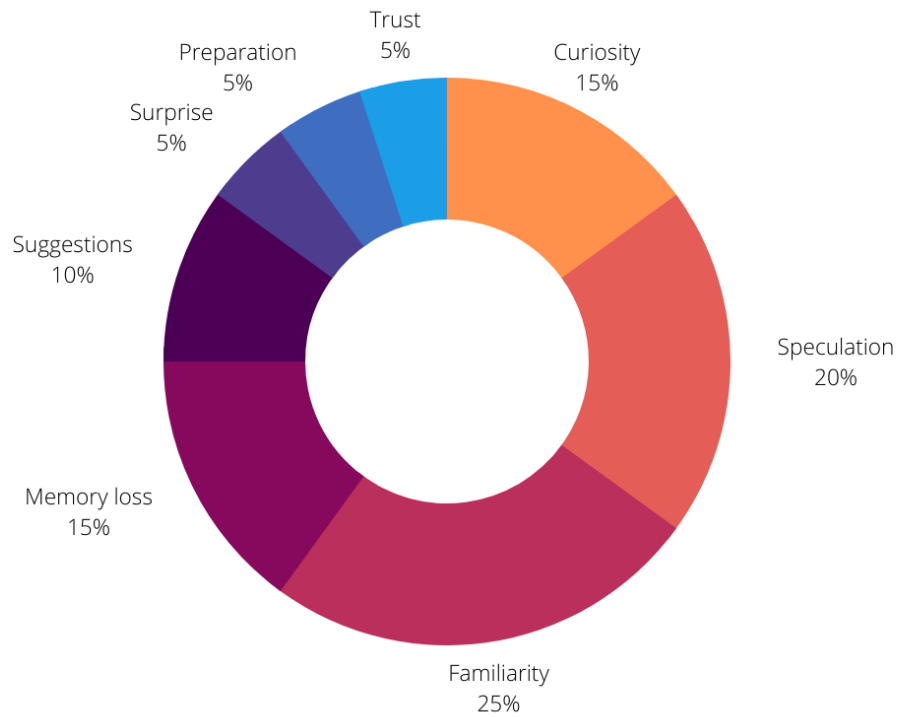


Figure 18. Results of the thematic analysis, showing the themes and clusters with a mixed variety of reactions, based on the codes from the reaction transcript.

For the video reactions, the major themes that were identified were ‘Confusion’ and ‘Memory loss’, see Figure 19. Many participants were constantly forgetting how to act but some participants managed to figure out what to do eventually, although many needed more instructions from the supervisors to deactivate AP. Many participants reacted strongly on the seatbelt and the auditory display signals. The reactions were mainly negative, and they were either surprised or scared by the signal, which could be seen from the body language when the takeover notifications initiated. Some were interrupted when being in a phone call or toggling around in the CSD, which in turn made them more confused when the takeover signal started.

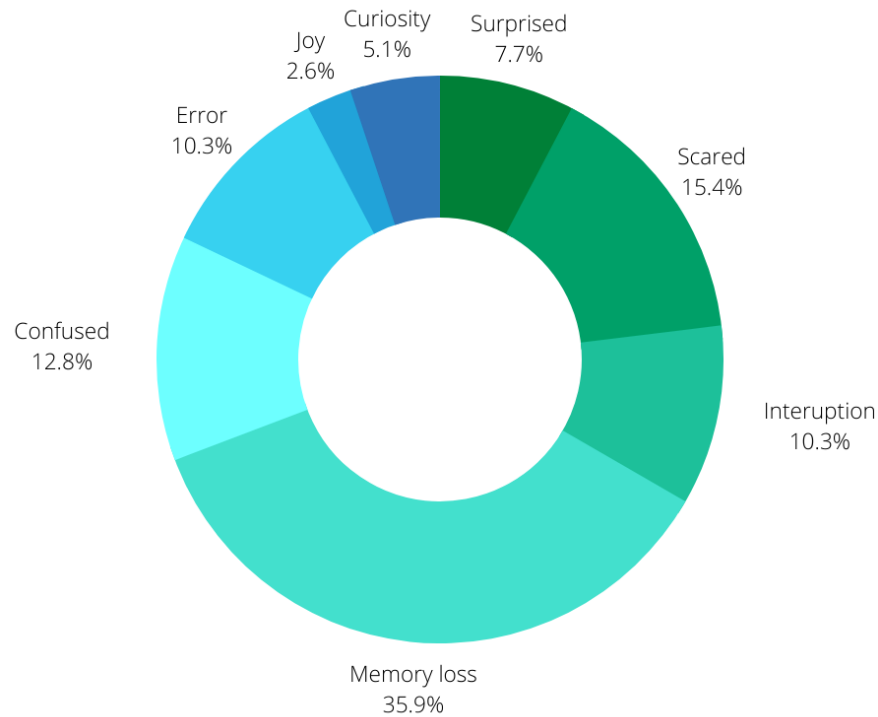


Figure 19. Results of the thematic analysis, showing the themes and clusters from the reaction video codes.

3.2.3 Errors

Errors were examined to see the total number of errors and what types of errors that occurred during the transition from AD to MD. The most prevalent errors were when the participants released the Takeover-buttons for deactivation too early, or when more instructions were needed from the supervisor to deactivate the AP. Other less prominent errors that occurred were 'Omission', 'Taking wrong action', or 'Confusion'. Altogether, there were a total of 46 errors where the 'Early Release Buttons' and 'Instructions Needed' each represented 39 % of the errors, see Figure 20. The 'Omission' and 'Taking Wrong Action' stood each for 9 % while 'Confusion' represented 4 % of the errors during takeover. Worth mentioning is that each error was counted regardless of which participant made the errors or if one and the same participant made more errors than the others.

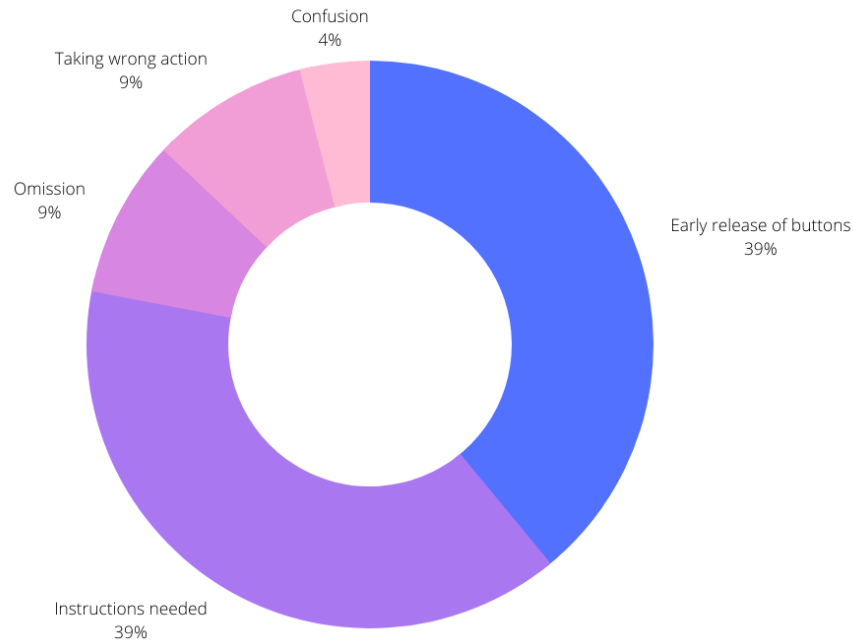


Figure 20. A pie chart showing the percental relation between the different errors that occurred during the transition from AD to MD.

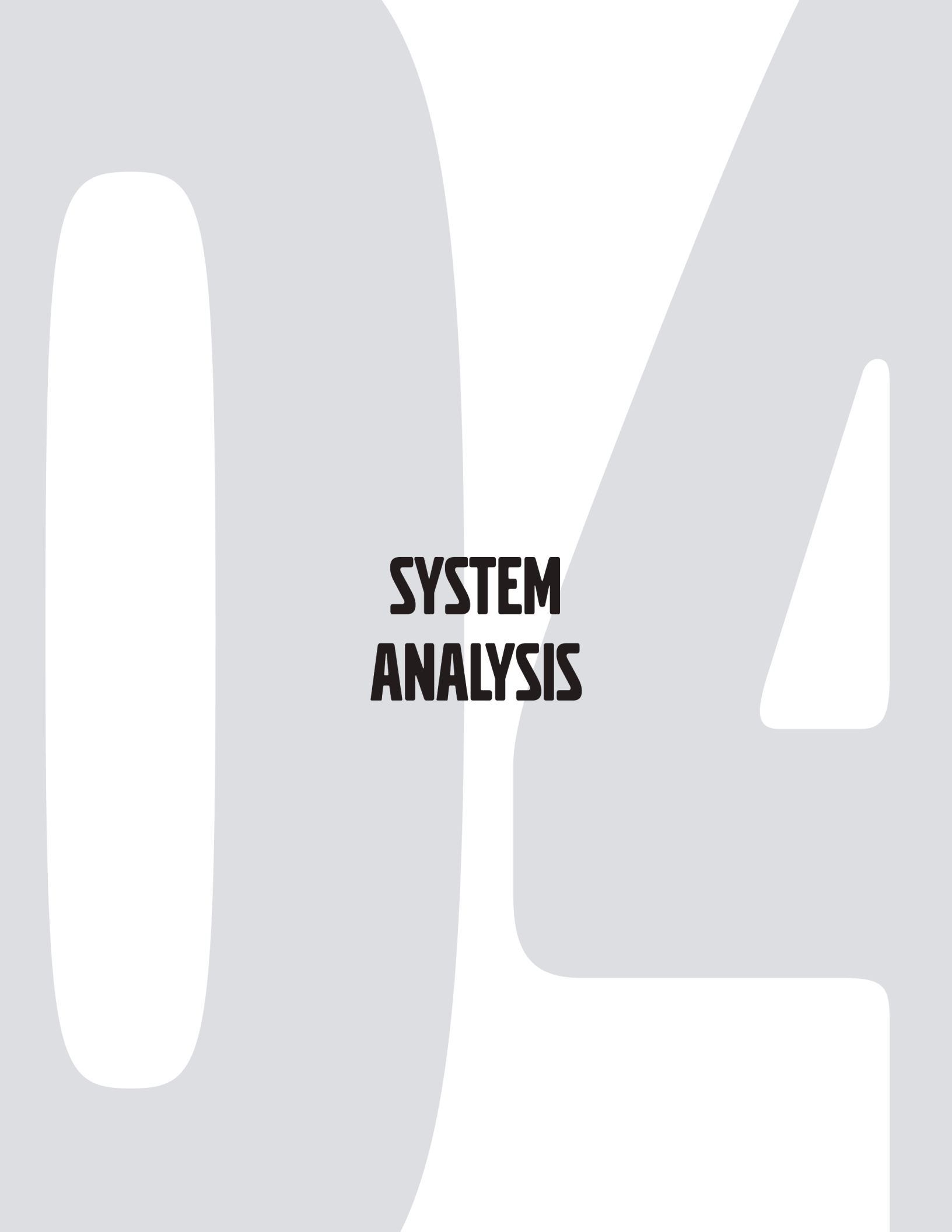
3.3 Summary and Implications

What can be concluded from the video coding analysis, is that the experience of transition was mostly interpreted as negative, which put the participants in stressful and confusing situations. The cues communicated by the automated system was excellent at getting the participants' attention, especially through the seatbelt and the auditory display. However, both the seatbelt and the auditory display resulted in mostly negative responses which seemed to be related to the lack of transparency and intuitive instructions on how to act upon the signals. Other explanations for the negative response seemed to relate to the participants' previous experiences. The tugging seatbelt was especially mentioned; this was interpreted as a warning sign for danger rather than a notification and a cue to act. Many participants needed instructions to complete the transition. The confusion on how to act led to several errors, mostly represented by releasing the deactivation buttons too early or by completely forgetting to press the buttons without instructions.

The timing of the transition was interpreted as random, and many participants started to speculate if the car knew something that they were not aware of themselves. Some participants also wondered if they did something wrong to trigger the transition. Since they did not know what to expect from the automated system, they could not fully trust it, but some mentioned that more experience would increase their acceptance of the system. However, it should also be mentioned that some participants were impressed of how good it felt and was surprised of how safe they felt using during AP.

Furthermore, the user interfaces during the transition managed to catch the driver's attention but did not manage to help the user to act in a correct manner. Finding a solution that notifies the user in a way that breaks through all the noise around the car is important. At the same time, it is important not to

cause any confusion, stress, and fear in the user. There were three ways for the car to catch the user's attention which were through haptic, auditory, and visual channels. The haptic and audio channels seemed to work most efficiently of catching the user's attention, although the information did not explicitly help them understand what to do. It is uncertain however, whether the haptic and audio signals performed better in terms of getting the participants' attention than the visual cues, or simply if the visual cues underperformed in contrast to the haptic and audio signals. The visual cues seemed, on the other hand, to perform better at telling the user of what to do but did not always manage to catch the user's attention. This implies that a combination of, or other modalities may be needed to optimize the car's ability to communicate with the user during the transition.



**SYSTEM
ANALYSIS**

4. System Analysis

A system analysis was conducted in order to further understand the transition and the constituent sub-solutions in a more detailed level (cf. Salmon, Jenkins, Stanton, & Walker, 2010). The goal of the system analysis was to increase the understanding by looking at the system from a different angle. By stripping down the system, two missing pieces have been added to the system which will be presented in this section.

4.1 Method

To complete a system analysis of the concept described Chapter 3, methods like the function-mean tree, hierarchical task analysis (HTA) and UX-curves were used. A function-mean tree was used to increase the understanding of the vehicle's different functions and means during the transition (cf. Robotham, 2002). Means are here referred to as the different parts of the system while the function is referred to the purpose behind each part of the system. The parts or necessary information channels are the means, that are parts of the car's infrastructure, and each mean has its function connected to them on different levels (cf. Robotham, 2002). Through a tree diagram, different means and functions are connected and arranged in a hierarchical manner with the main parts at the top and the sub-parts at the bottom. This method was beneficial to increase the level of understanding of the HMI from the automated system's point of view.

Furthermore, an HTA was conducted to get a deeper understanding of the system from the users' point of view. The purpose of the HTA is to dismantle different tasks of the automated system in a hierarchical manner to reach a certain goal (Salmon et al., 2010). The HTA has become the most used task analysis method since the introduction in the 1960s and was developed as a tool to understand and analyze complex cognitive tasks (Salmon et al., 2010). It was considered suitable for this project as the transition from AD to MD is considered relatively complicated. Through a tree diagram, different tasks are structured with the main goal of the task at the top and the sub-tasks at the bottom. These sub-tasks need to be achieved to reach the main goal at the top.

Finally, a UX-curve was created to estimate a hypothetical impact of improving different parts of the system. The purpose of the using a UX-curve was to get a better understanding of the UX during the different sub-tasks or phases described in the HTA. Based on reactions and emotions from the video coding analysis, various UX-curves were created. This approach to using the UX-curve was slightly modified since normally, users would draw their own UX-curve to explain their experience of using a prototype (Kujala, Roto, Väänänen-Vainio-Mattila, Karapanos, & Sinnelä, 2011). The UX-curve in this project could therefore be considered an interpretation of the feelings from all the users based on the video coding analysis during the transition. This method was used since it illustrated the UX in a clear and understandable way, allowing for more efficient discussions in the project.

4.2 Results

The results from the system analysis are presented here together with the UX-curves that include two supplementary pieces of the system – before and after the takeover procedure - the Pre-notification and the Post-notification. Assumptions were made on how the UX-curve of the transition would be affected with respect to these additional pieces.

4.2.1 Function-Mean Tree

The function-mean tree seen in Figure 21 presents the car's different means and functions during the transition from AP to MD. The means are highlighted in yellow while the functions are colored in blue. Since the tree diagram is structured in a hierarchical manner, the main function of the transition is arranged to the left while the sub-parts to the right. As the system revolves around the transition from AP to MD, the main part of the system consists of the mean 'AP End' with its function 'Give back control'. This means that when AP ends, the purpose is to give back the control to the driver of the vehicle. To do this, the vehicle uses multiple information channels to communicate with the driver. These are the seven (7) sub-means of the system which consist of the 'Auditory Display', 'Auditory Voice', 'Seatbelt', 'Center Stack Display', 'Instrument Cluster Display', 'Takeover-buttons', and 'Steering Wheel'. Each of the different sub-means has a certain function connected to it, like getting the driver's attention or providing instructions etc. Each of the different information channels or sub-means of the system are dismantled into smaller elements. For instance, the 'Seatbelt' was broken down into sub-sub-means like the 'Belt' and the 'Tugging'. In total, there were 12 sub-sub-means with one connecting function each. For instance, the 'Belt' enabled haptic feedback while the 'Tugging' got the driver's attention. The whole diagram can be seen in Figure 21.

The function-mean tree helped to clearly clarify how the system worked and what building blocks were needed. It also clarified what the most important parts of the system and the different functionalities that need to be fulfilled. Many of the different parts of the system fulfilled the same function which means that there are either too many parts included in the system, or that different parts are required to create a coherent and redundant concept. It is clear however that the tree diagram illustrates the level of complexity of the system, which could explain why many users struggled to deactivate AP within the timeframe of 10 seconds.

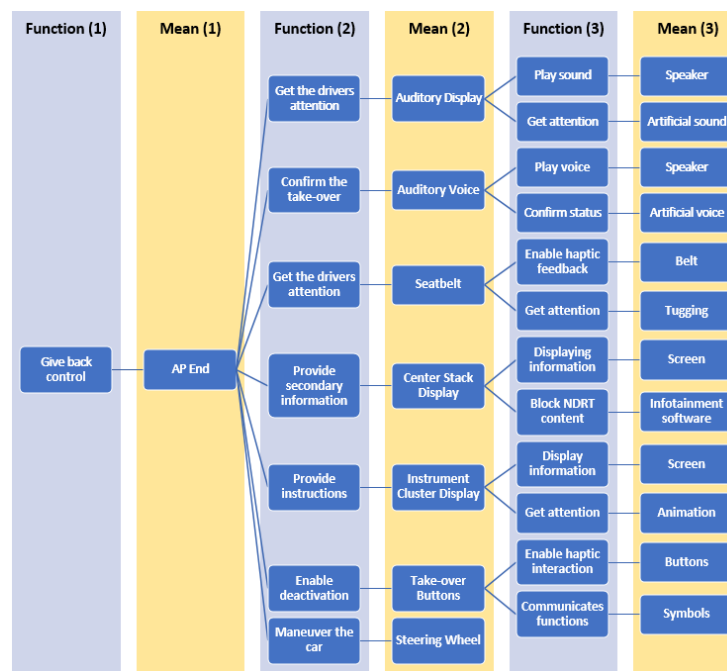


Figure 21. The Function-mean tree. Means are here referred to as the different parts of the system while the function is referred to the purpose behind each part of the system.

(1) illustrates the main system. (2) presents the sub parts. (3) consists of the sub-sub parts.

4.2.2 HTA

The HTA (Hierarchical-Task Analysis) in Figure 22 illustrates the different tasks that need to be conducted to deactivate AD. By stripping down the different tasks in a hierarchical manner, the HMI from the user’s point of view was clarified more in depth. At the top of the diagram in Figure 22, the main goal of deactivating AD can be found. The tasks shown below the main goal are the sub-tasks that need to be achieved in numerical order (first 1, then 2), to reach the main goal (top of the diagram).

As the HTA was based on the previous concept from the San Francisco Bay study, the procedures in steps 2-6, in Figure 22, are more thoroughly explained with an additional 13 tasks. This clarified the reason for why the system was unappreciated by so many participants. Within a restrained timeframe of 10 seconds, the user is put under a lot of pressure with multiple tasks to complete, which results in a negative user experience. Despite the number of parts seen in both the function-mean tree and the HTA, the system still fails to guide the user’s actions in a right manner. This could be solved by adding two very important pieces to the system: the Pre-notification and Post-notification. The Pre-notification is highlighted (red box left) and referred to as task 1 of predicting the signal, while the Post-notification is highlighted (red box right) and referred to as task 7 of understand why it happened, see Figure 22. By adding these pieces to the system, the hypothesis was to increase the UX of the transition by hopefully guiding the user to act in a correct way and by providing feedback on the action(s). A thorough description of the analysis of the HTA can be found in Table 2. A descriptive analysis of the added pieces to the takeover can be found in Table 3.

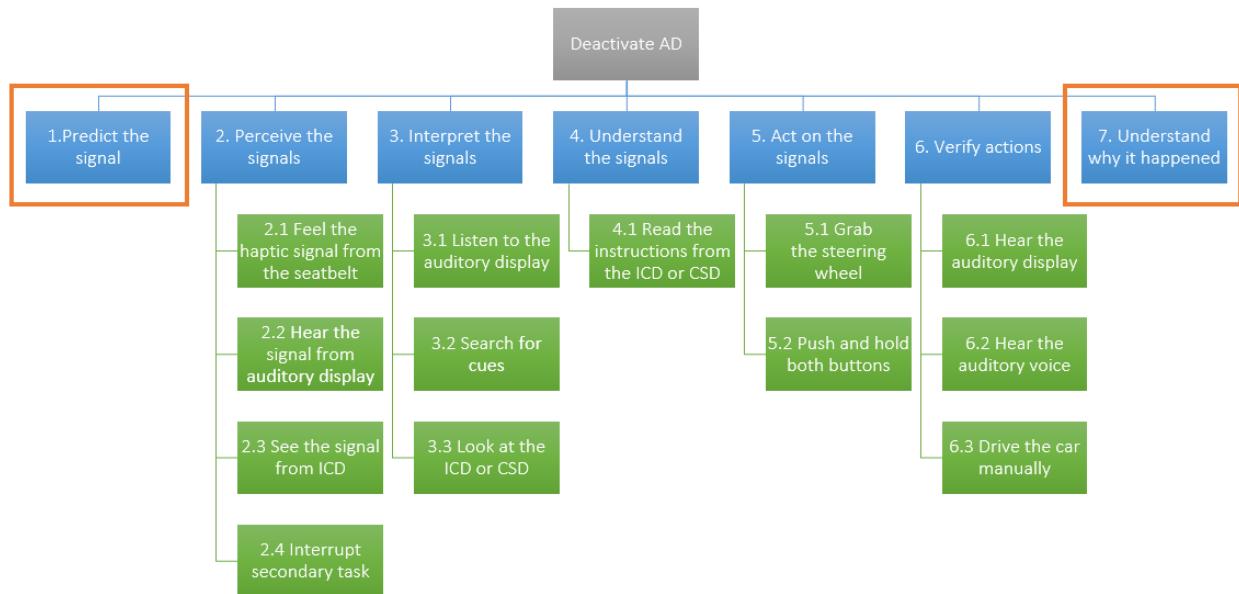


Figure 22. An HTA showing the added steps before (1) and after (7) the original deactivation sequence (2-6).

Table 2. Description of the user interpretation of step 2-6 in the HTA.

Descriptive analysis of the HTA

2	Perceive the signal	The current system was very effective at getting the drivers' attention but the haptic feedback from the seatbelt was interpreted as very intrusive and the drivers experienced fear, surprise, and stress during the second task 2 in the HTA.
3	Interpret the signals	Some users found it difficult to interpret the signals which caused to a lot of confusion. The cues must be more intuitive and interpretable to make the transition more understandable and less confusing. Some users did not know where to look and what the signals meant.
4	Understand the signals	The only source of explanation is through the ICD and the CSD. Inadequate information was given which made the users confused and frustrated when they did not find the information needed for taking back control.
5	Act on the signals	A very common reaction was to grab the steering wheel without knowing what to do. When the users understood and tried to deactivate the AD, they did not push the buttons long enough. This made the situation frustrating, and the users were confused when they failed to deactivate the system. The system needs to be more obvious for the driver.
6	Verify actions	The car lets the user know that the takeover is complete through both auditory and visual cues. The mode shift could also be felt in the steering wheel and the driving behavior. Most of the users understood that they had to keep driving themselves and felt a sense of relief when they succeeded with the transition.

Table 3. Description of the added steps 1 and 7 in the HTA.

Descriptive analysis of the added steps to the HTA

1	Prepare for the signal	Some users said that they were very surprised when the cues were given. Pre-notifications could be a good solution to prepare the driver in a more comfortable manner. Many users were busy with NDRT during AP and felt interrupted as the signal came very suddenly.
7	Understand why it happened	The system failed to make the users understand why the takeover was requested. Some felt guilty or ashamed as they thought they had done something to trigger the transition. By having a Post-notification, the system could increase the understanding of why it happened.

4.2.3 UX-Curve

A UX-curve was created based on the results from San Francisco Bay study, see Figure 23. This curve was created in relation to the different tasks presented in the HTA. Through each step of the tasks from 2 to 6, different emotions were experienced among the participants from interacting with the previous concept. These emotions had to be illustrated in one way or another which the UX-curve did in a rather simple and powerful way. Through the horizontal timeline beneath the HTA in Figure 23, emotions are illustrated in terms of either positive or negative emotions. The positive emotions are located above the horizontal centerline and the negative emotions below it. The stronger the feelings, the further away from the centerline the illustrative curve. By pinpointing the emotions on the chart, a continuous curve could be drawn in relation to the timeline of the transition.

The user experience from the previous concept is illustrated with an orange curve below the HTA, see Figure 23. When the takeover signals initiates, users perceive the signals. This is illustrated with a sharp dip in the curve. Some of the reasons were because of the sudden abruption of the NDRT, which caused emotions like fear, surprise, and stress. When the users start to interpret the signals, there is a slight positive change, but emotions remain negative as the users are still confused. When they try to understand the signal, the positive trend continues but emotions stay negative as the users are still confused and frustrated over the situation. When acting on the signal, many participants fail to deactivate the system which results in more negative emotions, as seen in the downward trend of the curve in step 5. When the users managed to deactivate the system, a sense of relief was experienced when their actions were confirmed through the audio signals. This results in the positive emotions seen in step 6. Some participants did not understand why the takeover was initiated, and some participants felt confused while others blamed themselves for triggering the event, which caused a sense of guilt. This is illustrated through a slight dip at the end of the curve in Figure 23. Even if the UX-curve is not fully accurate and is modified to the project's preference, the UX-curve still reflected valuable findings made in the video coding analysis by connecting it to the HTA.

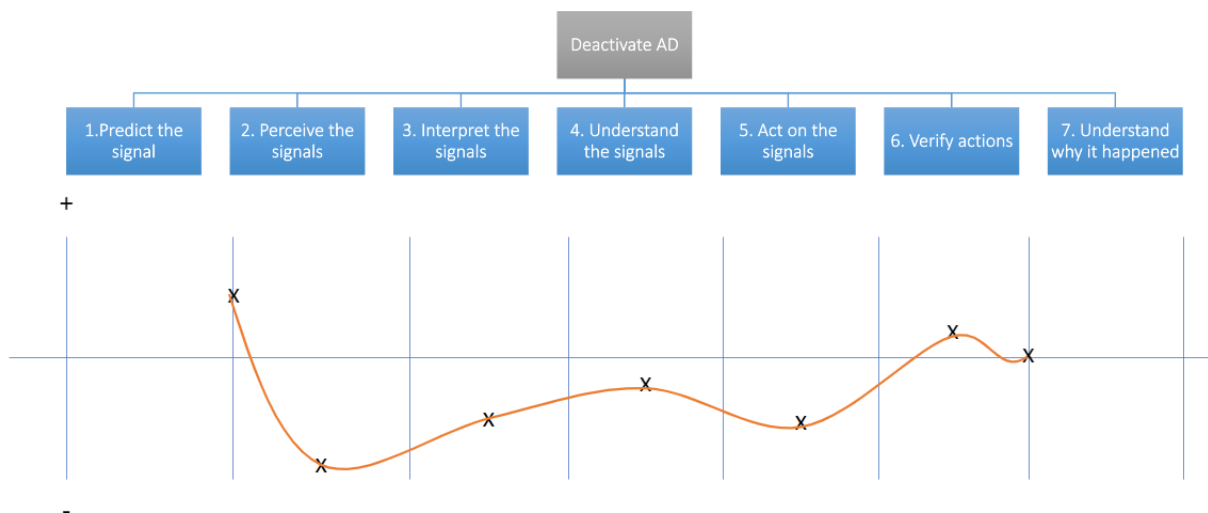


Figure 23. A UX-curve based on the participants from the San Francisco Bay study.

Based on the UX-curve created for the previous Volvo Cars concept, other UX-curves were created. The purpose was to determine potential areas where improvements could make the biggest positive impact on the user experience. As the transition was found to be a rather complicated system, it would be rather difficult to improve the whole system of the transition. Instead, different parts of the system were examined to see which one had the biggest impact on the UX. This was conducted by examining how the emotions would be affected through improvements in different stages of the transition. For instance, if a Pre-notification were to be added to the system, it would have a huge positive impact on initial steps of the takeover which is step 2. Since the different steps are connected to each other, improvements in step 2 would also have a huge impact on step 3 in Figure 24. However, the curve would follow the same negative pattern as the previous concept from step 4 onward, if no additional improvements were to be added to the system.

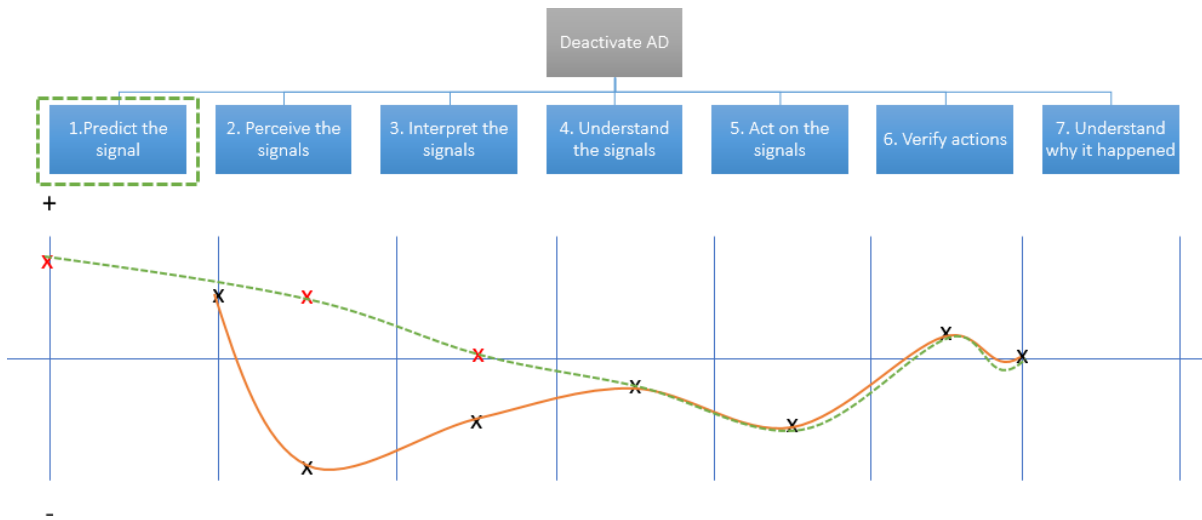


Figure 24. The green dotted line shows the interpreted improvements of the UX-curve if a Pre-notification were added

If improvements were to be added in the beginning of the 10 second Takeover-sequence, which is step 2 and step 3, the curve would change upwards in those specific sections but continue the pattern of the previous concept from step 4 onward, see Figure 25. The UX-curve would also not be improved to the same extent as with the Pre-notification.

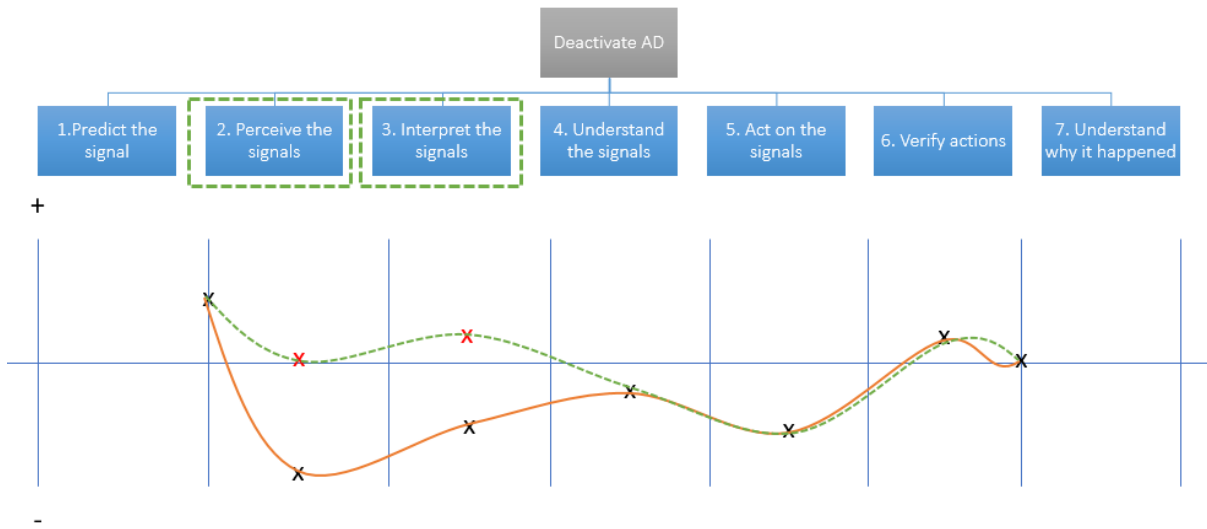


Figure 25. The green dotted line shows interpreted improvements on the UX-curve if improvements would be implemented in step 2 and 3.

If the system were to be improved in the end of the 10 second Takeover-sequence which is steps 4, 5 and 6, the concept would be improved in those specific areas but not in the beginning of the transition, see Figure 26. The sharp dip in the beginning of the curve would therefore remain.

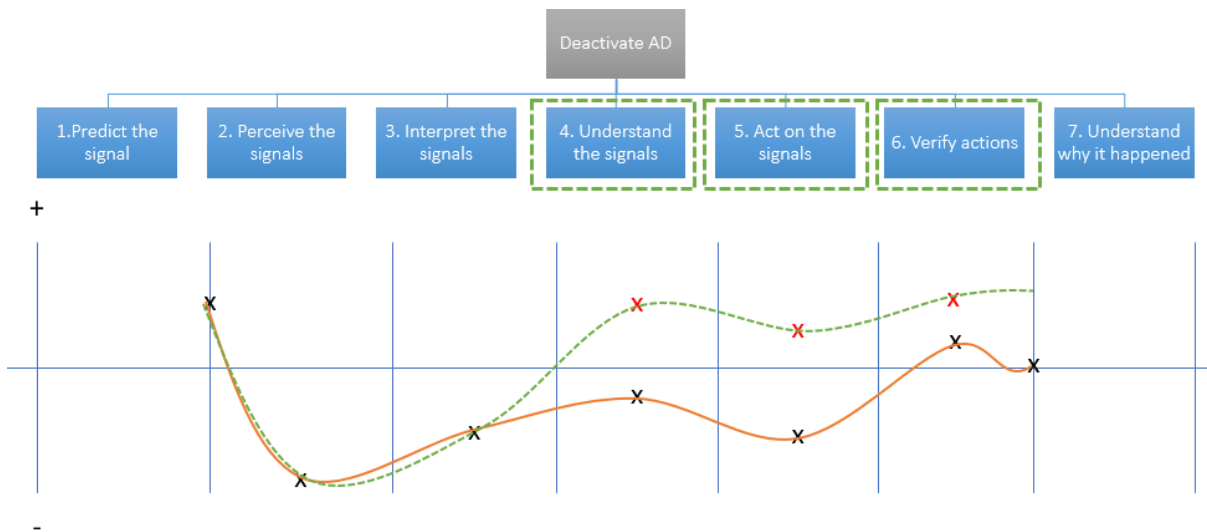


Figure 26. The green dotted line shows interpreted improvements on the UX-curve if improvements would be implemented in step 4, 5, and 6.

If a Post-notification were to be added to the system, the experience throughout the transition would stay the same as with the previous concept, except for the end of the transition, see Figure 27. By adding a Post-notification to explain the reason behind the takeover, emotions like confusion and guilt could be eliminated.

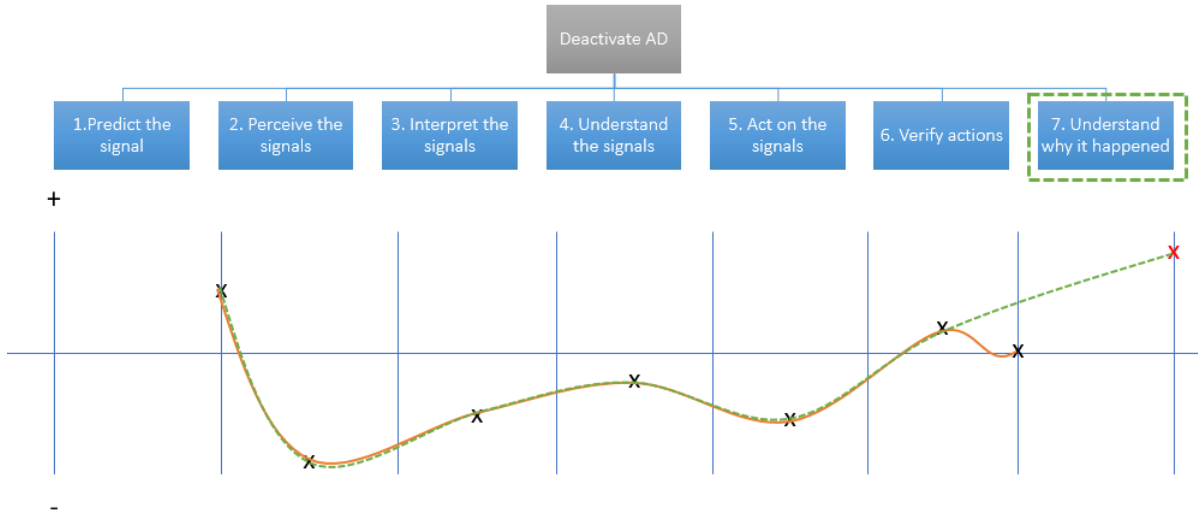


Figure 27. The green dotted line shows interpreted improvements on the UX-curve if improvements would be implemented in step 7.

This concluded that a combination of both Pre-notification and Post-notification should be the highest priority of the project. The reason was because they had the biggest impact on the UX together with the fewest tasks involved. Since each part is connected to other parts, which can be seen from the UX-curves, the Takeover-sequence cannot be ignored. The Pre-notification and Post-notification focused more on the emotions while the takeover focus more on the usability. As Hassenzahl (2018) implies that UX concerns both emotions and usability aspects, all the parts need to be considered.

4.3 Summary and Implications

In this chapter, a system analysis has been conducted of the previous concept from the San Francisco Bay study from a different perspective. Three different methods were used: the function-mean tree, the HTA and the modified UX-curve.

The function-mean tree gave valuable insights to understand the HMI of the transition from a systems point of view. It clarified important parts, building blocks and functionalities that need to be considered when redesigning the concept. As some building blocks fulfilled one and the same purpose of the system, it might indicate that the previous concept involved too many parts. The function-mean tree clearly illustrates through a tree diagram how complicated the transition system is. The HTA helped to understand the HMI of the transition from the users' point of view. By breaking down the different tasks involved in the 10 second interval of the transition, it becomes clear that the driver is put under a lot of pressure. By adding the Pre- and Post-notification to the system, the UX may be enhanced to create a more pleasurable transition from AD to MD.

Since the UX-curve was based on interpretation, the curves may not be fully accurate. It is however still helpful to get a certain understanding of potential improvements. The UX-curves were proven to be powerful in terms of illustrating different emotional reactions. It also verified the potential impact of the Pre- and Post-notifications of the transition. This narrowed down the scope of this project by focusing more on the Pre- and Post-notifications than the takeover itself. Together with the conclusions from the HTA, the Pre- and Post-notifications need to be implemented in the system to improve both the usability

and the UX of the transition. The UX-curve also indicated that changes in separate phases of the transition affect each other, meaning that the Takeover-sequence cannot be ignored. Furthermore, improvements need to be made to guide the user through a more pleasurable transition. If the improvements get implemented successfully, the drivers might get a sense of control and understanding instead of stress and confusion.



**DESIGN
GUIDELINES**

5. UX Design Guidelines

Design guidelines were created to summarize and put together the most important areas of interest and for potential improvements. The guidelines should not be considered as requirements but rather as inspirations for ideas.

5.1 Method

The video coding, the HTA, function-mean tree, and UX-curve altogether contributed with insights to create guidelines that could be of relevance when trying to improve the UX in the transition from AD to MD using different information channels and modalities. For example, auditory cues need to communicate meaning soothingly, while the overall experience of the transition needs to be less stressful. When the guidelines were created, they were sorted into different themes. The main themes for the structure were: Vision, Auditory, Haptic, Overall, and Usability. The Overall theme had a variety of different guidelines and was therefore structured into the sub-categories: Information, Risks, Understand, Feelings, Accessibility, Feedback, Communication and Attention. Furthermore, the design guidelines were prioritized from low to high, depending on how important they were considered with respect to the different phases 1 (Pre-notification), 2-6 (Takeover), and 7 (Post-notification) from the HTA, see example in Figure 28.

DESIGN GUIDELINES			Low	Medium	High
Criterion	Based on	Comments	Priority		
Vision			1	2->6	7
Show clearly visible communication	HTA	Distance from text, contrast, color etc.	x	x	x
Be bright enough to catch the attention	HTA	Spec from Volvo	x	x	x
Auditory					
Should be logically timed in relation to the users interpretation	VC		x	x	x
Clear auditory communication	VC		x	x	x
Convey the message soothingly	VC		x	x	x
Communicate for deactivating the system	VC	With different cues	x	x	x
Provide more information from the voice	VC		x	x	x
Use colors as a way to direct the attention	VC		x	x	x
Provide clear instructions and visuals from the ICD	VC		x	x	x
Be loud enough to catch the attention	HTA	Spec from Volvo	x	x	x
Minimise distracting noise outside ODD	VC	ANC, block radio, surrounding distractions.	x	x	x
Haptic					
Less aggressive jerks	VC	Dynamic increase of the jerks	x	x	
Increase the understanding of using the buttons	VC	Some cue that leads to the buttons		x	

Figure 28. Example of how the guidelines were prioritized from low (light blue) to High (dark blue). If the guideline had an impact on the phase they were marked with an x, and if not, they were left empty. The guidelines that were marked with an x was then color-coded in phase 1, 2-6, and 7 from the phases in the HTA.

5.2 Results

The guidelines were structured based on priority with the most important guidelines at the top of the spread sheet. Phase 1 (Pre-notification) resulted in 39 guidelines, phases 2-6 (Takeover) in 40, and phase 7 (Post-notification) in 27 guidelines through the prioritization. How the guidelines were structured from High to Low can be seen in Table 4. For a full version of the design guidelines on each phase, see **Appendix C**.

Table 4. Summary of the number of guidelines and the priority of the guidelines

Priority	Phase 1 Pre-notification	Phase 2-6 Takeover	Phase 7 Post-notification
High	11	22	5
Medium	20	17	12
Low	8	1	10
Total	39	40	27

5.2.1 Phase 1, Pre-notification

The design guidelines in the Pre-notification phase with a high priority can be seen in Figure 29. The High priority guidelines were meant to guide the idea when developing ideas in different phases. The guidelines could also be used to evaluate the designed concepts to see if they follow the suggested criteria. It is important to design a solution in the Pre-notification phase to prepare the users for a takeover. Many guidelines focused on changing the focus of the users and to interrupt them in a non-stressful manner. The Pre-notification should therefore help the drivers to guide their attention to the most critical information, and limit unnecessary information to prevent information overload and confusion.

DESIGN GUIDELINES [1]			
Criterion	Theme	Based on	Priority
Convey the message soothingly	Auditory	VC	High
Minimise distracting noise outside ODD	Auditory	VC	High
Allow the user to prepare for the take-over	Overall	VC	High
Minimise stress in relation to the transition	Overall	VC	High
Minimise the association with danger and fear	Overall	VC	High
Provide secondary information	Overall; Information	FMT	High
Catch the attention without evoking negative feelings	Overall; Feelings	HTA	High
Minimize surprising notifications	Overall; Communication	VC	High
Interrupt the users secondary tasks in a comfortable manner	Overall; Attention	HTA	High
Direct the attention to important functions	Overall; Attention	FMT	High
Block NDRT content	Overall; Attention	FMT	High

Figure 29. The high priority design guidelines in phase 1, the Pre-notification phase.

5.2.2 Phases 2-6, Takeover

The Takeover consists of a complex information distribution during the 10 seconds. The sequence would benefit from having clear instructions to avoid confusion and errors. The cues for the transition would need to be announced in a way that gets the drivers' attention without being too intrusive and overwhelming, since many users in the Volvo Cars study got scared and stressed at the beginning of the Takeover-sequence. The Takeover-phase received many guidelines based on the analysis of the HTA and the function-mean tree, since the Takeover-phase involves many information channels and functions. The high priority guidelines for the Takeover can be seen in Figure 30.

DESIGN GUIDELINES [2-6]			
Criterion	Theme	Based on	Priority
Show clearly visible communication	Vision	HTA	High
Clear auditory communication	Auditory	VC	High
Communicate for deactivating the system	Auditory	VC	High
Provide more information from the voice	Auditory	VC	High
Provide clear instructions and visuals from the ICD	Auditory	VC	High
Minimise distracting noise outside ODD	Auditory	VC	High
Minimise stress in relation to the transition	Overall	VC	High
Avoid creating an overwhelming experience	Overall	VC	High
Provide the driver with sufficient instructions	Overall	VC	High
Minimise the association with danger and fear	Overall	VC	High
Provide essential information	Overall; Information	FMT	High
Support correct action	Overall; Understand	HTA	High
Avoid confusion	Overall; Understand	VC	High
Avoid evoking negative feelings	Overall; Feelings	HTA	High
Catch the attention without evoking negative feelings	Overall; Feelings	HTA	High
Provide accessible cues	Overall; Accessibility	HTA	High
Enable feedback on interactions	Overall; Feedback	HTA, FMT	High
Direct the attention to important functions	Overall; Attention	FMT	High
Block NDRT content	Overall; Attention	FMT	High
Can be used by users with no experience of AD	Usability; Intuitiveness	HTA	High
Provide intuitive instructions for the user	Usability; Intuitiveness	HTA	High
Communicate function, (semantics)	Usability; Intuitiveness	FMT	High

Figure 30. The high priority design guidelines in phase 2-6, the Takeover-phase continuing for 10 seconds.

5.2.3 Phase 7, Post-notification

The Guidelines in the Post-notification phase highlight the problem that people did not know why the car requested the transition. If a new design could fulfill the guidelines, the transparency would be increased. The drivers would also know why the transition occurred, which would increase the user experience by ending the Takeover with a sense of joy instead of confusion and guilt. The guidelines with high priority can be seen in Figure 31.

DESIGN GUIDELINES [7]			
Criterion	Theme	Based on	Priority
Avoid the sensation of guilt	Overall	VC	High
Provide secondary information	Overall; Information	FMT	High
Increase the transparency	Overall; Understand	HTA	High
Explain the reason behind the transition	Overall; Understand	HTA	High
Confirm the transition	Overall; Feedback	FMT	High

Figure 31. The high priority design guidelines in phase 7, the Post-notification phase.

5.3 Summary and Implications

The high priority guidelines were considered most relevant to consider when designing the solutions for the separate phases of the transitions. However, the medium and low priority guidelines could contain relevant information too. The guidelines were based on the system analysis and the “based on” column in the guidelines is not very precise since the ideas for the guidelines were developed iteratively and their origin may be random for some of the guidelines. The Takeover was critical since it involved a lot of simultaneous information and the users had to act within the 10 seconds in phases 2-6. Furthermore, the guidelines for phases 1 and 7 would have a big impact on the user experience if the design solutions would fulfill them. Hereafter, phase 1 will be referred to as the Pre-notification, phases 2-6 will be referred to as the 10 second Takeover, and phase 7 as the Post-notification.



**CONCEPT
DEVELOPMENT**

6. Concept Development

The goal for the concept development was to produce concepts that included solutions for the Pre-notification, Takeover, and Post-notification of the transition. By using a rapid prototyping approach with multiple iterations and evaluations, four animated concepts were created.

6.1 Method

The ideation process followed a rapid prototyping approach together with rapid evaluation. The ideation started with a mood-board to create a common ground for different ideas. The ideas were then translated into different concepts through a rapid prototyping approach involving several iterations. Methods like brainwriting and brainstorming were used before organizing the ideas into different tables. By mixing and merging different ideas, more coherent concepts were created to increase the practicality of the concept. Through feedback from an expert review, four animated concepts were created using After Effects.

6.1.1 Ideation

To create a common ground for the concepts, a mood-board was created. A mood-board is the visual representation of different attributes a designer wants to achieve (Koch, Lucero, Taffin, & Mackay, 2020). The goal was to communicate different desires including aesthetics and expressed feelings. This was created by gathering several pictures from the internet and putting them together in a collage using Miro. The authors created one mood board each before presenting them to each other. One of the mood boards touched more upon the aesthetics and feelings the concept would evoke. This includes inspiration from the galaxy and nature like bioluminescence, which is a phenomenon that occurs when light is being produced from creatures like fireflies (Welsh & Kay, 2005). The other mood board revolved more around existing concepts of the interior from the automotive industry, where futuristically looking elements such as ambient lights, infotainments and head-up displays were presented. By merging the different mood boards, three inspiring value words were created: Nature, Game and Galaxy, see Figure 32. These value words were selected with the belief that these would facilitate creating more interesting ideas.

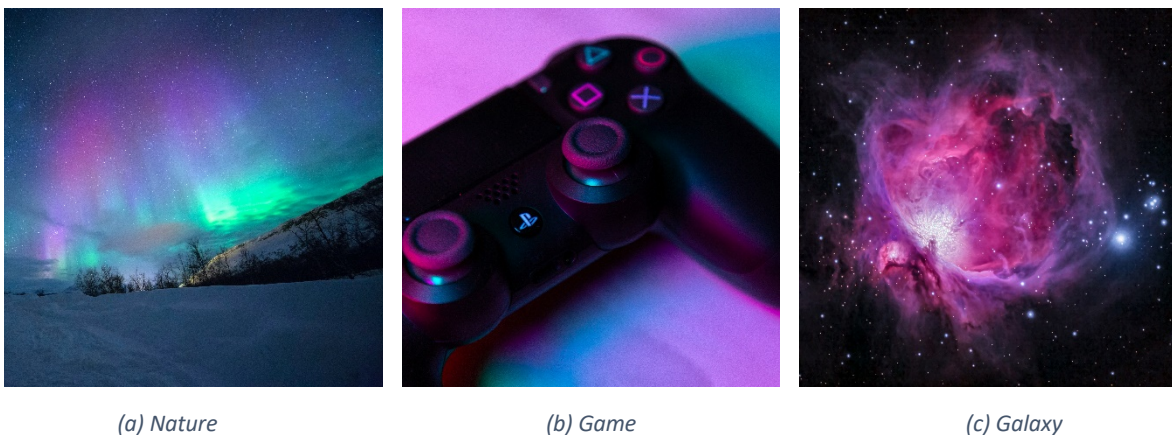


Figure 32. Final mood board. Pictures from Unsplash. All pictures are free to use under Unsplash License. (a) Northern Lights by Lightscape (2018). (b) Playstation by Taylor R (2019). (c) Nebula by Aldebaran S (2020).

To create concepts that would be as practical to implement as possible, the analysis of the concept in the San Francisco Bay study was used as reference with its included information channels. It was decided to continue working with these information channels while also considering other alternatives during the ideation phase.

A rapid prototyping approach was used during the development of the UI (User Interface) for the vehicle, where the UI is defined as the space where the HMI appears. Rapid prototyping for UX was suitable for this project since it allowed the development to proceed more efficiently (Smith, 2021). UI are primarily driven by user requirements and the rapid prototyping approach made it possible to quickly develop concepts or mock-ups that could be evaluated to receive user feedback. This ensured that the ideation was going in the right direction, making changes early in the process to better meet users' need (Smith, 2021). As rapid prototyping is not restricted by rigorous requirements (Smith, 2021), the approach suited this project perfectly as it was possible to produce multiple ideas within a big solution space.

The method used for ideating concepts was brainwriting which is the quiet version of brainstorming where ideas are being created individually before sharing it for discussions (Lucidchart, 2021). The first brainwriting session was conducted using Miro, a digital multipurposed platform with digital post-it notes. Miro allowed for a flexible workplace by enabling digital collaboration. The purpose of the first session was to explore the design space by screening different sources of inspirations. For instance, the Chinese car manufacturer NIO has developed NOMI which is an artificial intelligent assistant placed on top of the interior dashboard, see Figure 33 (NIO, 2020). Another inspiration from the Miro board was the Digital Cockpit 2021 from Samsung which uses a soft interior touch panel at the back of vehicle, see Figure 34 (Samsung Newsroom, 2021).



Figure 33. NOMI from NIO, the artificial intelligent assistant (NIO, 2020)



Figure 34. Soft touch panel in the Samsung Digital Cockpit 2021 (Samsung Newsroom, 2021)

The ideas were then structured in a table based on what information channel and phase it belonged to, see Table 5. Two tables were created separately before discussing them. Furthermore, a total of 99 ideas were created with 41 re the Pre-notification, 35 re the Takeover and 23 re the Post-notification. A schematic table of the number of ideas can be seen in Table 5 while a complete overview of the different ideas can be seen in **Appendix D**.

The next brainwriting session involved Lo-Fi sketches using post-it notes, see Figure 35.

Table 5. Schematic table of 99 ideas generated during the first Brainwriting session

Information channels		Pre-notification	Takeover	Post-notification
Visual	ICD	4	4	2
	CSD	8	7	5
Haptic	Buttons	2	11	3
	Steering wheel	5	3	1
Audio	Sonic User Interface	7	3	4
	Voice User Interface	4	3	4
Mix	Other	11	4	4
Total		41	35	23
Sum Σ		99		

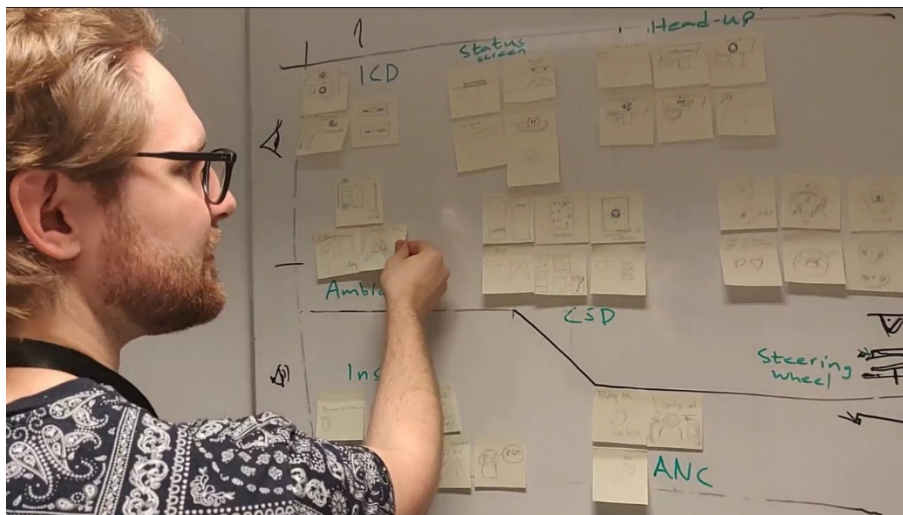


Figure 35. Structured ideas and sketches using post-it notes and themes.

This was conducted physically to increase the efficiency and rapidness of the discussions. The purpose of this session was to concretize different ideas from the Miro board. The ideas were categorized in different themes as were the ideas from the Miro board. A total of 103 concepts were created, 42 re the Pre-notification, 38 re the Takeover, and 23 re the Post-notification, see Table 6. For an overview of the concepts created using post-it notes, see **Appendix E**.

Table 6. The tables (a) to (c) presents the number of ideas created in the second session of Brainwriting. (a) presents the Pre-notification ideas. (b) presents the Takeover concepts. (c) presents the Post-notification concepts.

(a) Pre-notification

Visual	Ambient	CSD	HUD	ICD	Status screen	Steering wheel
	2	7	8	3	5	7

Audio	ANC	Inspiration
	3	6

Haptic	Steering wheel
	1

(b) Takeover

Visual	Ambient	Buttons	CSD	ICD	Steering wheel
	4	7	5	8	5

Audio	SUI	VUI
	4	4

Haptic	Buttons
	1

(c) Post-notification

Visual	Buttons	CSD	HUD	ICD	Icons
	3	1	1	1	5

Audio	SUI	VUI
	2	6

Haptic	Avatar	Buttons
	2	2

As the concepts noted on post-it notes needed further development, another brainwriting was needed. Based on this session, it was decided to skip audio cues and continue with it in the final concept. The reasons for focusing on the visual cues only were due to difficulties of evaluating different concepts both visually and auditory. The haptic concepts were also eliminated due to the uncertainty of conducting a physical user study later in the process. The final brainwriting session was carried out using Procreate and Adobe Photoshop, seen Figure 36.



Figure 36. Digital sketching in the final Brainwriting session using Procreate.

The purpose behind shifting to digital sketching was to concretize and visualize the concepts more clearly. (Unfortunately, the sketches from this session cannot be presented since they were created on a template of confidential material.) By merging different concepts from the previous session to create a complete sequence, a total of 39 concepts were created, see

Table 7.

Table 7. 39 concepts generated by merging different ideas

Buttons	Steering Wheel	ICD	CSD	HUD	Other
Dynamic Pictogram	Illustrative Animation	Nebula	AD Zone	Car to Finish Line	Ambient Light Pulse
Edge	Focused Ambient Light	Galaxy	“Phone” Notification	Avatar & Speak Bubble	Ambient Light Wave
Flipping buttons	Lights on hands	Waves	Breathing Avatar	Loading	Avatar Eyes
Circulating Buttons & Logo	Pulsating Light	Radio Waves	Appearing Logo		Abstract Avatar
Big Bang	Countdown	Path	Disclaimer & Tutorial		Icon
Firefly	Glow		Screen Saver		
Glow	Lightning				
Path	Vanishing Logo				
Dynamic Rotation	Glowing Logo				
Water	Closing Circle				

Most of the concepts revolved around the same system as the concept used in the San Francisco Bay study, by either using the ICD, CSD or the Takeover-buttons of the vehicle. Other concepts were more novel and consisted of a HUD, or a screen on the steering wheel, or an Avatar on the top of the dashboard, or using more ambient lights.

6.1.2 Evaluate

In a rapid evaluation, a PMI was conducted to eliminate impractical and incomplete concepts. PMI stands for plus-minus-interesting and is a decision-making tool to assist the evaluation process to make decisions based on positive, negative and interesting aspects of concepts (Sharma & Saarsar, 2017). By evaluating each of the 39 concepts using the PMI, a total of 27 concepts remained before merging them to create more coherent concepts, see

Table 8.

Table 8. 27 concepts remaining after the PMI evaluation

Buttons		Steering Wheel		ICD		CSD		HUD		Other	
Dynamic Pictogram	✓	Illustrative Animation	✓	Nebula	✓	AD Zone	✓	Car to Finish Line	✓	Ambient Light Pulse	✓
Edge	✓	Focused Ambient Light	✓	Galaxy	✓	“Phone” Notification	✓	Avatar & Speak Bubble	✓	Ambient Light Wave	✓
Flipping buttons	✗	Lights on hands	✗	Waves	✗	Breathing Avatar	✓	Loading	✓	Avatar Eyes	✗
Circulating Buttons & Logo	✗	Pulsating Light	✓	Radio Waves	✓	Appearing Logo	✓			Abstract Avatar	✓
Big Bang	✓	Countdown	✓	Path	✓	Disclaimer & Tutorial	✓			Icon	✓
Firefly	✗	Glow	✗			Screen Saver	✓				
Glow	✗	Lightning	✓								
Path	✓	Vanishing Logo	✓								
Dynamic Rotation	✗	Glowing Logo	✓								
Water	✗	Closing Circle	✓								

These concepts were merged based on their functionality and expression. To categorize and merge the concepts, the themes from the mood board were used with an additional theme labelled Other. Incompatible concepts were eliminated while similar concepts were combined which narrowed down the number of concepts. Furthermore, 9 concepts remained to be evaluated through a digital expert review. The concepts in relation to the inspiration and the phase of the transition can be seen in

Table 9 where the x represents the concerned transition phases.

Table 9. The structure of the 9 remaining concepts.

Inspiration	Concept	Pre-notification	Takeover-phase	Post-notification
Nature	Lightning	X	X	
	Firefly	X	X	X
Galaxy	Nebulous	X	X	X
	Space	X	X	X
Game	Game	X	X	X
	Sci-fi	X	X	X
	Laser		X	

Other	Logo	X		X
	IKEA manual	X	X	

Lightning was inspired by the weather and a storm approaching that escalates into a thunderstorm. Concept Firefly was inspired by the pulsating light from a firefly or a starry sky. The concept Space and Nebula was inspired by the galaxy and tries to mediate the feeling of an exploding star and stardust. The idea was to mimic the sensation of the travelling through time and space. Game, Sci-Fi and Laser were inspired by futuristic game interfaces. Game consisted of retro-like interfaces, Sci-Fi used more hi-tech looking aesthetics, and Laser imitated a laser beam by using ambient light in the UI and around the dashboard to get the users' attention. The Logo concept used the Volvo logo in the UI to catch the users' attention in the transitions between different illustrations on the screens. The concept also included a screen on the steering wheel which could be a good place to put important information as the screen is placed in front of the driver. Finally, the idea behind the IKEA Manual concept used an instructional tutorial with clear illustrations and minimum text, similar to an IKEA Manual. By making AP a feature that needs to be actively enabled, the idea was to have the users go through instructive step-by-step illustrations of how it works.

These 9 concepts were then evaluated through an expert review where five experts from the car industry were introduced to the concepts. The experts then provided constructive feedback of the concepts in terms of feasibility and practicality. The review was conducted online, the aim of the review was to narrow down the scope to eliminate impractical concepts. Furthermore, the concepts were iterated upon once again by mixing and merging different parts, which eventually resulted in four concepts that covered the whole transition.

6.1.3 Animation

Four concepts were animated in higher fidelity to define the ideas and to turn them into complete concepts. Videos were created using After Effects and Photoshop and the aim with the videos was to be able to test the concepts with potential users, to see how they experienced and understood the visual cues in the system. It was important to put the concepts in a context to increase the understanding of the timing of the different cues and the dynamic shift between them.

To create a context, an image of a Volvo car interior, as well as a video sample of a car driving in first-person perspective were used. The video was created using a tripod and a smartphone while the image of the car's interior was retrieved from the Volvo Cars' Content Store. The image was then modified to make it easier to edit in After Effects. For instance, the windows and displays were masked out using Photoshop and then placed in front of the video to make it look more like a car driving in AP. The buttons were also simplified to make it look more like the original ideas from the storyboard. The result of the template for the concepts can be seen in Figure 37.



(a) Masked interior of a Volvo car.



(b) Recorded video sample.



(c) Template for the concept with the image and video placed behind each other

Figure 37. Creation of the template for the concepts. The process can be seen from (a) to (c).

The animation of the concepts was then created by using a set of keyframes on different layers to adjust different properties such as color, scale, opacity, and position etc. To create a sense of occupation during AP, a video of a Volvo Cars advertisement was placed on the Center Stack Display. The video seen in Figure 38 was retrieved from the Volvo Cars' Content Store to avoid any copyright issues that may be involved. The purpose for placing the video material in the Center Stack Display was to simulate the sensation of looking at YouTube or a TEDx Talk video during AP, making it more interactive.

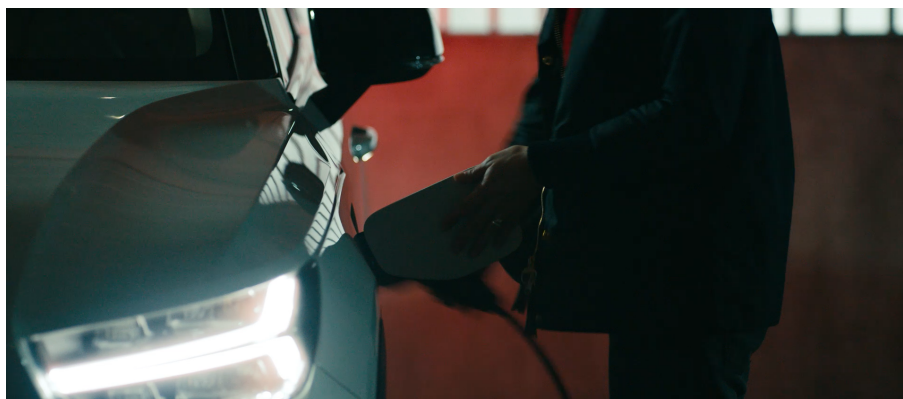


Figure 38. Screenshot from the retrieved video from Volvo Cars' Content Store.

To save the animations and render them more quickly, Adobe Media Encoder was used. Different settings of the rendering program were adjusted to optimize the quality outcome before rendering the animations. Each concept resulted in a 36-second-long video with the same interior and context in the background. Every concept was fully rendered before trimming them into their respective sequence: Pre-notification, Takeover, Post-notification and before pushing the buttons.

6.2 Result

The results from the expert review together with the four animated concepts are described in this section.

6.2.1 Expert review

The expert review resulted in a few statements for further improvements. The experts liked the inspiration used for the concepts and could see a clear communality between the different phases of the transition. The concepts which were particularly mentioned was Space, Lightning, Firefly, and Game. Some ideas from the concepts were especially mentioned and the take-aways from the review is summarized in Table 10.

Table 10. Positive and negative feedback from the expert review.

Positive feedback	Negative feedback
Concept Space, Lightning, Firefly, and Game are promising.	Lightning notifications are difficult to see in daylight.
Good inspiration for the concepts	Ambient light from below the steering wheel area can be hard to see in daylight.
The Progress bar that was used as a Pre-notification was good.	Use the most relevant information where the attention is drawn.
The cloudy to precise and the blurry to sharp transition in the infographics was interpreted positive	Avoid information overload and be careful with too many focus areas simultaneously.
ANC (Active Noise Cancelling) could be used as an auditory notification.	The Volvo logo transition was not interpreted as a modern and appreciated way to switch between information.
Good to use CSD for Pre-notifications	Pedagogic animations are missing. Explanations of how to take over is needed.
	More ideas are needed in the Pre- and Post-notification phases of the transition.
	The tutorial concept (IKEA Manual) is outside the scope of the transition.
	There might be good to have a solution for the MRM (Minimal Risk Maneuver).
	The screen on the steering wheel has safety and regulation issues. Questionable if it is necessary.
	Some concepts are not complete and are more like part solutions.

Finally, more pedagogic illustrations were needed to clarify the information from the concepts.





The concepts presented to the experts were presented in a rather low fidelity (Lo-Fi) format, which could make it difficult to understand them. The reason why experts were chosen for the evaluation was because they had prior knowledge about the system, which made it easier for them to understand the

Lo-Fi concepts. They could also give constructive feedback based on their expertise in the field of research.

6.2.2 Animation

In the next step of the process, the concepts were created in higher quality as the users for the planned user study would not be very familiar with the system. The four concepts called Lightning, Firefly, Galaxy, and Game where therefore animated in 2D using After Effects. The concepts are described more in depth in Table 11.

Table 11. Description of the four remaining concepts.

Concept	Description	Example figures
Lightning	The concept guides the driver's attention by static changes in the UI and uses lights that imitate lightning in the car's interior. The lights together with pedagogic illustrations in the ICD and the CSD are the main characteristics of the concept.	
Firefly	The concept is based on a scenario where the car is about to leave the ODD and therefore must deactivate AP. The concept explains this by showing a GPS map in the CSD during the Pre-notification together with an explanation after the Takeover.	
Galaxy	Nebulosus and space dust appear in the interface to create a sense of a dynamic environment in space. The dynamic shift between the different cues is used to guide the attention of the user to the most important information, by illustrating changes of energy. When important information is shown, the stardust collects its energy and becomes precise and clear. Galaxy also has a small round screen above the CSD that shows the AP status to the user.	
Game	A game inspired concept that uses sharp-edges and a more precise design language. The interface is designed to imitate interfaces seen in various computer games and has more traditional looking graphics together with futuristic elements inspired by the look of VR and AR together with sci-fi and game movies. The concept uses clear visuals in the HUD that is placed in the driver's field of view.	

So far, the concepts only used visual cues to determine whether the signals were sufficient to convey the intended message of the takeover. The concepts were later evaluated in a user study to examine how the participants interpreted the visual cues. All concepts took around 5 seconds for the Pre-notification, 9 seconds for the Takeover, and 5 seconds for the Post-notification. Firefly and Game were created with a slightly different scenarios where the vehicle knew far ahead when AP would end, which allowed the system to anticipate and prepare the driver much earlier. For instance, the Game concept had a timeline that indicated that something would happen when it reached the end. The full animation for each concept can be seen through the link or QR code in **Appendix F**.

Concept A; Lightning

Lightning was inspired by elements of nature, how the weather behaves during rainy days and how electric charges are created before a lightning strike. The concept mainly worked with information from

the ICD, CSD, ambient light and the movement of buttons and shifting colors from blue to orange. This concept also works with illustrations of how to take over as well as an explaining text of what to do.

In the Pre-notification, the Lightning concept changes from having an electrically charged cloud that spouts electronic particles whenever the car is accelerating, to an electrically charged string. An explanatory text in the middle of the screen fades in and tells the driver to “Prepare” while illustrating how to prepare by holding the steering wheel in the CSD. As the ambient light below the seat slowly fades in and out, the ambient light behind the windshield from each side moves towards the center, behind the steering wheel. Before vanishing, the ambient light continues to circle around the Takeover-buttons of the steering wheel to direct the attention towards the buttons. The Pre-notification sequence can be seen in Figure 39.



Figure 39. Pre-notification seen in (a) to (d).

Right after the circling light around the buttons, the midsection of each buttons starts to glow, similar to how the light strikes down and hits the ground. The centerline in the ICD starts to move like electricity, sending out shadows of its movements in both vertical directions before fading out and disappearing. The line becomes straight once again before morphing into the shape of the Takeover-button on each side of the circled instruction in the ICD saying, “Push and Hold”. As the buttons starts to glow in the ICD to notify the driver to push the buttons on the steering wheel, the buttons with a similar look together with hands start pushing the buttons simultaneously in the CSD. The signal repeats itself but in orange before the driver decides to push the buttons to take over which is indicated through feedback given in

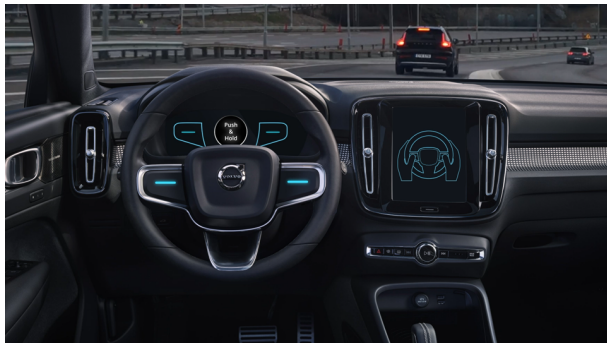
the ICD. As the centerline in the ICD starts to glow while the circle in the middle starts rotating, the buttons are pushed. The animation for the Takeover can be seen in Figure 40.



(a) Takeover starts. Pulsating electric waves appear in ICD. Raindrops disappear in CSD. Instructions given in ICD and buttons are glow.



(b) ICD saying push and hold.



(c) Buttons appear in the ICD.



(d) Buttons in the ICD and the CSD pushes the buttons at the same time.



(e) Escalation point triggers the same animation of the buttons and shift from blue to orange.



(f) Electric animation in ICD, everything in orange.



(g) Push animation in ICD.

Figure 40. Takeover-sequence seen in (a) to (g).

When the Takeover is complete, the ICD in the middle tells the driver to “Drive the car” before switching to the manual mode UI. On the CSD, a message field appears explaining why the Takeover occurred by saying “Cars were driving faster”. The animation for the Post-notification can be seen in Figure 41.



(a) AP OFF. Post-notification message appearing in ICD.



(b) Second Post-notification message appear in CSD.

Figure 41. Post-notification seen in (a) to (b).

Concept B; Firefly

Firefly was inspired by nature’s bioluminescence, how fireflies glow and move in the dark. This concept worked with information from the ICD, CSD, ambient light, as well as the buttons on the steering wheel. It works with glowing colors together with a shift from blue to orange. Instructions are given in the form of text as well.

In the Pre-notification, the ICD tells the driver to “Get Ready” while the edge of the screen starts to glow at the same time as the ambient light behind the windshield starts to glow. In the CSD, a map is shown that indicates to the driver that they are approaching the end of the AP-zone, which in turn triggers the transition. This was inspired by how airplanes indicate to passengers when they are approaching their destination, by turning off the content in the screens and showing a map instead. The yellow dot in the CSD then transforms into an illustration of a steering wheel that indicates that it is time to grasp the steering wheel. This concept is based on a slightly more futuristic scenario where certain roads are certified for AP, and the car can therefore prepare much earlier and be aware of when the AP needs to end. The Pre-notification can be seen in Figure 42.



(a) AP ON



(b) Pre-notification starts. Map appears in CSD. Instructions given in CSD. Ambient light in windshield appears.



(c) Map disappearing from CSD. Only leaving the yellow dot. Dot, shine arounds ICD and ambient light in windshield pulsates.



(d) Dot transforms to steering wheel in CSD. Pulsation stops.

Figure 42. Pre-notification seen in (a) to (d).

When the Takeover starts, the text in the circle on the ICD shifts to “Push & Hold”. The Takeover-sequence is also amplified through an illustration of a swarm of blue fireflies that moves out from the circle and disappears. The idea is to direct the focus towards the ICD to notice the message inside the circle. The centerline on the Takeover-buttons fades to blue and the buttons in the steering wheel illustration on the CSD start to blink. If no action has been taken, all the illustrations change color to orange to mediate a sense of urgency. At the same time a new swarm of fireflies around the circle is activated. When the buttons are being pushed, the circle in the ICD is filled in three distinct steps to indicate the countdown of holding the buttons. Meanwhile, a swarm of dots is moving towards the center of the circle before disappearing completely. The Takeover-sequence can be seen in Figure 43.



(a) Instructions given and particles emitted from ICD. Steering wheel in CSD push buttons. Buttons glow.



(b) Illustration in CSD lets go of the buttons.



(c) Everything turns orange. Particle illustration appears again in ICD.



(d) Push button animation in ICD. Circle filled in three steps.

Figure 43. Takeover-sequence seen in (a) to (d).

When the Takeover is complete, the message in the circle on the ICD tells you to “Drive the Car” and then switches back to the manual UI with a speed indicator inside the circle. The CSD also goes back to the manual UI, before a message field appears at the top of the screen saying “AP-zone ended”. The Post-notification is illustrated in Figure 44.



(a) Post-notification message given in ICD. CSD returns to manual interface.



(b) Post-notification message appears in CSD.

Figure 44. Post-notification sequence seen in (a) to (b).

Concept C; Galaxy

Galaxy was inspired by how the universe looks like, how the Milky Way galaxy moves and how the nebula and stardust look in the dark. This concept communicates using the ICD, ambient light, buttons, and the “avatar” on top of the interior hood in combination with glow, movements, and shifting color from blue to orange. This concept illustrates how to take over with symbols together with an explaining text.

When the car is in AD, the speed indicator circle is surrounded by an adaptive nebulae that increases in intensity when the car is accelerating and decreases when the car slows down. The avatar screen on top of the dashboard shows a kind of pulsating energy surrounding a circle and a text stating “AP ON”. Then a light pulse in the windshield moves towards the steering wheel, and the nebulous gas cloud in the ICD collect its energy from the circle to create a sharp glowing circle in blue. The speed indicator switches to “Prepare” and the “AP ON” in the avatar screen fades away and leaves the circle empty. The NDRT in the CSD fades into a screensaver to mimic the movement of space dust particles in space. The Pre-notification ends with a new light pulse in the windshield that moves towards the steering wheel and then the light circulates once around the buttons on the steering wheel. The Pre-notification can be seen in Figure 45.



(a) AP ON. Stardust from ICD. Avatar above the CSD saying AP ON.



(b) Pre-notification starts. Ambient light in windshield moving towards the center.



(c) ICD saying Prepare. Nebula transforms into an audio circle. CSD showing starts moving through the empty space. Avatar stops moving and AP ON no longer visible.



(d) Ambient light moves towards the center again.



(e) Animation around the buttons.

Figure 45. Pre-notification seen from (a) to (e).

The energy around the circle in the ICD explodes out from the circle and a close-up illustration of the steering wheel fades in. In the illustration it says, “Push and Hold” and the buttons start flashing. The centerlines on the Takeover-buttons on the steering wheel start to glow in blue simultaneously. All interfaces are then shifting to orange to indicate a sense of urgency at the escalation point. When the buttons are pushed, the energy moves towards the center of the circle in the ICD before exploding completely. The Takeover-sequence can be seen in Figure 46.



(a) Pulsating audio circle in ICD. Stars in CSD moves faster through space. Buttons and avatar still glowing.



(b) ICD zooms into an illustration of a steering wheel. Instructions given in ICD.



(c) Ambient light moves towards the center at the escalation point.



(d) Animation around buttons in orange.



(e) Cues in orange.



(f) Push button animation.



(g) ICD circle glow to emulate energy being absorbed.



(h) Energy ball exploding when button push is complete.

Figure 46. Takeover-sequence seen in (a) to (h).

When the Takeover is complete, the speed indicator returns together with the gas cloud around the circle in the ICD. The avatar then illustrates a green confirm modal before saying “AP OFF”. The avatar then transforms into a clock by showing the time. The purpose is to decrease the sense of aliveness and smartness of the vehicle and clarify that the vehicle is now in manual mode. The CSD also turns back to the standard driving mode. The full Post-notification sequence can be seen in Figure 47.



(a) MD interface



(b) Checkbox appears in avatar to confirm action



(c) Avatar saying "AP OFF"



(d) Avatar showing time instead.

Figure 47. Post-notification seen in (a) to (d).

Concept D; Game

Game has a more futuristic and sci-fi inspired look. Based on inspirations from both AR and VR, this concept takes advantage of the HUD to communicate together with the ICD, CSD, buttons and a combination of illustrations, text, glow and shifting colors.

During the Pre-notification of the concept, the HUD uses a loading bar on the left side of the windshield to indicate the time left until AP disables. As the bar gets lower and reaches the bottom, the loading bar disappears and a text saying "AP END" appears. Meanwhile, the CSD illustrates a symbol that indicates to the driver to hold the steering wheel. A blue loading circle then appears in the middle of the ICD with a text saying "Get Ready" appears. When an overtaking car appears in the windshield, the overtaking car is encapsulated by a blue shimmering light, indicating that something is happening, and that the driver should pay attention. The Pre-notifications end with a blue circulating light around the Takeover-buttons to direct the drivers' focus to the buttons. The whole Pre-notification sequence can be seen in Figure 48.



(a) AP ON. Loading bar in the HUD.



(b) Pre-notification begins. Glowing car in the HUD. HUD saying AP END to the left. Loading circle appears in ICD with instructions. CSD with steering wheel illustration.



(c) Car stops glowing. Animation around buttons.

Figure 48. Pre-notification sequence from (a) to (c).

The Takeover starts with the disappearing text saying “AP END” in the HUD. Meanwhile, the steering wheel symbol in the CSD indicates that the buttons should be pushed, and the buttons in the illustration start to glow. In the ICD, an animated circuit board radiates out from the center of the screen before disappearing, leaving an afterglow on the edge of the screen. The reason for using a circuit board for the animation in the ICD was to create a sense of futurism with the technology being visible behind the display. This was thought to create the same sensation as in the movie Matrix, with their iconic code rain in green (Oberhaus, 2019). An instructive text “Push & Hold” appears in the center of the ICD. When the Takeover reaches the escalation point, an orange light circulates around the buttons and a new circuit board animation burst out from the circle in the middle of the screen. When both the buttons are pushed, the circle in the ICD starts circulating while counting down before disappearing. The whole Takeover-sequence can be seen in Figure 49.



(a) Animated circuit board burst out from the center of the ICD. CSD illustrates the steering wheel. Text in ICD saying Push & Hold. Buttons glowing in blue.



(b) Afterglow around the edge of the ICD. Buttons in CSD illustrations is glowing



(c) Escalation point, animation around buttons but in orange.



(d) Everything turns orange. Pulsating circuit board animation from the ICD



(e) Afterglow on the edge of the ICD. Buttons in the CSD illustration glows.



(f) Animation in the ICD counting down when buttons being pushed.

Figure 49. Takeover-sequence from (a) to (f).

When the Takeover is complete, the ICD and the CSD returns to the manual interface. A message appears in the HUD to the left of the windshield saying, “Cars were driving faster”. Before the text appears, a futuristically inspired frame was created to catch the driver’s attention. The reason behind the text was to provide the user with information of why the Takeover was initiated, reducing the feeling of confusion. To see the whole Post-notification sequence, see Figure 50.



(a) Manual interface after buttons pushed.



(b) Post-notification message.

Figure 50. The Post-notification sequence is illustrated from (a) to (b).

6.3 Summary and Implications

The concept development resulted in four animated concepts of the transition which were named Lightning, Firefly, Galaxy, and Game. Concept Firefly was based on a scenario where the car was driving on a certified AD road, whereas the other concepts were based on a scenario where the traffic around the vehicle drove faster, which triggered the Takeover request.

The process included many ideas and a wide range of partial solutions for the three phases of the transition. The transition was first stripped down to its basic elements and was thereafter built up again with improved partial solutions that were merged into complete concepts. As the level of details and pedagogic information increased, the concepts kept evolving through an iterative process during the concept development. The first ideas were of Lo-fi character and included a wide range of solutions. The initial screening was used to get inspiration and ideas from a wide range of sources. To concretize and develop the screened ideas, sketches were used as an efficient tool during brainwriting sessions. When the ideas were sketched digitally, they became more defined and irrelevant ideas were eliminated.

The expert review gave valuable insights on the concepts and developed the concept in the right direction. Through the feedback from the expert review, four animated concepts were created by mixing, merging, and eliminating different parts of the concepts. The four animated concepts were improved mostly thanks to the added Pre- and Post-notifications, but they also utilized more pedagogic animations and texts that were intended to improve the transparency of the HMI during the transition.

The development of the four concepts was rather time consuming since the concepts had a much higher fidelity than the earlier sketches. The animation process required a lot of computing power and if better computers had been used in the beginning, the process would have been much more efficient. For this project, laptops were used which resulted in crashing issues and slow renderings, which made the work more difficult. It could be questioned if it was necessary to make four animated concepts to evaluate the visual signals or if two concepts would have been sufficient to retrieve similar results from the user study that was conducted to try the concepts out (as described in the next chapter).

Using animation as a medium was a powerful tool to convey design expressions based on movements and to be able to evaluate the timing of the UI. To be able to evaluate the concepts in a user test, the transition had to be displayed as different sequences for the users to experience the complete transition, especially since many users may be unfamiliar with AVs. All the concepts were animated in a scenario with perfect road conditions which could make it difficult to evaluate emotional responses in a user test. However, the four concepts were considered sufficiently detailed for a user study that could test the visual cues.

The background features a light gray to white gradient. Large, white, rounded shapes are scattered across the page, including a vertical oval on the left and a large, irregular shape on the right. The text 'USER STUDY' is centered in the middle of the page.

**USER
STUDY**

7. User Study

An online user study was conducted to evaluate the four remaining concepts: Lightning, Firefly, Galaxy and Game. This was conducted by collecting qualitative data through semiconstructed interviews to determine which concept worked better in terms of UX and usability. The data would then be analyzed to create the final concept.

7.1 Method

This section presents the participants, the structured procedure, and the analysis of the user study of the four concepts.

7.1.1 Participants

The user study was conducted online with 12 participants. The participants were acquaintances to the authors and were chosen due to accessibility and driving experience. To get an even distribution between the gender of the participants, an equal number of men and women aged between 20-60 were selected for the user study. The aim was to evaluate the users' understanding in terms of the information presented to them through the four concepts.

7.1.2 Procedure

By first presenting the animation of the concepts, the participants were then interviewed on the topic of their experience. Each participant only saw two concepts each. Through a calculation of permutation with 4 concepts in a combination of 2, the number of participants needed for the user study was 12 which can be seen in Figure 51.

$$\begin{aligned}
 P(n, r) &= P(4, 2) \\
 &= \frac{4!}{(4 - 2)!} \\
 &= 12
 \end{aligned}$$

P = permutation of participants
 n = total number of concepts
 r = number of concepts selected

Figure 51. Calculation of number of participants

The distribution of showcased concepts for each participant can be seen in Table 12.

Table 12. Distributed concepts among the participants. Concept: A (Lightning), B (Firefly), C (Galaxy), D (Game).

Participant 1	Participant 2	Participant 3	Participant 4
AB	BA	CA	DA
Participant 5	Participant 6	Participant 7	Participant 8
AC	BC	CB	DB
Participant 9	Participant 10	Participant 11	Participant 12
AD	BD	CD	DC

Each concept was thus tested by six people, and each concept was shown three times as the first concept in the test. Due to Covid-19, the user study was conducted online through the videocall application Zoom. The reason for choosing Zoom was because of the ability to optimize screen sharing, which allowed for a seamless playback of the animated videos of the concepts.

Since parts of the interviews were recorded, a GDPR form was created based on a template from Volvo Cars. The form was sent to each participant for approval before the test to save time during the user test, see **Appendix G**.

To collect as much qualitative data as possible, the user study was carried out through predetermined interview questions in a semiconstructed manner. The interview was also combined with laddering and probing techniques to gain more data from the users when necessary. Table 13 shows the questions the user study aimed to answer.

Table 13. Questions of relevance for the user study.

Pre-notification	How well do the users understand that something is going to happen?
Takeover-phase	How well do the users understand the car's intention for the user to take control?
	Do the users understand that they must push the buttons to take back control?
Post-notification	Do the users understand the reason behind the Takeover request?
	Does the car provide sufficient information to the users?
General	What concept do they prefer and why?
	What elements of the interface do they like and what elements do they dislike?

The users were first presented with a brief introduction of the purpose and a short description of the context. The user then got to see Concept 1 without the procedure of pushing the buttons. The purpose was to see how well they interpreted the signal before taking any action. Next, the user got to see the whole sequence from the Pre-notification to the Post-notification to see how well they interpreted and experienced the concept one a more holistic level. Lastly, the user was presented the concept's different sequences, one at a time, while being interviewed between each sequence. The sequences that were presented to the user were the Pre-notification, the Takeover and the Post-notification. As for Concept 2, the user was presented with the concept in the same manner as Concept 1, except for the sequence before pushing the buttons. The reason for not showing this sequence again was based upon the assumption that the user already knew too much, making it almost pointless of showing it again. The data collected in Part i, would therefore be more accurate as the answers would not be affected by the biased learning effects from the previous concept. The procedure can be seen in Table 14, while the complete structure with all the questions for each part of the user test, can be seen in **Appendix H**.

Table 14. Procedure of the user study.

Concept 1		Concept 2	
Part i	Before pushing the buttons	-	-
Part 1	Whole sequence	Part 1	Whole sequence
Part 2	Pre-, Takeover and Post-notification	Part 2	Pre-, Takeover and Post-notification

7.1.3 Analysis

An analysis of the comments was conducted. The first step of the analysis was to separate the positive and the negative comments on each sequence of the concepts. Each concept was also categorized according to a theme to make the grouping of all the comments more efficient later in the analysis. The comments from each participant were collected and sorted in a spreadsheet for each concept. To clarify certain comments from the note taking document, the video recordings of the interview were used. The structure of the spreadsheet was divided into two parts: the phases at the top row panel and the participants on the left side panel. Each of the comments were then arranged according to this structure. The top row panel consisted of the Pre-notification, the Takeover, the Post-notification, General, and Part i (cf. Table 14). Each of these columns consisted of a column of rating, using the PMI evaluation and notetaking.

The take-aways for each concept were then arranged in a new spread sheet that explained how the concepts were interpreted, together with a summary of the positive, the negative, and the general opinions about each concept in different phases of the transition. The comments from each participant on each concept were summarized for each phase. The take-aways were then summarized and rated, using a PMI based on the comments and how well the concepts performed in terms of UX and usability. A summarized experience of each concept could therefore be presented. For full review of the comments, see **Appendix I**.

7.2 Result

The interview answers gave valuable insights in how the concepts were perceived and a summary of the takeaways from the user study can be seen in **Appendix J**.

7.2.1 Concept A; Lightning

The general opinion about concept Lightning was positive in the Pre-notification and Takeover-sequence but lacked explanations on why the transitions happened in the Post-notification. Participants seemed to like the aesthetics and the intuitive illustrations and texts.

“It looked nice and futuristic. It required me to actively grab the steering wheel.”

The Pre-notification performed exceptionally well where 5 out of 6 participants understood that they had to prepare for a Takeover. Most of the signals were understood correctly, especially the steering wheel symbol, the “Prepare” text in the ICD, and the ambient lights which got the users’ attention and understanding. The static change in the ICD together with the windshield lights seemed to get the users’ attention as well. Furthermore, most participants wanted audio signals as a complement to the visual cues to increase the attention and understanding of the system. Both beep sounds and GPS-voices were mentioned as suggestions to improve attention. One test participant focused on the road and missed the visual signals completely in one of the playbacks. Another felt overwhelmed while the information felt fuzzy at the same time.

In the Takeover-phase, 4 out of 6 participants understood the signals and how to take back control. Some interpreted the signals as clear and intuitive. Many of them noticed the shifting color and flashing

around the buttons. They also noticed the text “Push and hold” in the ICD and the illustration of holding the steering wheel in the CSD. One person did not understand why the signals occurred and did not understand them as having to take back control and drive. Some mentioned that they wanted information beforehand to understand the system and to act in a correct manner.

The most notable signal in the Post-notification was the instruction “Drive the car” in the ICD. One person noticed the message on the CSD but did not have enough time to read it. The Post-notification was not effective at increasing the transparency and understanding of why the transition occurred. Additionally, none of the participants understood the reason of the transition. As the information felt unclear and insufficient, some participants wanted a clearer AP status. One person misinterpreted the flashing buttons with turning lights. For the participants in Part i, 2 out of 3 understood that they had to take over, but none mentioned that they had to push the buttons. They also described the situation as difficult, as they wanted to look at the steering wheel, the screen, and the road at the same time, which did not feel safe.

7.2.2 Concept B; Firefly

Concept Firefly was not successful in the Pre-notification and Takeover phase. Although people seemed to appreciate the GPS map with the yellow dot in the CSD, they did not really understand the reason for the signal. In the Pre-notification phase, 3 out of 6 people noticed the GPS map with the yellow dot. One person liked it because of the clear contrasts. Furthermore, 4 out of 6 participants understood they should prepare for the Takeover. They noticed the instruction “Get ready” in the ICD, the steering wheel illustration in CSD, and the flashing light on the steering wheel. The signals were mostly noticed but some had difficulties understanding the intention of the car. For the Takeover-phase, 3 out of 6 participants understood how to act to take back control, mostly because of the glowing buttons, the steering wheel symbol and the text. Some participants noticed the signals but were confused that both buttons lit up and misinterpreted it for turning lights.

“I think it wanted me to change to the right lane. [...] Normally you would see flashing turning lights.”

There was also some confusion regarding the shifting color and why they were supposed to push the buttons. For the Post-notification, 3 out of 6 mentioned that they felt safe with the information presented to them. Most participants noticed the glow and text “Drive the car” in the ICD. Furthermore, none of the participants noticed the message in the CSD and did not understand the reason for the transition. Many participants did not feel that there was enough information given, and some experienced the transition as stressful. They suggested more time to be given and earlier signals to feel safer. One participant did not fully understand the speed indicator in the ICD and was generally confused of how the system worked. They therefore suggested instructions beforehand to understand the system better. All participants suggested audio signals, using both instructive GPS voice and beep sounds. However, one participant preferred this concept over the Galaxy concept because of the clearer, easier, and cleaner interfaces.

For the participants from Part i, only 1 out of 3 understood how to act and assumed they should drive manually. Furthermore, all participants from Part i, noticed the steering wheel symbol, while one of them did not understand the symbols fully. One participant misinterpreted the text in the ICD saying “Push and hold” with pushing the brake.

7.2.3 Concept C; Galaxy

Many participants interpreted Galaxy as intuitive and clear. The aesthetics were also an aspect in this concept that was highly appreciated by many as it was considered futuristic and clean. The strongest sequence in this concept, but the weakest in comparison to the other concepts, was the Pre-notification. Many noticed the cues and signals given in the ICD and some expressed great appreciation of the glow, colors, illustrations, and buttons on the steering wheel. In the Takeover-sequence, 4 out of 6 participants understood they should take back control. What was especially noticed in this concept was the illustration and text in the ICD. The ambient light also helped the users gain awareness of the situation.

The least favorable sequence in this concept was the Post-notification as 5 out of 6 thought the information given was insufficient. Many did not understand why it occurred but assumed the event was triggered because of the overtaking car. Some also expressed great concern with the glow as they thought it was annoying and too intense. One participant wanted to familiarize themselves with the system first to appreciate this concept. What was unique with the Post-notification was the Avatar on top of the dashboard in the vehicle. The Avatar was appreciated for those who noticed it as it clarified the driving mode. However, one participant felt flooded with information from the other screens, making the Avatar harder to interpret.

"I did not notice the small screen with "AP ON" (the Avatar) when the bigger screen in front were glowing."

In the Pre-notification, some felt confused of why it happened and did not know which driving mode was active. Comparing this to the 3 participants from Part i, 1 out of 3 understood they somehow had to take back control. They also assumed that the Takeover was initiated due to the overtaking car. Some of the participants felt that the text "Push and hold" in the ICD was a bit unclear and paid more attention to the road than the interior of the vehicle. Overall, all participants felt like sound signals would make this concept much clearer and that Galaxy was preferable to Lightning.

7.2.4 Concept D; Game

Based on the comments and a PMI evaluation, Game was ranked the highest compared to the other concepts. Through the PMI, it was scored equally good in the Pre-notification and the Takeover-sequence as Lightning. When asking the participants which concept they preferred, Game was preferred over the others including Lightning as it was considered clear, intuitive, and clean. What was highly appreciated in this concept was the HUD as many found it helpful to understand the transition in the Pre- and Post-notification. In the Pre-notification, which was the strongest sequence in this concept, 5 out of 6 understood that they had to take back control. With the HUD, they felt a sense of clarity when the overtaking car started glowing. The Takeover-buttons were also appreciated as they started glowing which made the participants aware of the situation. Some noticed the text "Get Ready" in the ICD. However, it is uncertain whether they understood the meaning of what to get ready for. One participant felt confused why it happened and expressed a sense of confusion over the driving mode. As some participants thought the overtaking car was the reason for the Takeover, some also assumed that it occurred due to an alertness check by the vehicle.

“It could be checking my alertness. There are many autonomous cars that wants you to pull the steering wheel to see if you are awake.”

In the Takeover-sequence, 5 out of 6 participants seemed to have understood the sequence well. Most of the participants noticed the cues that were given like the buttons, the ambient light, the illustrations, and the text instructions. The glow and the shifting color also seemed to effectively direct the attention of the participants to the automated system. What was less appreciated in this sequence was that the time for the Takeover felt insufficient. Some also found the countdown animation in the ICD to be confusing. The reason was simply due to the interpretation of having to push the buttons three times instead of holding it for three seconds. Someone forgot the text in the ICD, even if they understood the Takeover through the illustration in the CSD. Another participant misinterpreted the system and thought the car wanted to check their alertness.

In Post-notification, the weakest sequence in this concept, but stronger than the other concepts, 3 out of 6 thought they got enough information to understand why it happened. They felt safe and, as mentioned earlier, the HUD with the explaining text made them appreciate the experience of the transition more. Some of the participants still did not know why it happened even after reading the post-message. Someone explained that they did not like the idea of having to read something after taking over and wanted to keep their eyes on the road.

“I think the text was confusing. If I were to own an autonomous car, and something happens that forces me to drive, then you get a little ... not upset but awakened, and out of nowhere, you have to focus on reading a text as well.”

Someone else did not feel like the car was demonstrating actively how to take over. One participant noticed the text in the HUD but forgot it. One participant felt like the system was flooded with too much information, with too many screens to look at at the same time. Others thought it was unclear of why they should push the buttons. Comparing this to the unbiased participants in Part i, some mentioned that it was too distracting with too many screens, and that they did not notice the text during the Takeover-sequence until it turned orange. Someone else understood they should push the buttons to take over and thought it occurred due to the overtaking car. Overall, most participants felt the need of having sound signals to make this concept more appreciable.

7.3 Summary and Implications

The user study was successful in that it gave valuable insights on which design concept that worked, and which did not. Through a PMI evaluation based on the comments from the participants, concept Game was ranked the highest in all the phases in relation to the other concepts. The reason was most likely because of its clear visual signals in the HUD, explaining the reason of the Takeover together with the other pedagogic signals. The HUD messages in the concept were noticed by more participants than the other screens like the CSD. The reason could be because the information was presented in the driver's view field and was therefore easier to recognize.

All the concepts except Game provided unclear messages in the Post-notification. which was placed in the CSD and was therefore often missed. The Pre-notification was interpreted rather stressful, and more time would be needed in the Pre-notification for the drivers to interpret the messages. The signals were

often noticed, but many users did not fully understand the signals since they were completely unaware of how the system worked. Therefore, more clear and more pedagogic instructions should be used to guide the driver's attention and action in the right direction. The concepts used many visual information channels, and it could be questioned if all the screens were necessary in this concept. Furthermore, important information needs to be placed in the driver's view field, and the CSD should only be used for secondary information.

The test revealed that visual information could easily be missed if the attention is drawn elsewhere, and it could be concluded that it was necessary to use more than the visual senses in the HMI for the transition. All participants suggested audio signals to improve the clarity of the visual signals. Some described it as not feeling comfortable and safe using the automated system without any sound involved. Some users wanted an auditory voice that could help them understand the situation better, like a GPS. The test also proved that multiple visual information channels could lead to information overload with a limited attention span, especially among elderly users. The steering wheel illustration was successful at mediating the intention of holding the steering wheel and pushing the buttons. Some participants missed the animated illustration of the steering wheel in the CSD and had to read the text in the ICD instead.

Some users would feel more comfortable using the concepts if they got more experience with the system beforehand. That is something that could be seen also in the answers between the first and the second concept that were presented to each participant. When the participants experienced the second concept, they were already familiar with the scenario and could therefore interpret the signals more easily as they knew what they were looking for. However, the user study was structured in a way to limit the risk of uneven amount pre-experiences between the concepts, but the learning factor was not eliminated completely.

Since the tests were conducted online, there was a risk of poor resolution of the videos presented to the users. This could alter the experience of the concept negatively as some cues could go missing. To prevent this from happening, the users were asked beforehand if the image looked clear and that they should inform during the user test if the videos were to be presented in poor resolution. It is however not possible to ensure that the playback for each video sequence had the same quality each time. Another potential drawback of the test was the frozen imagery at the end of each sequence, which gave the users more time to think and analyze the interface than they would do in a real scenario. Since concept Game scored the highest based in the analysis of the data from the user study, it was decided to continue with this concept through further improvements.

**FINAL
CONCEPT**

8. Final Concept

A final concept was developed based on the feedback from the user study, using concept Game as a starting point. The aim was to develop a final concept that would improve the user experience in the transition from AD to MD, and to make the concept possible to evaluate in an expert evaluation.

8.1 Method

To develop a final concept, a new guideline was created to form an action plan for further improvements. After Effects was used to recreate the animated elements for each information channel of the system while Unity was used to assemble the system in a VR environment. Auditory voice, now referred to as VUI (Voice User Interface) and auditory sound, referred to as SUI (Sonic User Interface), were added to the system to enhance the experience of the visual cues presented to the user.

8.1.1 Guidelines

First, some general guidelines for improvement were created based on the conclusions from the user study of the four concepts. The conclusions were then translated into guidelines for each phase of the transition. The concept was evaluated in terms of how well it performed in comparison to each of the individual guidelines. Based on the user study, it was concluded that the Pre-notification was a good complement for the transition. It was discovered that audio cues were necessary to make the visual cues clearer and more evident. The steering wheel illustration in the CSD was efficient to prepare the users for the Takeover by making them grab the steering wheel. Some concepts from the user study felt overwhelming with multiple different information channels involved. The information channels therefore needed to be narrowed down to the most important ones for the user. Based on the user study results, it seemed like the ICD and HUD were the most natural places to look at when noticing something urgent in the car. Most of the participants noticed the information given in the ICD, which might be due to old driving habits.

All the guidelines for the Pre-notification could be applied to concept Game, except for the ambient light in the windshield. As the HUD already involved a lot of movement, the ambient light could conflict with the HUD by adding another flashing light to the windshield. As for the glowing buttons on the steering wheel, it already functioned well in the concept which means it should remain. Additionally, improvements could be made in the pedagogic illustrations and the duration of the Pre-notification.

All the guidelines for the Pre-notification phase can be found in Table 15.

Table 15. Guidelines for the final concept in the Pre-notification phase.

	Guidelines for Pre	Comments	Status of concept Game
ICD	Keep the steering wheel symbol	Mentioned by multiple users	Consider
Ambient light	Reduce the level of intensity and movements		Consider
	Keep the moving light in the windshield		Missing
Buttons	Keep the glowing light inside		Exist
Pedagogic information	Clarify the instructions in illustrations and texts		Improvements needed
	Clarify why they should prepare		Improvements needed
	Keep animated illustration of the steering wheel	Mentioned by multiple users	Improvements needed
Suggestions	Explain reason for Takeover		Improvements needed
	Prepare (to drive) in ICD		Consider
	Increase the duration of the signals		Consider

To prevent the association with turning lights during the Takeover, a guideline for this was created in the ICD. According to the user study, the steering wheel illustration clearly worked to make the user grab the steering wheel and was therefore something that should be kept for the final concept. The instructional text in the ICD helped many participants understand how to use the buttons on the steering wheel. However, it needed to be specified more clearly. Concept Game would benefit from implementing clearer and more pedagogic information for the Takeover-phase. The color change from blue to orange was appreciated by some users and concept Game already utilized that in a proper manner. All the guidelines for the Takeover-phase can be found in Table 16.

Table 16. Guidelines for the final concept in the Takeover-phase.

	Guidelines for Takeover	Comments	Status of concept Game
ICD	Keep the steering wheel symbol	Mentioned by multiple users	Exist
	Avoid association with turning lights in the button animation	Mentioned by multiple users	Exist
Ambient light	Reduce the level of intensity and movements		Exist
	Keep the moving light in the windshield		Missing
Buttons	Keep the moving light around, and the glow inside buttons		Exist
Pedagogic information	Clarify the instructions in illustrations and texts		Improvements needed
	Clarify why they should push the buttons		Improvements needed
	Keep illustration of the steering wheel	Mentioned by multiple users	Improvements needed
Suggestions	Push and hold the buttons		Consider
Color	Keep the color change from blue to orange		Exist

The Post-notifications were not successful in most of the concepts, and it was only concept Game that was somewhat successful in explaining the reason for the Takeover. The reason for this could be because of the size of the text and because the HUD was used to present the message instead of the CSD. The MD UI had to be presented differently compared to the AP UI since some users were confused with the AP status. The guidelines for the Post-notifications can be found in Table 17.

Table 17. Guidelines for the final concept in the Post-notification phase

	Guidelines for Post	Comments	Status of concept Game
ICD	Improve the UI of the MD mode		Improvements needed
Pedagogic information	Clarify more clearly why the request happened	Mentioned by multiple users	Improvements needed
	Expand the size of the post-message	Mentioned by multiple users	Improvements needed
	Extend the time of the post message	Mentioned by multiple users	Improvements needed
	Clarify the message and make it more intuitive	Mentioned by multiple users	Improvements needed

Even if concept Game was successful in terms of the Post-notification, improvements were needed according to guidelines in Table 17. The information needed to be bigger and clearer, and the UI in the ICD needed to be distinguished between AD and MD.

The analysis of the interviews resulted in some general guidelines to consider when developing the final concept (see Table 18). According to the user study, all participants wanted sound to be included in the

HMI to clarify the signals. This could have a huge impact on the experience and could potentially greatly improve the concept. The HUD seemed to have worked properly to get the users' attention compared to the CSD.

Table 18. General guidelines for the final concept.

	General guidelines	Comments	Status of concept Game
Status	Clarify AP status	Mentioned by multiple users	Missing
HUD	Keep the highlighted car		Exist
ICD	Keep text message	Mentioned by multiple users	Exist
Pedagogic information	Minimize multiple information screens	Mentioned by multiple users	Consider
Sound	Include sound in all phases	Mentioned by multiple users	Missing
Suggestions	Consider using navy blue in the interface		Consider
Color	Have clear contrasting colors in the UI		Exist

When comparing concept Game with the general guidelines, it could be further improved regarding some aspects. The concept did not have a proper way to clarify the AP status.

To present the essential information to the user in an efficient manner, information overload should be avoided and the CSD should thus only be used for secondary information as it is not positioned in front of the driver. Visual cues on the steering wheel is a possible alternative and the area in front of the driver is a good option for placing information. If the visual cues are successfully implemented, it could increase the UX, trust, and acceptance, and result in an enhanced human-vehicle experience (Muthumani, Diederichs, Galle, Schmid-Lorch, & Forsberg, 2020).

All users requested sound signals to complement the visual cues. This is something that could be implemented in the final concept by using both VUI and SUI.

One person from the previous user study suggested using navy blue for the UI instead of the cyan, which could also be an improvement to the aesthetics.

8.1.2 After Effects

The animation of the final concept was created using After Effects and Unity. After Effects was used to create the different elements of the UI while Unity was used to assemble the different elements into a coherent HMI. The elements used for the whole system were the 'ICD', 'CSD', 'HUD' and the 'Takeover-buttons' on the steering wheel. As mentioned earlier, both VUI and SUI were integrated in the system as it was desired by many participants from the user study.

Audio

The SUI signals were used in three scenarios throughout the transition: 'Pre-notification', 'Takeover' and 'Post-notification'. Due to lack of time, already existing sounds were used, both from Volvo Cars and external creative common platforms like Freesound. The VUI was created using a platform called

Voicebooking where words were converted into a synthetic voice. The sound file was then edited on an iPad using the music production software Garageband. Various plugin-effects were used, and the high frequencies were lowered to remove any unwanted noise. The aim was to modify the sound to make it sound more anthropomorphic and synthetic, creating a sense of robotic intelligence. The idea was to create a sense of smartness in the vehicle which hopefully would have a positive impact of the UX during, before, and after the transition. All the audio sources, like the traffic noise, VUI and SUI, were added to the ICD video to adjust the volume and synchronize it with the animations in the other screens. Adding the traffic noise made it possible to adjust the audio level of this source to replicate the active noise cancelling (ANC) effect used in certain headphones.

Visuals

In the CSD, the NDRT video during AP was created by gathering different cinematic video samples of the nature from a creative common platform called Pexels. The reason for choosing nature as the NDRT content of the video was to resonate with Volvo's vision of sustainability by going fully electric by 2030 (Volvo Cars, 2021). To keep track of the synchronization between each animation, the ICD was first created to guide the animations that would be presented on other screens. The reason for choosing the ICD was because of it being the primary information channel for the user, while the other channels, such as the CSD and HUD, were considered secondary information channels. Although many elements from the Game concept were replicated, there were major changes made which in some cases resulted in a complete recreation of some elements. Another important aspect that had to be considered was where each sequence of the animation should start and end, as well as how the transition between each sequence should look like. As Unity is built on scripts and the video material that would be inserted into the program would be triggered by different events, it was important to be aware of this as the transition from After Effects to Unity would be more seamless.

Set-up

To prepare the material for Unity to be interactive in the 'Final evaluation', different scenarios had to be presented depending on the user's action in Unity. In total, there were three potential scenarios depending on their action: not pushing the buttons, pushing the buttons before the escalation point, and pushing the buttons after the escalation point of the Takeover. As the minimal risk condition was out of the scope for this thesis, this scenario was excluded from this concept. As the minimal risk condition was excluded from this thesis, the scenario 'the user not pushing the buttons' would result in a loop. The loop was created to be undetectable by the user to avoid the user from feeling guilty if they failed to deactivate AP. If this would happen, the concept would have failed to convey the messages to the user in time.

To structure the animations in an organized manner, a scheme had to be created. Besides the Pre-notification, Takeover, and Post-notification sequence, it was important to consider how the animation would look like when AP was on and off (see Table 19). It was also important to get the right dimensions of the composition created for the animations to maintain the resolution in Unity. The size of the ICD was concluded to be 1920x720 pixels while the CSD had 768x1024 pixels.

Table 19. Different Sequences between Different Elements of the System.

	AP ON	Pre	Takeover	Post	AP OFF
ICD	Seq. 1)	Seq. 2)	Seq. 3.1) Loop		
			Seq. 3.2) Blue Push		
			Seq. 3.3) Orange Push		
HUD	Seq. 1)	Seq. 2)	Seq. 3.1) Loop		
			Seq. 3.2) Blue Push		
			Seq. 3.3) Orange Push		
Buttons		Seq. 1)	Seq. 2.1) Loop		
			Seq. 2.2) Blue Push		
			Seq. 2.3) Orange Push		
CSD	Seq. 1)	Seq. 2)		Seq. 3) Confirm	
Sound		Seq. 1)	Seq. 2.1) Loop		
			Seq. 2.2) Push and Confirm		
Voice		Seq. 1)		Seq. 2)	

8.1.3 Unity

To create the VR environment, Unity was used. Instructions and tutorials from Volvo’s homepage were used to set up Unity with Package files. This section presents a simplified process of creating the Unity project.

Converting the Transparent Videos

As the Package Files with the environment and the car were modular, it was supposed to be possible to implement the video sequences in Unity through Video Player components. Due to compatibility and codec issues, the video files first had to be rendered into QuickTime File Format (QTFF), to maintain the transparent background. To import the files into Unity, they had to be converted into WebM through a platform called FFmpeg. The conversion of the video files was accomplished by entering a script in the Command Prompt terminal as an administrator (see **Appendix K**).

Creating the Scene Set

To import the converted video files into Unity, the environment and the car had first to be imported. To set this up, a Scene Set was created where the car and environment were imported and installed from the Package Manager. The environment used for this scenario was a four-lane highway, two on each facing side. The vehicle used in the project was a XC40 Recharge, which was also installed from the Package Manager. In Figure 52, the scene in the editor window of the project is illustrated through the highway and the XC40 Recharge.

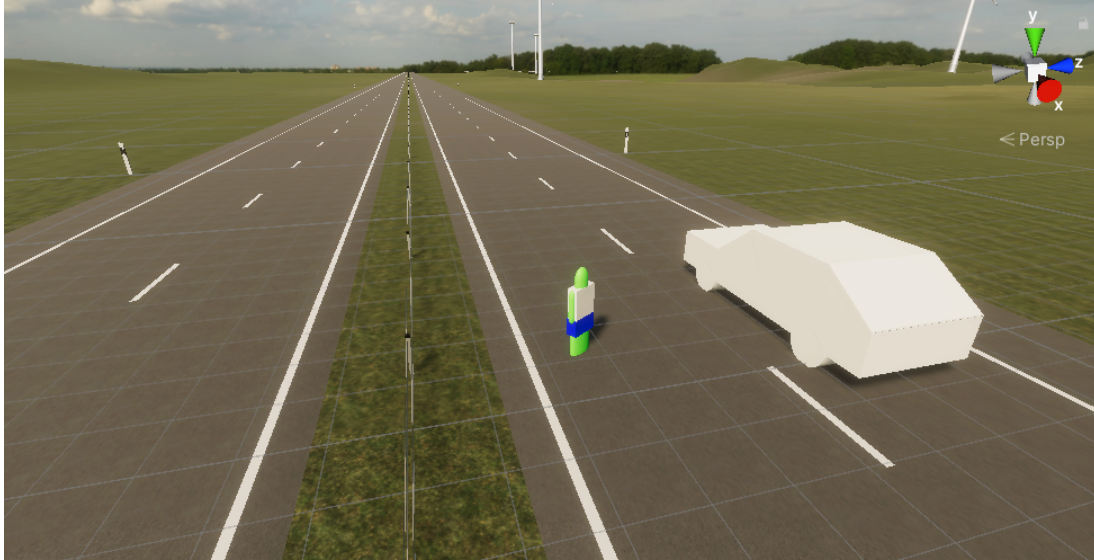


Figure 52. Unity project seen from the editor window.

In the Editor Window, different components and parameters were adjusted to add more functions to the project. For instance, the CarMover component was imported and added after receiving the script from one of the experts. The CarMover component simulated AP in the XC40 Recharge, by making the car follow the highway path while avoiding the surrounding traffic. Through this component, it was also possible to adjust the speed of the vehicle. To control the viewpoint of the driver in the vehicle, a component called Controllable HumanHDP from the Package Manager was assigned to the driver's seat in the vehicle.

The Overtaking Car

To create the overtaking 'glowing' car in the simulation, a manually placed prefab car had to be placed into the scene seen in Figure 53, since the traffic around the car was spawning in a randomized order. The car that was used for the overtake was a grey XC90, which was placed in front of the drivers' vehicle, to see if it would follow the assigned path on the road in the simulation.



Figure 53. Prefab of the overtaking car.

To create the trajectory for the overtaking car, an asset had to be downloaded from the asset store which was called Path Creator. This enabled the ability to manipulate the path using Bezier paths. To create the path and assign it to the overtaking car, a script had to be created (see **Appendix K**). This allowed for the speed of the overtaking car to be adjusted in the parameter window. To make the overtaking car coordinate with the Pre-notification, the position of the path had to be adjusted.

To create the shimmering effect on the overtaking car, a glowing material was applied on the body of the prefab. This was done by creating a new shader and applying it to the new material. The glowing shader was created through graph coding using different vectors and nodes. This provided the ability to adjust the emission and saturation of the glow in the material. The new shader was then assigned to the body on the overtaking car, creating a glow effect on the car that would resemble the HUD of the Game concept which can be seen in Figure 54.



Figure 54. Glowing overtaking car

Importing the Videos

To import the videos with the different cues and information channels, the videos had to be applied inside the prefab. The prefab of the self-driving car consisted of many different components which were only accessible when entering it in the editor window, see Figure 55.



Figure 55. Editor window of the prefab.

There were two approaches to import the videos to the project. The first approach worked for the existing screens of the interior, the ICD and the CSD, where the videos were imported into the project in MP4. By creating a component called Video Player, the MP4 video could be imported. For the video to be visible, a Render Texture component had to be created in addition to the Video Player component. A Material component was also created, to connect the different components to each other.

As for the WebM videos for the buttons and the HUD, the process was a little different. Once the videos were converted and imported into Unity, the video files had to be transcoded. The Video Player together with the material and the render texture component would then be created in the same manner as for the MP4 video. Different parameters were adjusted in the editor window to disable the foggy background of the transparent plane before it could be presented in the project.

Unfortunately, due to the time limit and the difficulty of programming, it was not possible to make the Unity set-up interactable. Instead of making the set-up interactable, each element of the concept consisted of a long continuous video-sequence that was presented through the transition. Each video started at the same time, coordinated with each other despite not being interactable.

8.1.4 Internal Evaluation

To evaluate the final concept before the user study, an internal evaluation was conducted by comparing the final concept with the guidelines that were presented in Chapter 5. The aim was to see how well the concept fulfilled the high priority guidelines for the 'Pre-notification', 'Takeover', and 'Post-notification' of the transition. When comparing the concept with the guidelines on each phase of the transition, it was possible to see if the guidelines were applied to the final concept or not. The guidelines were used as a reference and the final concept was evaluated using the high priority guidelines of the different

phases of the transition.

8.2 Result

The following section presents the result of the methods applied when shifting from After Effects to Unity. The results of the final concept will be presented, both with its respective element in After Effects, and the assembled elements in Unity. An action plan based on the new guidelines is also presented, along with an internal evaluation of the concept.

8.2.1 Action Plan

Based on the guidelines presented, an action plan was drawn up for the final concept. The purpose was to specify what changes that were necessary to improve the concept in each phase. In

Table 20, actions for each phase are presented. The goal was to make the information more presentable and logical, and that the concept would be clearer in terms of visuals and audio. One major change to the concept was the added VUI and SUI, which will be explained more in depth in the next section.

The illustrations in the ICD provided clearer instructions with illustrations in combination with the text. The HUD was visible throughout the transition. The CSD was eliminated during the Takeover-sequence to minimize information overload. In general, the speed in the movements were decreased, the information prolonged, and texts were made bigger and clearer.

Table 20. Action plan for the changes to be made in concept Game.

	Pre	Takeover	Post
Sound	VUI: Cars are driving faster, prepare to drive + ANC	Futuristic simple sound before and after escalation point	Add pling sound
		Feedback sound when pushing buttons	Add voice: Autopilot, deactivated + ANC
ICD	Implement text: "Prepare to drive"	Text: "Push and hold buttons"	Make MD interface different from AP Interface
		Steering wheel symbol slide to the left	
		Change aesthetics of circle when pushing the buttons	
HUD	Delete the timeline		Move information to above CSD or above steering wheel
	Text: "Autopilot ON" in green color	Text: "Autopilot END" Blue to Orange	"Autopilot OFF" White
			Consider having a frame for information (Text: AP status, cars were driving faster)
	Keep glowing car		Increase time of "Cars were driving faster"
CSD		Fade off to black	Checkbox illustration that confirm the deactivation of AP
General	Extend duration of Pre-alerts a few seconds		
	Use nebulae illustration from concept galaxy in AP mode		
	Keep ambient light under steering wheel	Decrease the speed of the light around the buttons	
	Needs improvement for illustration, text, and placement	Needs improvement for illustration, text, and placement	

8.2.2 After Effects

Based on the action plan, each of the elements was created while paying more attention to the details. Instead of animating all elements in the same composition as in the previous user study, each concept was animated separately with respect to the action plan.

ICD

The ICD was created first of all animations as it was considered the most important information channel. This also determined where each transition between the different sequences should start and end. It was evident that some sequences should be longer than others (as described in the previous chapter). The ICD was divided into five sequences as presented earlier in Table 19. The first sequence for AP ON was created using elements from concept Galaxy since the aesthetics were appreciated by many user study participants. Using elements from Galaxy together with Game was believed to create a positive experience and create a sensation of a Sci-Fi environment. The speed indicator within the center of the screen was kept in the same location as before while the bursting star dust from the center was made more discreet by decreasing the size and opacity of the animation (see Figure 56. ICD, AP ON

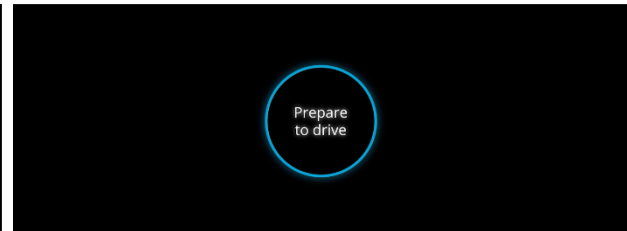


Figure 56. ICD, AP ON

The second sequence for the Pre-notification was created by removing the loading bar and adding an animation for the sound instead. While the star dust would fade out to form a blue circle in the center, a second circle around the center would appear, moving in relation to the VUI and SUI that were added to the system. As the VUI and SUI started cueing, the noise of the traffic was reduced to replicate the ANC effect. This circle would then solidify while only presenting a text saying, “Prepare to drive”. With the VUI telling the driver to “Prepare to Drive” while also showing it on the screen in the ICD, the pedagogic presentation of the information has been clarified and improved. Previously in the Game concept, the only information presented on the ICD was “Get Ready” which caused a lot of confusion of what to get ready for. When the text and the blue circle disappear after being presented to the user for a while, an illustration of hands holding the steering wheel appears instead. This illustration sends out a pulsating animation of a circuit board around the center, like the previous Game concept, but this time with SUI integrated in the system. The illustration would then slide to the left to create space for the Takeover-sequence. The purpose is to give the user a final heads up before presenting the cues for the Takeover-sequence. The whole Pre-notification sequence can be seen in Figure 57.



(a) Coordinating audio animation



(b) Instruction text



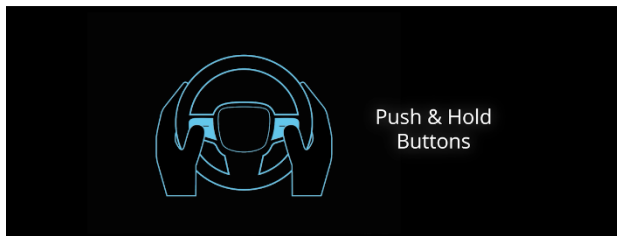
(c) Steering wheel



(d) Pulsating circuit board

Figure 57. ICD Pre-notification. (a) presents the coordinating audio animation that pulsates with the frequency of the sound. (b) presents the pedagogic instruction given to the user to prepare to drive. (c) presents the appearing illustration of hands holding the steering wheel. (d) presents the pulsating circuit board animation before sliding to the left.

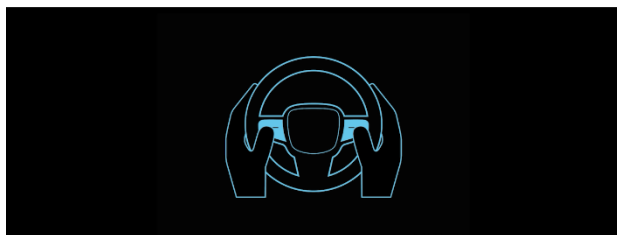
The third sequence of the ICD consists of three different outcomes depending on how the user would interact with Unity. Sequence 3.1, which is the loop, consists of a 10 second animation of the Takeover-sequence before returning to its starting point. This sequence consists of the illustration of the steering wheel with hands pushing the buttons back and forward while also presenting a text saying, “Push & Hold Buttons”. This was to clarify any uncertainty of what the user should do which was not clear enough in the previous Game concept saying, “Push & Hold”. The animation then shifts from blue to orange to indicate the escalation point of the transition. Furthermore, another pulsating animation of the circuit board in orange can be seen in the screen. If the user fails to do anything within these 10 seconds, the video loops and returns to its starting point, shifting from orange to blue again. The whole Takeover-sequence can be seen in Figure 58.



(a) Instruction Text



(b) Escalation point with pulsating circuit board



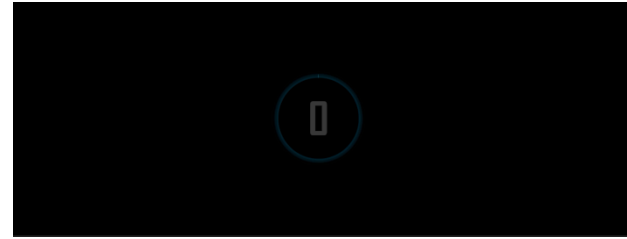
(c) Buttons being pushed



(d) Countdown begins



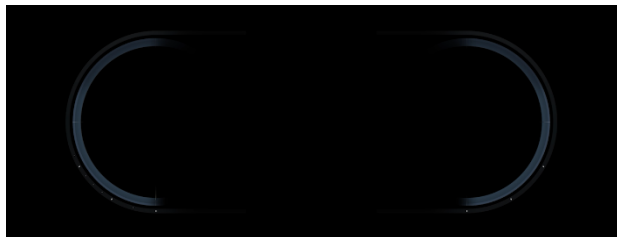
(e) Breathing animation around countdown



(f) Disappearing countdown

Figure 58. ICD Takeover seen from (a) to (f). (a) illustrates the text appearing. (b) presents the pulsating circuit board as the escalation point. (c) shows the steering wheel being centered again when pushing the buttons. (d) Indicates the countdown when the buttons are being pushed. (e) illustrates the end of the countdown. Around the countdown circle there is a second circle with a slower movement. (f) illustrates how the countdown disappears from the ICD.

If the user manages to push the buttons during the 10 seconds, the illustration of the steering wheel wobbles and moves to the center again before transforming to a futuristic loading bar seen in Figure 58. This loading bar has also been redesigned compared to the previous concept. Instead of having dashed lines circulating around the center, the circle is now unified. As the illustration of the steering wheel scales down and disappears, the loading bar scales up while appearing, making it more seamless. As the user continues to push, the circle decreases and counts down from 2 to 0 before vanishing to present the MD interface seen in Figure 59. These animations also occur in relation to the VUI and SUI to create a more immersive sensation of the experience.



(a) MD interface appearing



(b) MD interface

Figure 59. ICD Post-notification. (a) presents how the MD interface slowly fades in with animations. (b) illustrates how the MD interface looks like when finished animating its entry.

HUD

Once the animations for the ICD were created, the animations for the other elements were created much quicker. The animations for the HUD were drastically changed compared to the previous concept. The HUD consisted of five sequences shown in Table 19. The first sequence of the HUD during AP ON no longer had the loading bar that illustrated how much time was left before the Takeover. The reason was that the users did not notice this animation on the HUD. Instead, the HUD was used to clarify the driving mode status throughout the transition. As this was not crucial information for the Takeover, but rather something that would increase the understanding through redundancy, it was decided to use the HUD as a secondary information channel. The AP ON sequence now consists of a frame that encapsulates the information presented in the HUD. This was important as it was noticed in the user study that the information presented in the HUD might have been invisible due to the constant change of the environment behind the HUD. The background also had a slight tint of blue to make the windshield less transparent and the text more evident. During AP ON, the text glows in green to create a contrast to the blue background while showing the text “Autopilot ON”. The change from writing Autopilot instead of

AP was made to make the text clearer. To make the text more intuitive, ON is written in bold uppercase letters (see Figure 60).

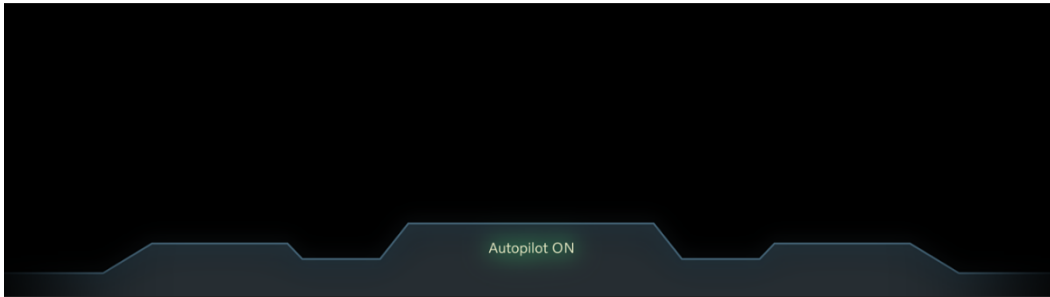


Figure 60. AP ON.

The second sequence of the HUD during the Pre-notification transforms the content of the text from “Autopilot ON” to “Autopilot END”. The text END is also written in bold uppercase letters to make it clearer that the AP is indeed ending. During this sequence, the color of the text shifts from green to shiny blue. To catch the user's attention, a small animation of the text was created, where the word ON disappears behind the word Autopilot before appearing with the word END (see Figure 61).

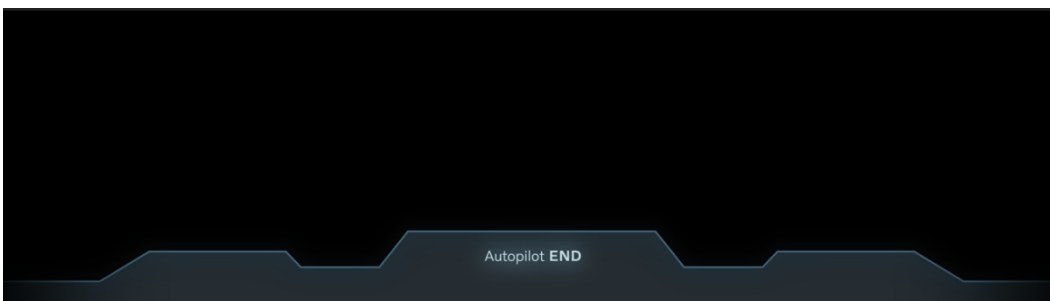


Figure 61. Pre-notification and Takeover. Autopilot END.

During the sequence of the Takeover, the HUD was not to catch too much attention as the idea was for the ICD to be the most prominent information channel. For the loop sequence, the HUD does not present any new information besides switching from blue to orange after the escalation point (see Figure 62).

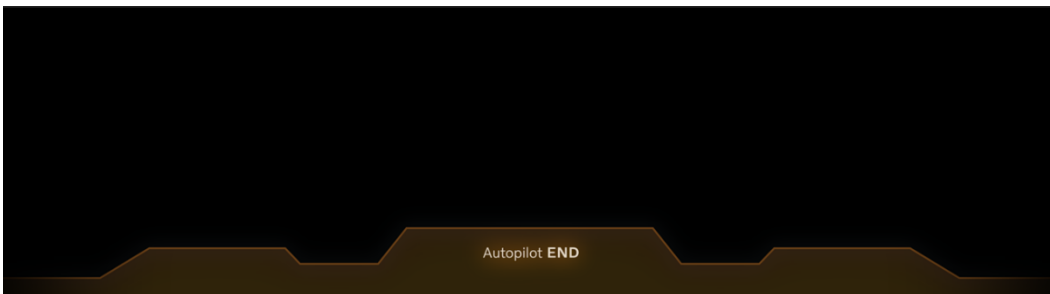
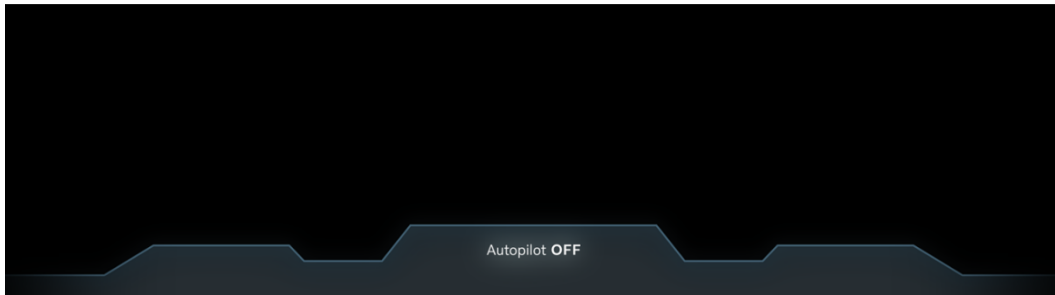


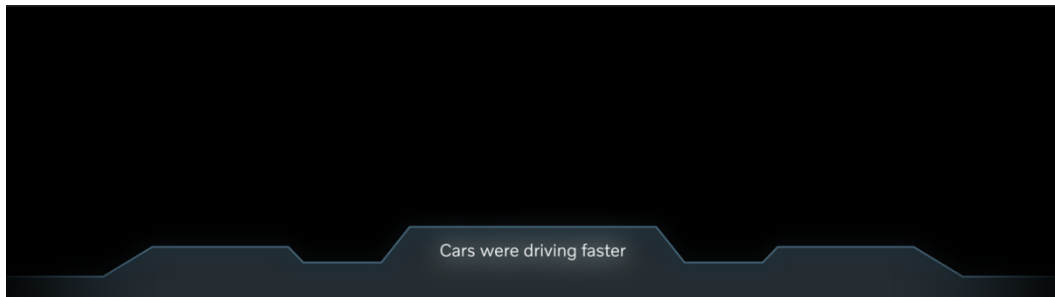
Figure 62. Takeover. Escalation point. Autopilot END.

If the user fails to push the buttons within the 10 seconds of the Takeover-sequence, the animation fades back to blue and plays the same sequence again until the user pushes the buttons. Once the user manages to push the buttons and complete the Takeover, the text switches color from blue to white

showing “Autopilot OFF” together with the auditory voice and sound in the system. The text then fades out and shows “Cars were driving faster”, as the previous concept, but with less movements and a longer duration. The text then fades out together with the frame to give the user a maximum point of view with minimum distractions on the windshield. Depending on if the user pushes the buttons before or after the escalation point, different animations are presented for each scenario to maximize the seamless transition between the different phases. The Post-notification sequence can be seen in Figure 63.



(a) Post-notification. AP OFF.



(b) Post-notification. Cars were driving faster.

Figure 63. Post-notification from (a) to (b).

Buttons

The animations for the buttons consist of four sequences. The sequence during AP ON and AP OFF does not communicate anything like the previous concept to minimize unnecessary distractions in less attention demanding sequences. During the more critical sequences, such as the Takeover-sequence, more thought has been put into re-animating the design of the concept. In the first sequence during Pre-notification, the mid-section of each button starts to glow in white as seen in Figure 64. This occurs simultaneously together with the VUI and SUI of the system.

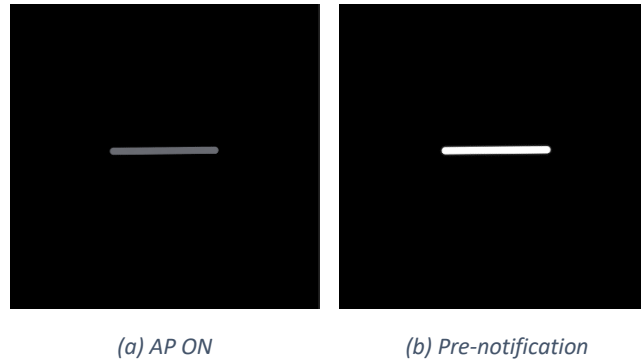
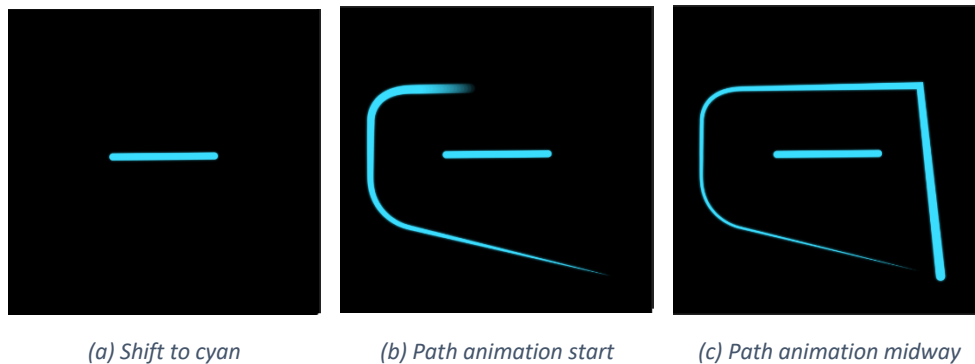


Figure 64. Buttons from Autopilot ON to Pre-notification. (a) illustrates Autopilot ON while (b) illustrates Pre-notification glowing in white.

During the Takeover-sequence, the mid-section of the buttons changes from white to blue like the previous concept but with a slight delay. This happens simultaneously with the pulsating circuit board on the ICD. One negative aspect that was considered regarding the animation on the buttons was the intensity of the animated path. To decrease the intensity, the timing of the animated path around the buttons were postponed with a few seconds. The speed of the animation was also slightly decreased. The animated path pauses for a moment before completely disappearing from the steering wheel to decrease the intensity of the movement. The animation was repeated twice to create a level of redundancy of the information presented to direct the attention towards the steering wheel. To direct the focus more towards the center of the steering wheel, the animation of the path was reversed and moved towards the center instead of away from the center like the previous concept. This could be the reason why some participants interpreted the light from the buttons as turning lights in the previous user study, as the animated path were moving in the direction away from the steering wheel. The Takeover-sequence can be seen in Figure 65.



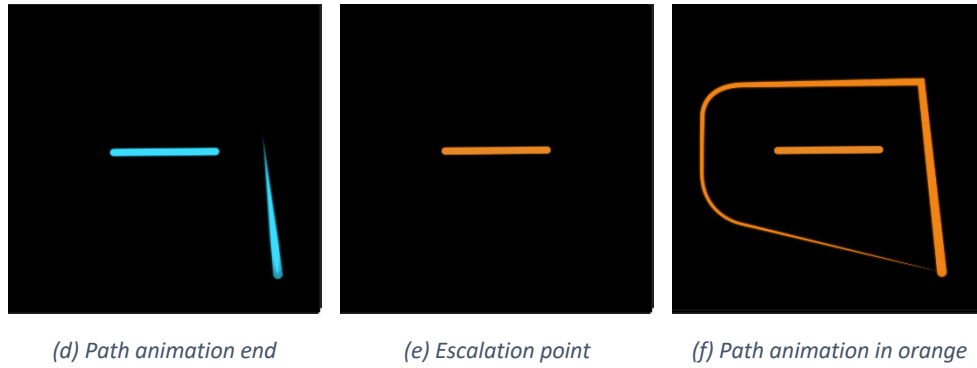


Figure 65. Buttons Takeover. (a) shows how the color changes from white to cyan. (b) to (d) shows how the animation flows around the button in coordination to the audio. (e) shows how the color change to orange in the escalation point. (f) shows how the animated path continuous in the same manner as (b) to (d) but in orange.

When the Takeover-sequence reaches the escalation point, the mid-section as well as the animated path turn orange. The animation moves slightly faster and is repeated faster than before the escalation point. If the user fails the push the buttons within the 10 seconds, the Takeover-sequence is repeated until the user pushes the buttons. If the user pushes the buttons, the color of the buttons turns white and fades out as seen in Figure 66.

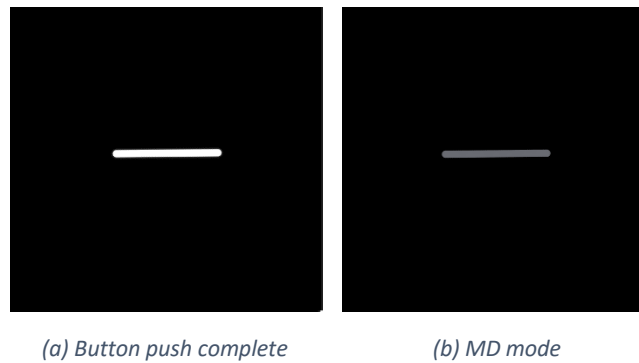


Figure 66. Buttons Post-notification. (a) presents how the buttons look like when they are being pushed. (b) presents how the buttons look like during MD.

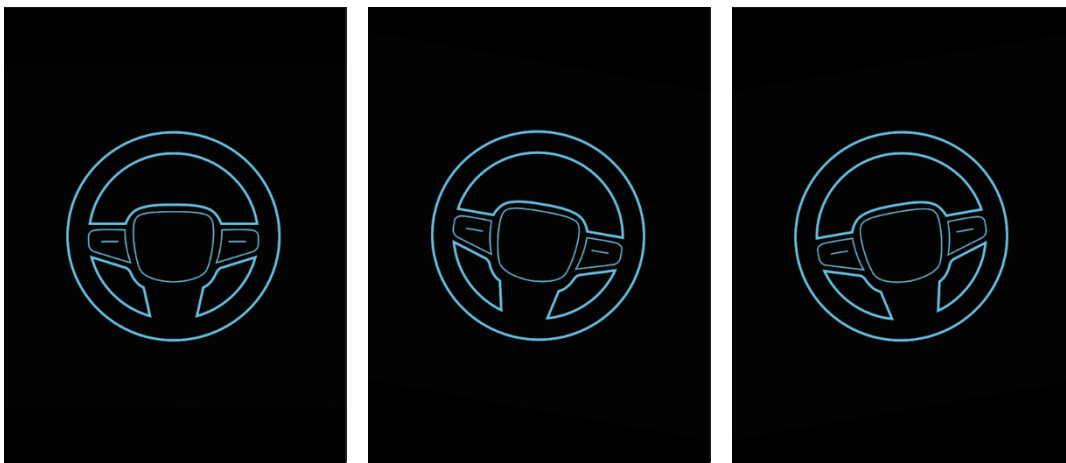
CSD

The CSD consists of three sequences. During AP ON, the screen displays an NDRT video sequence to create a more realistic scenario of the AP environment. Instead of having the video from the previous concept, which was a horizontal video presented in a vertical screen, a new vertical video was created. This would optimize the view of the video on the screen for the user which would create a more immersive sensation of the experience. This was important as a cropped video might obscure the content being presented, causing a sensation of frustration or irritation. A sample picture of the NDRT video during AP ON can be seen in Figure 67.



Figure 67. CSD AP ON with a NDRT video

During the Pre-notification sequence, the content on the screen fades out and an illustration of the steering wheel shows up. To increase the users' understanding, the steering wheel twists and turns slightly to indicate to the drivers that they should take over soon. This can be seen in Figure 68. When the Takeover-sequence approaches, the steering wheel on the CSD fades out to appear in the ICD instead. The CSD remains black throughout the Takeover-sequence to maximize the focus towards the ICD and the buttons instead. Another reason is to prevent information overload for the user, which could be caused by providing too many simultaneous information channels. This is more important during the more critical point of the transition which is the Takeover-sequence.



(a) Steering wheel appears

(b) Small animation to the right

(c) Small animation to the left

Figure 68. CSD Pre-notification. (a) to (c) presents the animation of the steering wheel, giving the user a sense of preparation.

As a sign of confirmation for deactivating AP, the CSD presents a green check mark, like the one seen in the avatar of the Galaxy concept. Not everyone noticed the avatar during the previous user test as the screen was too small, but for those who did, it was very clear. To make it more noticeable this time, the size of the check mark is much bigger compared to the one in the previous version. The check mark also appears in coordination to the SUI from the system. Once the green check mark fades out, the MD

interface fades in, indicating that AP is off and the NDRT content is no longer available to the same extent. The animated sequence of the CSD during the Post-notification can be seen in Figure 69

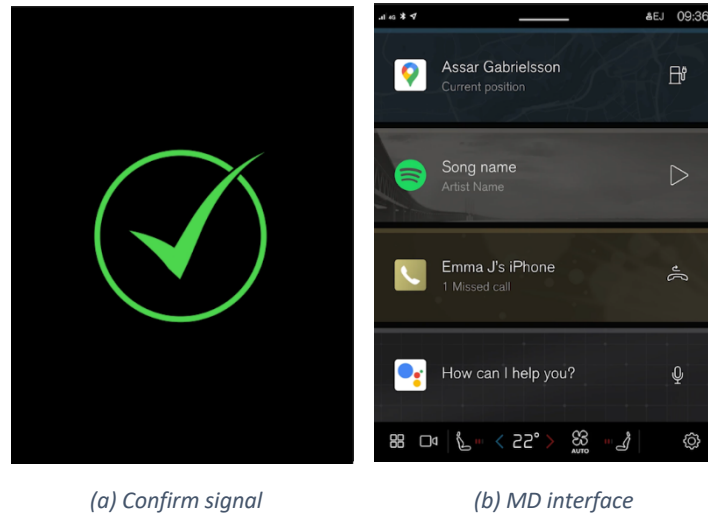


Figure 69. CSD Post-notification. (a) presents the confirm signal which appears in coordination with the sound. (b) presents the MD interface when AP is completely turned off.

Audio

In Pre-notification, the SUI signal used notification-like sounds from Volvo Cars before the VUI is being presented by stating “Cars are driving faster, prepare to drive”. The next SUI signal appeared during the pulsating circuit board from the ICD, both in blue and orange. This sound was extracted from Volvo Cars and was used with the belief of creating a sense of awareness rather than a warning. During the Takeover-sequence when the buttons are being pushed, two SUI signals are being presented; One click-sound from Volvo Cars which indicates that the buttons are being pushed together with a crystal-like sound from Freesound that fades in and out during the push sequence to indicate that the buttons are being held. During the Post-notification, a positive confirmation sound is being played right before the final VUI is being presented stating “Autopilot, deactivated”. The idea behind each of the sound elements was for them to not be perceived as too aggressive but rather express a sense of assertiveness and awareness.

During the previous user test, many participants commented that they would appreciate a GPS like VUI as some did not like the idea of having to read information while taking over. The idea behind using the VUI was also to make the car sound more intelligent and assertive but not aggressive and ‘panicking’. A couple of inspiration sources were therefore needed like superhero movies, such as Spiderman and Ironman, in which they talk to AI assistant VUI systems, and existing VUI assistant products like Siri and Alexa. It was important not to use the VUI too much as it could inhibit the perception of the surrounding environment. It was therefore necessary to use it only during the Pre- and Post-notification where the user has less cognitively load which is why the VUI was not used during the Takeover. Before the VUI signal explains the reason for the Takeover, the driver should already know that they are driving in MD. The purpose is therefore just to repeat the status to the user to confirm their action once again. In correlation to the VUI and SUI, the ANC is activated to cancel the surrounding noise around the car while paying more attention to the audio signals from the system.

8.2.3 Unity

Once each of the elements were created, they were rendered and converted before importing them to the Unity project. Despite not making it interactive, it was decided to proceed with Unity as it would give the user a more immersed experience when trying the concept in VR. The concept will therefore be presented for each sequence where the full animation can be seen through the link or QR code in **Appendix L**.

Pre-notification

The Pre-notification, seen in Figure 70, presents the different elements in the UI and the shift from AP to prepare. The AP mode was set to 40 seconds to get enough time to feel like the car was driving autonomously. During AP, the CSD presents the cinematic video sequence that looped until the Pre-notification started. This would create a sense of occupation or NDRT like watching a TEDx Talk video or looking at YouTube. The ICD also displays the nebulous animation taken from one of the previous concepts which also indicates at what speed the AP is driving. As the car speeds up, the nebulous would emit star dust. If the car would slow down, it would instead absorb star dust. In the HUD, the mode status of the AP can be seen saying “Autopilot ON” while glowing in green.

Once the Pre-notification starts, the glowing prefab car outside would make an overtake at high speed which in turn would activate the Pre-notification. The HUD mode status would then shift from green to cyan while showing the text “Autopilot END” instead. The ICD pulsates in coordination with the audio and voice signals before shifting into a solid circle with a white text, “Prepare to Drive”. The white text in the ICD only appears after the VUI finished saying “Cars are driving faster, prepare to drive” right before the SUI. In the meantime, the CSD fades out and turns completely black until the audio finished cuing both the VUI and SUI signals. The buttons start glowing in white and the CSD then presents the animation of the steering wheel twisting and turning before going black again right before the Takeover-sequence. The circle in the ICD also shifts from a circle to a steering wheel which occurs simultaneously as the CSD turns back from the animated steering wheel. The purpose for this was to shift focus from the CSD to the ICD where the primary information would be presented during the Takeover-sequence.



(a) AP ON



(b) Pre-notification begins



(b) During Pre-notification

Figure 70. Pre-notification. In (a) the AP interface can be seen. In (b) the beginning of the Pre-notification can be seen. In (c) the cue during the Pre-notification can be seen.

Takeover

During the Takeover-sequence, the AP status remains in the HUD from the Pre-notification by saying “Autopilot END” in blue. The ICD pulsates with the circuit board animation around the illustrated steering wheel together with an audio signal. The buttons shift from white to blue while also presenting the circulating animation around. The instructions in the ICD are then given, stating “Push & Hold Buttons” while flashing the buttons of the illustrated steering wheel in the ICD. The animated circle around the buttons is repeated once again before the system enters the escalation point and turns orange in the buttons, HUD, and ICD. While the color shifts to orange to indicate the escalation point of the system, the circuit board animation is being presented once again together with an audio signal in the ICD to grab more attention from the driver. The animated circle around the buttons moves slightly faster. When the buttons are being pushed on the steering wheel, the color in the buttons changes from

orange to white. The ICD also presents a countdown animation of the time left of holding the buttons before deactivating AP. The whole Takeover-sequence can be seen in Figure 71.



(a) Takeover begins



(b) Takeover before escalation point



(c) Takeover after escalation point



(d) Takeover when buttons are being pushed

Figure 71. Takeover-sequence. In (a) the Takeover begins. In (b) the cue before the escalation point can be seen. In (c) the cue of the Takeover-sequence can be seen after the escalation point. In (d), the animation for the countdown when the buttons are being pushed.

Post-notification

During the Post-notification of the transition, the HUD shifts color to white while showing “Autopilot OFF” instead. The CSD also shows a green check mark which is being presented together with an audio signal as a confirmation of the users’ actions. This would also be enhanced through the voice telling them that AP is deactivated. Once the VUI finishes talking, the HUD changes the text to an explanation saying “Cars were driving faster” which was mentioned during the Pre-notification. The purpose of this was to create a sense of redundancy of the information being presented twice in two different ways. The information presented in the HUD was extended with a few seconds to give the user time to read the instruction before it disappears completely and presents the MD interface only, see Figure 72.



(a) Post-notification after buttons pushed



(b) Post-notification of why it happened



(c) MD interface

Figure 72. In (a), the Post-notification can be seen with the green check mark after the buttons have been pushed. (b) presents the Post-notification in the HUD of why it happened. In (c) the MD interface can be seen.

8.2.4 Internal Evaluation

The final concept fulfilled all guidelines for the Pre-notification of the transition. Many improvements and applications were implemented which can be seen in Table 21 together with the information channels affected by each guideline.

Table 21. Fulfillment of the guidelines, improvements, and applications for the final concept in the Pre-notification of the transition.

Criterion	Theme	Fulfillment	Improvements, Applications	ICD	CSD	HUD	Buttons	Audio
Convey the message soothingly	Auditory	yes	Carefull choice of audio, removing noise with ANC, timing, fading off NDRT content, white glowing buttons		x	x	x	x
Minimise distracting noise outside ODD	Auditory	yes	ANC					x
Allow the user to prepare for the take-over	Overall	yes	Increasing time prior to the take-over phase, audio and voice, Pedagogic information (text, placement and illustrations) smooth movement of the steeringwheel symbol, Interrupting NDRT, changing AP status in HUD	x	x	x	x	x
Minimise stress in relation to the transition	Overall	yes	Increased time of the text "Prepare to drive", smooth movements in the UI, explaining the reason with voice, fades the NDRT content earlier	x	x			x
Minimise the association with danger and fear	Overall	yes	Increasing time to prepare, reduce intensity of movements, even distribution of information, Increased clarity in text and illustrations, careful placement of visuals and choice of sound	x	x			x
Provide secondary information	Overall; Information	yes	Added audio cues, AP status in HUD, glow in buttons, dynamic movements in illustrations, minimize information overload,		x	x	x	x
Catch the attention without evoking negative feelings	Overall; Feelings	yes	Timing of the cues, balanced sense of urgency, slower animations, careful choice of audio	x	x	x	x	x
Minimize surprising notifications	Overall; Communication	yes	Timing of the cues, pauses between strong cues, intensity of the cues	x	x	x	x	x
Interrupt the users secondary tasks in a comfortable manner	Overall; Attention	yes	Fading of CSD, increased time to prepare, timing of animation in CSD and audio				x	x
Direct the attention to important functions	Overall; Attention	yes	Timing of audio and visual cues, smooth movement of the steeringwheel symbol, fading off NDRT content, circle in ICD has visual feedback from voice message	x	x			x
Block NDRT content	Overall; Attention	yes	Fading of CSD, introducing the Steeringwheel symbol in the CSD, blocking NDRT		x			x

For the Takeover-phase, the final concept fulfilled almost all high priority guidelines except for 'communicate for deactivating the system' (by audio) and 'Provide more information from the voice', see Table 22. The reason for that is because the voice and audio used in the final concept were moved

to the Pre-notification instead of the Takeover-phase to minimize the risk of information overflow in the most critical phase of the transition. The decision was made came later in the process and those initial guidelines regarding audio were not truly relevant for the Takeover-phase when the Pre-notification had been introduced.

Table 22. Fulfillment of the guidelines, improvements, and applications for the final concept in the Takeover-phase of the transition.

Criterion	Theme	Fulfillment	Improvements, Applications	ICD	CSD	HUD	Buttons	Audio
Show clearly visible communication	Visual	yes	Placement of HUD, increasing size of text, minimize information overload, cleaner UI, improved circulating lights on buttons	x		x	x	
Clear auditory communication	Auditory	yes	Including voice and audio cues in the concept. Lowering noise with ANC, removed lower frequencies in the voice and added effects, careful choice of sound					x
Communicate for deactivating the system	Auditory	no	The Voice is placed in the Pre-phase instead to minimize distractions during the take-over					
Provide more information from the voice	Auditory	no	More information implemented in the pre-phase					
Provide clear instructions and visuals from the ICD	Visual	yes	Added steeringwheel animation in ICD, audio, and more pedagogic text, cleaner UI	x				x
Minimise distracting noise outside ODD	Auditory	yes	ANC, removing NDRT content		x			x
Minimise stress in relation to the transition	Overall	yes	Careful choice of audio, pedagogic illustration and text in ICD, added AP status in the HUD, better timing of the different information screens, improved movement in the button light, fading off the CSD	x	x	x	x	x
Avoid creating an overwhelming experience	Overall	yes	Removing information on the CSD, minimizing unnecessary information. Careful choice of sound. Timing of the cues	x	x	x	x	x
Provide the driver with sufficient instructions	Overall	yes	Improved illustrations and pedagogic text in ICD, added voice and audio feedback. Added AP status in HUD. Improved lights around the buttons	x		x	x	x
Minimise the association with danger and fear	Overall	yes	Careful choice of audio, primary information moved to ICD, improved illustrations and size of texts	x				x
Provide essential information	Information	yes	Minimize unnecessary information. ICD as the primary information source. Pedagogic Steeringwheel animation in ICD, AP status in HUD	x		x		
Support correct action	Overall; Understand	yes	Steeringwheel animation in ICD and improved visibility of text, more pedagogic text in ICD, improved light around the buttons, audio feedback when pushing the buttons. Cleaner UI in ICD, Cleaner countdown when pushing buttons	x			x	x
Avoid confusion	Overall; Understand	yes	AP status in HUD, improved pedagogic illustration and text in ICD. Better movement and light around the buttons, moving information from CSD to ICD	x		x		
Avoid evoking negative feelings	Feelings	yes	Improved timing of the UI, careful choice of audio	x		x		x
Catch the attention without evoking negative feelings	Overall; Feelings	yes	Improved timing of the UI, careful choice of audio	x		x		x
Provide accessible cues	Overall; Accessibility	yes	Moving all primary information to the ICD and the buttons, use of ANC and audio feedback	x			x	x
Enable feedback on interactions	Overall; Feedback	yes	Implementing audio and visual feedback when the car wants attention and when pushing the buttons	x			x	x
Direct the attention to important functions	Overall; Attention	yes	Changing the circulating light around the buttons. Steeringwheel animation with clear instructions to push the buttons, audio cues	x			x	x
Block NDRT content	Attention; Usability;	yes	CSD is shut off		x			
Can be used by users with no experience of AD	Intuitiveness	yes	Improved pedagogic illustrations and text in ICD, AP status in HUD	x		x		
Provide intuitive instructions for the user	Usability; Intuitiveness	yes	Improved steeringwheel animation in ICD, pedagogic text and better visibility of text in ICD. Moved instructions to the ICD.	x				
Communicate function, (semantics)	Usability; Intuitiveness	yes	Illustrative animation in ICD. Lights around the buttons, visual and audible feedback when pushing the buttons, AP status in HUD	x		x	x	x

For the Post-notification, the final concept fulfilled all high priority guidelines, see Table 23, and the transparency of the transition was improved significantly when the solutions for the Post-notification were applied.

Table 23. Fulfillment of the guidelines, improvements, and applications for the final concept in the Post-notification of the transition.

Criterion	Theme	Fulfillment	Improvements, Applications	ICD	CSD	HUD	Buttons	Audio
Avoid the sensation of guilt	Overall	yes	Uplifting sound, green check box in CSD, AP status in HUD, Explanation of reason in HUD		x	x		x
Provide secondary information	Overall; Information	yes	AP status in HUD, Explanation of reason in HUD, voice, lights in buttons disappear		x		x	x
Increase the transparency	Overall; Understand	yes	Green check mark in CSD, AP status in HUD, Explanation of reason in HUD, Voice message and audio when AP is deactivated, buttons stops shining, increased time to convey message in HUD before it disappears. MD interface deviates from the AP interface	x	x	x	x	x
Explain the reason behind the transition	Overall; Understand	yes	Message in the HUD		x			
Confirm the transition	Overall; Feedback	yes	Uplifting sound, Voice message, green check box in CSD, Change back to manual driving interface in ICD and CSD, AP status in HUD, HUD disappear, lights in buttons disappear	x	x	x	x	x

8.3 Summary and Implications

Based on the internal evaluation, the final concept was successful when comparing it to the initial guidelines that were formulated after the video coding and the system analysis. The concept was improved significantly and many changes to the UI were made such as the position of graphics, aesthetics, implemented sound and voice, movements, timing, and pedagogic illustrations and texts etc. Many of the negative aspects of concept Game that were mentioned in the user study were eliminated when the Action plan was implemented to increase the transparency between the user and the vehicle.

When animating each element of the final concept in After Effects, it was difficult to see how one element would affect other elements and the elements together. For instance, if the sequence of the HUD were to be extended with 2 seconds, it would be difficult to know how it would affect the synchronization with the other elements. When importing the video of the HUD in Unity, it was clear that the frame around the text for the HUD was too distracting in relation to the other screens. The solution for this was to eliminate the frame and just have the text presented in the HUD.

Working with Unity to showcase the concept in a VR environment proved to be more challenging than anticipated. The project file was supposed to be modular with the traffic, cars, and environment already existing in a project folder from a shared platform called GitHub. This made it possible to retrieve all assets and prefab from that package folder and inserting it in the Unity project. However, there were many struggles along the way as some essential files for the project that were needed for the scenario were confidential. This made it more difficult to work with the project as some files had to be created from scratch again. For example, the file for the function of driving in AP was needed, however it was not accessible due to confidentiality for external parties like master thesis students. Luckily, experts from Volvo were reachable and managed to help in this matter by creating the script for this project. This struggle would not have occurred if full access had been granted at the beginning of the project.

As the project progressed, the learning curve for working with Unity got steeper along the way with a constant battle against time. The idea was to make the VR environment as immersive as possible while also replicating the animation from After Effects as much as possible. However, this was not possible as one of the more prominent struggles when working with Unity was the coding aspects. As Unity is a script-based game development platform, it was very difficult to work with the software with limited programming skills. It was possible to work with Unity without coding to some extent which was the initial idea of working with the software. However, as the project progressed, more specific needs and programming skills were required. This was solved by either simplifying one of the elements, looking at tutorials, or asking for help from experts. One of the aspects from the concept that was simplified was the flashing overtaking car in the HUD. This was solved by simplifying the animation to just having the car glow stationary until the car disappeared from the view field. This affected the experience of the concept as it was not very visible.

Due to limited knowledge of Unity and programming, it was difficult to know beforehand how time-consuming it would be. If this had been realized earlier in the process, it would have been much easier to estimate and plan for the development of the final concept in Unity. Avoiding unnecessary detours when working with the final concept could also have been achieved if more knowledge had been had, for instance, the format issue of the videos with transparent background that was encountered halfway through the development of the final concept.

Working with the different platforms made the concept look slightly different, almost like looking at two different concepts in Unity and After Effects. For instance, the contrast in the HUD seemed to work fine in After Effects but when importing it into Unity, the text was not as visible anymore. The text in ICD seemed to be big and clear in After Effects but when importing it to Unity it looked rather small and not very evident. To solve this issue, one approach could be to work from one platform only. If the concept were to be created in Unity, working with Unity only would have been the best option to avoid this issue, and the opposite for After Effects.

A large, light gray, stylized number '10' is centered in the background of the page. The '1' is a simple vertical bar with rounded ends, and the '0' is a large oval with rounded ends. The text 'FINAL EVALUATION' is centered over the '0' in a bold, black, sans-serif font.

**FINAL
EVALUATION**

9. Final Evaluation

The final evaluation of the concept was carried out with experts from the field, to evaluate the concept in term of usability and emotional responses. The purpose was to see how successful the concept was based on an analysis of the results of both qualitative and quantitative data. This section presents the method, result, and conclusion from the evaluation.

9.1 Method

The method used for evaluating the final concept was a study with 6 experts at the innovation lab at Volvo Cars. Both qualitative and quantitative data were collected for a final analysis of the evaluation. The goal of the study was to evaluate how successful the concept was in terms of usability and emotional experiences.

9.1.1 Expert Study

The qualitative data were gathered in interview where questions were asked regarding emotional responses and usability. The reason for this was to get a more nuanced analysis of UX, which Hassenzahl (2018) refers to as influenced by both hedonic and pragmatic aspects. The interviews consisted of nine questions about: emotions, usability, the Pre- and Post-notifications, and some overall questions. As both the Pre- and Post-notifications were relatively new phenomena to the automated system, the interview questions focused more on these phases. For all the questions, see **Appendix M**.

As emotions are a rather complicated concept, data regarding emotional responses were extracted also in other ways than just interview questions. The qualitative data was therefore complemented with quantitative data, using both a questionnaire and a UX-curve, filled out by the users (in this case experts) themselves (see Figure 73). The purpose of the UX-curve was to compare the result of the final evaluation with the initial estimated UX-curves from an early stage of this project. This would indicate how well the final concept compared to the estimated UX-curves.

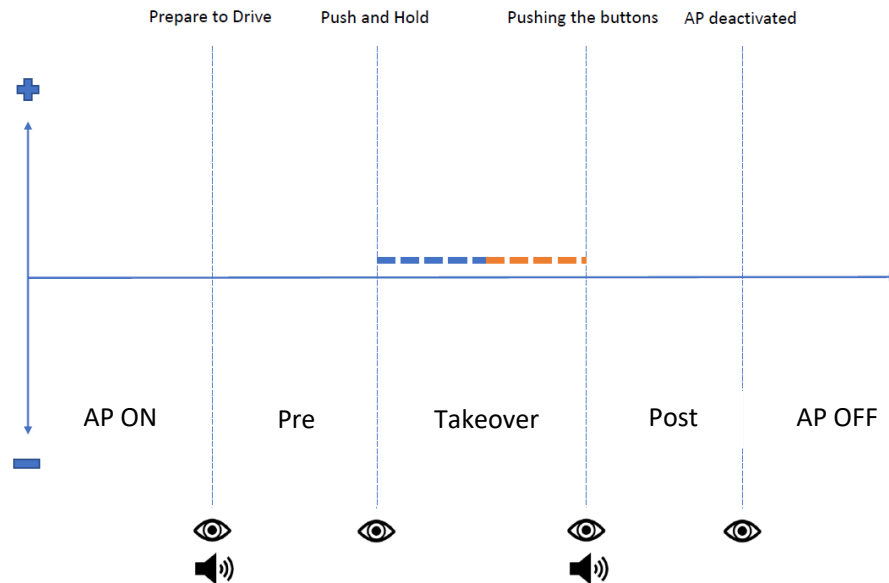


Figure 73. UX-curve of new concept.

The questionnaire was created using Microsoft Form, making it possible for the experts to answer the questions anonymously. To access the questionnaire, the users had to scan a QR code with their phone camera, which would guide them to the link to the questionnaire. The mean value from each answer would then be calculated automatically, which streamlined the process of analyzing the questionnaire data. The questionnaire consisted of 7 statements which the participants were able to respond to on a Likert scale ranging from 1 to 6, see **Appendix N**. The reason for choosing a six-level Likert scale was to eliminate the possibility of putting the answer in the middle, forcing the users to either agree or disagree. The statements concerned their level of appreciation towards the different information channels during the transition, which involved both visual and auditory cues. The final question was an open question, which allowed the participants to describe their own experience of the concept using three value words.

The participants consisted of 6 experts from Volvo Cars. The reason for choosing experts was partly because of accessibility and difficulties of bringing external users to Volvo Cars due to the pandemic. Using experts for the evaluation also allowed for more profound answers to be collected, based on their level of knowledge from the automotive industry. This would result in a more detailed analysis of the concept, compared to regular users who may not pay attention to those details of the concept. However, the experts could either be too critical and too sensitive to certain details, which could influence the evaluation both positively and negatively. For instance, their experience of the concept could be influenced by and compared with an already existing concept they might know about.

As the test involved the usage of a VR set-up, it was important for the users to wear both a face mask and a VR face mask. It was also important to wipe the inside cushion of the VR headset with a sanitizer between each participant to prevent the spread of any virus. The VR set-up used for the expert study was called Varjo VR-3, which has built-in eye and hand trackers. As the VR set-up required a better computer compared to the laptop used throughout the project, the project files for the simulation were

transferred to a high performing desktop. The headset was used together with audio headphones on a test rig, replicating the sensation of sitting in a real Volvo Car. To make the VR set-up work, experts from the studio positioned the camera inside the Unity environment, creating a real sensation of a driver's point of view. To increase the perception of space and distance inside the car, hand-tracking was enabled which made the experience more immersive and closer to a real experience seen in Figure 74. The VR recording of the concept can be seen through the link or QR code in **Appendix L**.



Figure 74. Hand tracking in VR.

The procedure for each participant of the expert study started by giving them a GDPR form, to get their consent of recording both visually and audially (**Appendix O**). A short introduction of the project and the agenda was then given before mounting the VR rig for the participants to experience the concept. Next, the participants were asked to fill out the UX-curve and the questionnaire. Finally, an interview with predetermined questions was conducted to elicit more qualitative answers. During the interview, the participant was given the opportunity to explain more in depth their UX-curve and the questionnaire results. In Figure 75, one of the participants during the expert study can be seen using the VR headset.



Figure 75. Test participant during the expert study.

The test followed a tight schedule, and two interviewees (the authors) interviewed one participant each to speed up the process. Unfortunately, one of the participants fell sick and could not participate in the study. Luckily, three employees from the studio were available and volunteered to participate instead. The schedule for the expert study can be seen in Table 24.

Table 24. Schedule of the expert study.

Time	Participant ID	Notes
13:00-13:15	1	Late
13:20-13:50	2 & 3	Split up
13:55-14:25	3 & 4	ID 4 sick
Replaced	4	Replaced ID 4
Bonus	5	Extra
Bonus	6	Extra

9.2 Result

This section presents the result of the analysis of the data collected from the 6 participants in the expert study. The overall experience of the concept was positive, and the Pre-sequence seemed to have affected the transition in a positive way. The result from the analysis will present the take-aways from the interview, the results of the UX-curve, and the questionnaire results.

9.2.1 Interview

When asked about emotional responses, it seems like the general experience of the concept was negatively affected during the Takeover as it was not possible to interact with the concept by pushing the buttons. According to two participants, it felt weird as their actions did not lead to AP turning off.

However, the emotions they felt were generally positive. Some experienced the concept as clear, cool, and futuristic. Most of the participants appreciated the Pre-sequence as they were positively surprised, while others liked the idea of having enough time to prepare for the transition.

"In 'prepare to drive' I was pleasantly surprised. An unusual part that does not yet exist. It is good since it makes you start to sit properly, check the traffic, adjust your feet and hands, and get ready to drive. In contrast to what is done today, for instance Pilot Assist and Tesla, this step is missing. [...] Having this step is very important. The system warns you and I'm happy that it existed because it should be included."

The audio was also something that was appreciated in the Pre-notification. One participant felt though like the Pre-notification was too sharp and would like to know how to prepare to take over. However, the overall experience of the participants was relatively positive.

One person felt that the countdown during the Takeover was 'stupid', as it would draw attention away from the road with too many distracting motions involved. They also felt that the text in the HUD should be placed on the windshield in front of the driver instead of in the center above the CSD. One participant felt like the sound was too intrusive and that the visual cues resulted in too much information in combination with the sound. Another participant mentioned that the system had a lot of information but empathized this in a good way.

Regarding the usability of the information, many participants expressed appreciation towards the concept and thought that the information was clear, both in terms of visual and auditory cues. One person mentioned that the information felt serious but in a positive way.

"I think it felt serious, which is positive because it is something I have to do, something that is required of me."

This meets one of the guidelines, stating that the concept should be perceived as assertive rather than aggressive. As each participant got to experience the concept only once, it seems like many participants needed experience to get used to the system. Regarding the voice, two people felt skeptical of its practicality as it could easily be overused. One of them also said that the voice could create a sense of smartness in the car which could be a good thing as this could increase trust in the system. One participant liked the explanation of why something happened as it brought a sensation of expectancy. One expert said that they did not know how to act in the Pre-notification while someone else felt like they had enough time to understand, react and prepare for the Takeover.

When asked about how easy it was to interpret the information during the transition, there were mixed feelings. It seems like the audio was a lot easier to interpret while the visual cues were more messy and less coherent.

"The visual feedback was a bit more chaotic. It was a lot happening in the visual feedback as I remember, so that is the least favorable."

Someone mentioned that they were not sure how the visual and auditory cues would work separately, but the combination was generally good. One expert felt like it was very intuitive while another did not

know where to focus. In general, it seems like the information managed to catch everyone's attention, despite just seeing it once.

When asked how prepared they felt during the transition, most of the participants felt prepared as it felt clear. Someone mentioned that it felt slightly intrusive and that the transition from the Pre- to Takeover-sequence was not very fluid. Another participant mentioned that it was difficult to know the level of urgency during the Pre-notification. In general, many participants felt they had enough time and that they felt prepared. Regarding the experience of the first cue during the transition grabbing their attention, it felt overall clear and obvious. Someone said it felt positive and safe but someone else mentioned that perhaps it was too obvious and that the sound was too sharp. One expert said that it felt immediate while someone else felt like they had difficulty knowing where to look.

When asked if they understood why the car requested the Takeover, everyone seemed to understand and said that it was because of other cars were driving faster. One person said that something happened outside the ODD while someone else said cars were speeding up instead of cars driving faster, which was mentioned both audially in Pre-notification and visually in the Post-notification.

To get a general impression of how they experienced the concept, the experts were asked what they appreciated more and what they appreciate less about the concept. As for what was appreciated, the general impression was positive where the Pre-notification was mentioned by a few. The buttons and audio were also mentioned, both the VUI and SUI. Words as 'safe' and 'retro' were used by some. Regarding the less appreciated aspects, it was mentioned that the interaction was confusing, which was mentioned earlier. It seems like the non-interaction of Unity affected the experience of the concept negatively. Someone explained that they thought the visuals were too complicated while someone else mentioned that the Pre-notification needed improvements. One of the experts expressed that the pushing of the buttons was not very ergonomic, and it might be necessary to find other, alternative ways of deactivating the AP.

When asked whether they would feel comfortable using the concept in a real scenario, there were mixed feelings. Some said 'yes' while others said that they would need experience to get used to it. One participant would not feel comfortable as the solution felt too chaotic. In general, it felt though like most experts would like to use this concept in a real context but with minor improvements.

9.2.2 UX-Curve

Looking at the UX-curve in response to the new concept (Figure 76), there is a drastic change compared to the estimated response to the previous concept from the San Francisco Bay study (which is the orange curve in the diagram). It is also evident that the anticipated effect of the Pre- and Post-notification - the green curve - was correctly estimated. The blue curve in Figure 76 and Figure 77 is the interpolated value of all the curves created by the participants during the expert study. There is a slight peak in the Pre- and Post-notification, meaning the experience was enhanced which in turn affected the experience in the Takeover-sequence. Even if the Takeover-sequence was considered the least favorable sequence in the new concept, it is still on the positive side of the UX-curve, meaning that the UX had been improved. The drastic dip of the orange curve in Figure 77 is eliminated which also argues for an enhanced UX in the transition from AD to MD.

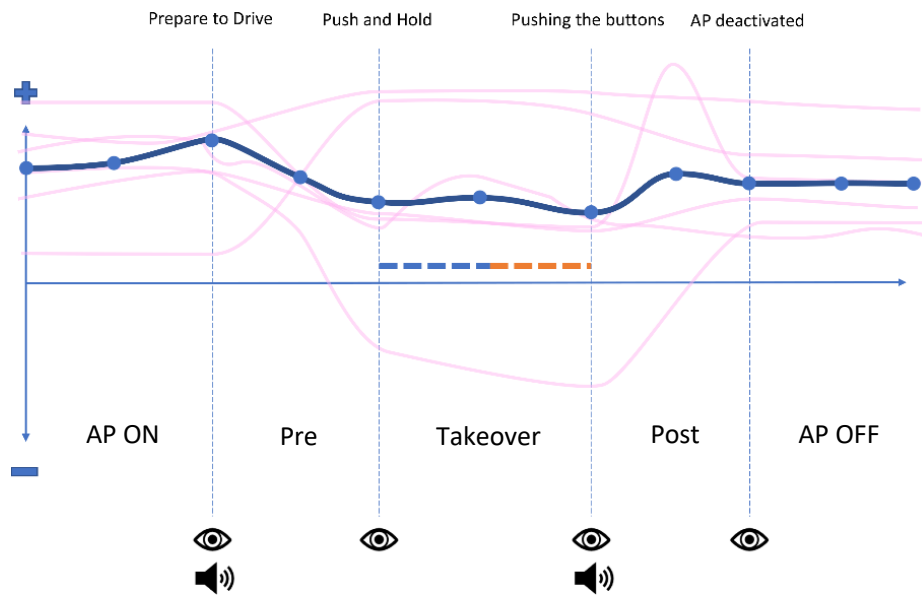


Figure 76. Interpolated UX-curve from all participants (Blue). UX-curve from each participant (Pink).

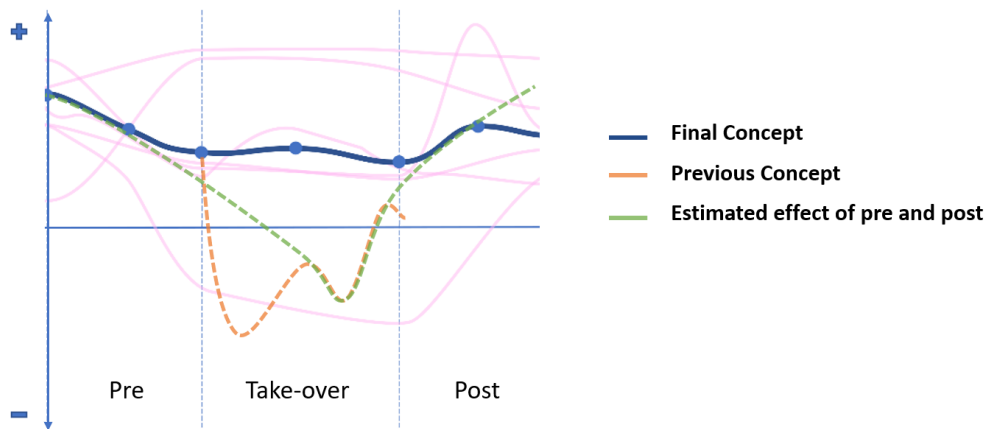


Figure 77. Comparison of the result and the estimated improvements from implementing a Pre- and Post-notification to the transition. Previous concept (orange), estimated effect of pre and post (green), and the final concept (Blue).

9.2.3 Questionnaire

As for the questionnaire, which took about two minutes to complete for each participant, all statements scored above 4 (mean value), meaning that the concept was considered positive. The highest rated statement in the questionnaire was the appreciation towards the audio signals. The lowest rated statements were statements 2, 3 and 5, see Table 25, which concerned cues being coherent and logical, appreciation of voice, and the visuals being clear and easy.

Table 25. Questionnaire.

No.	Question	Rating
1	I got sufficient information to understand what the car wanted me to do	4.50 / 6
2	The visual and audio signals felt coherent and logical	4.33 / 6
3	I appreciated the voice messages	4.33 / 6
4	I appreciated the audio signals	4.83 / 6
5	The visual information was clear and easy to interpret	4.33 / 6
6	I felt safe	4.50 / 6
7	Define your experience with three words	Figure 78

Regarding the value words approximately 8 out of 10 words were positive while the rest were considered negative. The positive words concerned themes like 'Informative', 'Calm', 'Safe' and 'Positive'. There were also other words, labelled mix, such as 'Futuristic'. Among the negative words, 'Confusion' was mentioned twice, and the word 'Complex' once (see Figure 78).

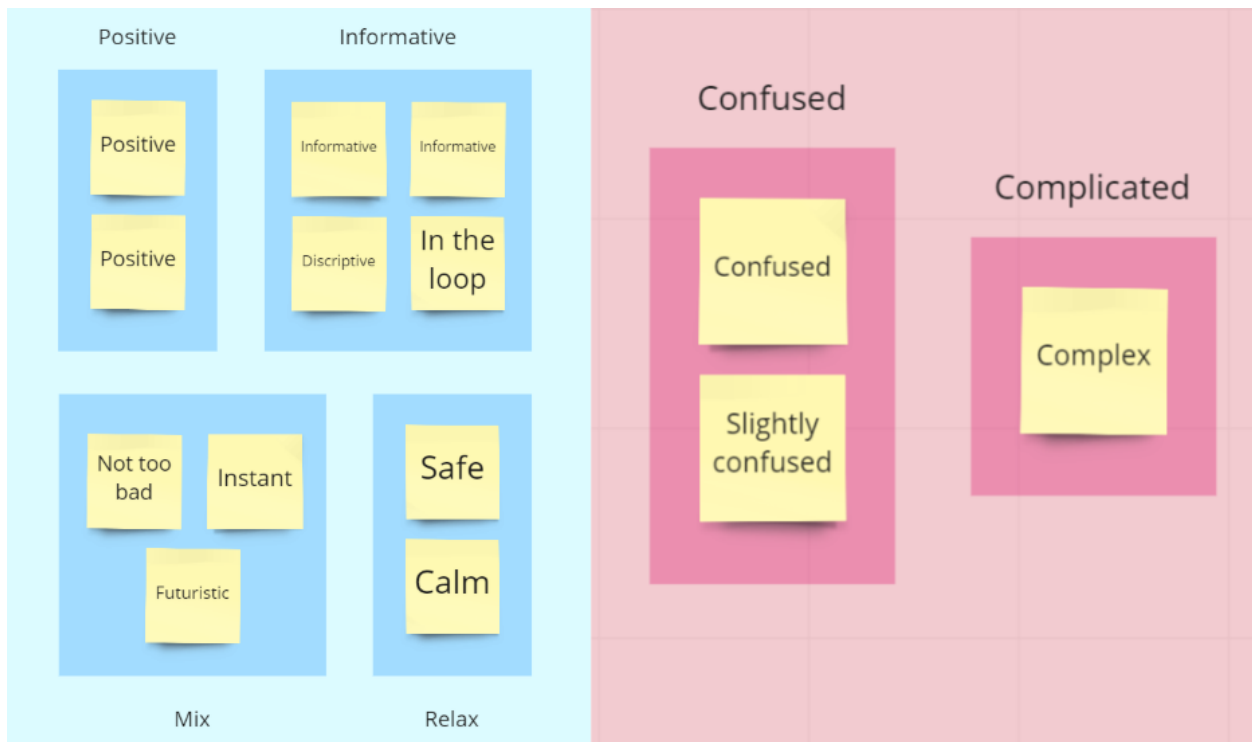


Figure 78. Value Words. Left blue side illustrates positive words. Right pink side illustrates negative words.

9.3 Summary and Implications

Generally, the concept was positively interpreted by most of the participants in the expert study. The Pre-notification made some of the experts positively surprised and most felt that they had enough time to prepare for the Takeover. One participant wanted to know how to prepare, and thought the information given in the Pre-notification was slightly insufficient. The sound signal was mentioned as too sharp, but most people seemed to have liked the audio. The VUI was appreciated, but some were

skeptical of its practicality from a design perspective. The experts suggested that it might be better to achieve the same level of transparency without any VUI if possible. They also mentioned that there is a risk that users might get annoyed with the VUI when they familiarize themselves with the system. It may therefore be positive to implement options to deactivate the VUI in the design of such a system. Generally, the audio was easy to interpret for most of the participants.

Regarding the visual signals, there were mixed feelings. Some were impressed and thought the information was clear and appreciated in terms of the aesthetics. Others thought the visuals were too complex and incoherent with too much motion. The new design had improved the pedagogics of texts and animations, which may have increased the level of information and possibilities to interpret the signals. Some said that the visual information felt serious in a positive way, which can be considered positive since the design intended to be assertive but not aggressive. The lights around the buttons were appreciated as this guided the users' attention which increased their understanding of how to act. One of the experts did not appreciate the countdown when the buttons were pushed as it was distracting, drawing attention away from the road. One expert wanted the HUD text to be placed in front of the driver instead of above the CSD.

Most participants felt prepared for the Takeover and that they also had enough time to prepare, which can be considered a success. All participants understood the reason for the Takeover request, which could also be seen as a success, since the reason for the Takeover was one of the biggest flaws in the San Francisco Bay concept. Most participants would feel comfortable using the concept in a real scenario, but some would need more experience before using it.

The comparison of the new UX curves with the interpreted UX-curve reveals that the assumptions were correct; the implementation of both the Pre- and Post-notification had a positive effect on the overall experience. The value words were mostly positive. However, even if the Takeover-phase was appreciated by many, it was also the least appreciated phase which can be due to the complexity and increased intensity of that phase. Another reason could be due to the buttons being used to deactivate the AP, which may not be the best possible option. Other more ergonomic options for deactivating AP should therefore be examined.

The initial idea was to evaluate the concept in an online expert review. However, as it was possible to borrow the VR headset in the studio, it was decided to conduct a physical user study with company internal experts only. The VR setup made it possible to do an evaluation of the final concept as close to a real car as possible. Doing it physically, with a realistic set-up would therefore extract more data from the study, both quantitative and qualitative. It also made it possible for the participants to experience the concept more clearly in an immersive environment, instead of looking at a flat screen.

There were both advantages and disadvantages using experts for evaluating the final concept. The benefits were that they were accessible and allowed to be involved according to the restrictions and regulations during the pandemic at Volvo Cars. With their knowledge and familiarity of the automated system, the study could be conducted in a more efficient manner, with a shorter introduction and explanation of the system. It also allowed for experts to go more into depth, paying more attention to details. The downside, however, was that the data collected may have been biased, as their knowledge of the automated system may have affected their answers and experiences. It is therefore difficult to determine whether the data extracted from the experts was purely based on their observation of the

concept, or their prior knowledge of the system. Either way, the feedback extracted from the experts was valuable and brought useful insights to evaluate the concept's level of success.

The set-up of the VR test rig was rather complicated. For instance, there were many errors along the way, when transferring the project file to a high performing desktop. To solve this, the project had to be reconstructed from scratch, making it very time consuming. The next challenge was to actually set up the VR test rig which turned out to be more complicated than first anticipated. This would not have been possible without the help from the experts from the studio at Volvo Cars. Due to time limits of the set-up, there was no time for a pilot test. It was noticed halfway through the study, that the audio volume was too high. This may be the reason why some users experienced the audio as too sharp and intrusive. The final two participants experienced the concept with a lowered volume and did not mention anything about the audio being sharp or intrusive. It is however not possible to determine afterwards whether it was because of the lowered volume or because of them feeling that way based on the concept.

Because of the lack of possibilities to interact with the concept, the experience of the concept was negatively affected, as the participants actions did not lead to the automated system actually turning off. In the interpolated UX-curve of the final concept, the least favorable part of the concept was the Takeover-sequence, which may have been affected by the lack of interaction. One plausible explanation for this might have been because of the instructions given in the beginning not being clear enough for the experts. However, it is not possible to determine whether it was affected by the instructions only, the concept itself or possibly both.

Furthermore, working with VR was a very interesting experience. Despite struggling with many obstacles, it was an educational experience. In terms of sustainability, working with VR may have contributed to a lower carbon footprint compared to a test conducted with real cars, which would have affected the carbon footprint to a higher degree. However, the experience in a VR environment can never truly be compared to a real car scenario where unexpected situations can occur. The simulation only showcased the concept in perfect road conditions and the sense of risk that is present in a real car scenario may not have been present in the expert study. Therefore, the simulation may have affected the study to be more positive than it normally would in a real scenario.

DISCUSSION

10. Discussion

This part of the thesis discusses relevant topics to consider when designing solutions for AVs. The methods used in the thesis project and their effects on the result are discussed, together with acceptance, ethics and sustainability issues related to self-driving vehicles.

10.1 Methods and Results

When enhancing the UX for AVs, it is important to consider both the pragmatic and hedonic attributes according to Hassenzahl (2018). Based on the results of this project, it is evident that a Pre- and a Post-notification are needed to enhance the UX during transition from highly automated drive to MD. Thus, only offering the Takeover-sequence results in a negative experience and should be developed further together with the Pre- and Post-notifications. It is also important to have a multimodal approach when working with different information channels in the car. Therefore, working only with visual signals is not enough but is a very good starting point for many concepts.

The San Francisco study indicated that something is missing in the HMI, and that improvements had to be implemented to enhance the UX of the transition. This has been evaluated both internally, on the basis of guidelines, but also externally with potential users. Despite the UX-curves not being fully accurate in the diagrams, the result still illustrates that the emotional experience during the transition using the new concept did not oscillate as much as the experience did during the San Francisco study. However, the San Francisco study concept used haptic feedback which was interpreted as aggressive. This was not implemented in the new concept, developed as part of this project due to the uncertainty of conducting user studies physically. Concluding whether the UX-curves were affected by the presence or absence of haptic information is unfortunately not possible. Therefore, future investigation is needed, either by comparing the final with the previous concept including only the visual and audio cues or adding haptics to the final concept and comparing it to the previous concept.

As the final concept was evaluated using VR, it is not possible to determine whether the results reflect a real case scenario like in the San Francisco study. Firstly, because there is probably a lower risk perception in a VR environment, the participants may feel less negative towards the inability to disable AP with the Takeover-buttons. In addition, external factors that might affect the UX was not considered in the VR environment. For instance, unexpected events might occur in a real car scenario, like the weather shifting or the windshield getting dirty. In addition, since the experts were familiar with automated systems, it was easier for them to interpret the final concept compared to regular users. This might have resulted in more positive and biased feedback. The users from the San Francisco study were also able to try the features many times compared to the experts evaluating the final concept of this thesis project. This may have resulted in an unfair comparison between the two concepts.

When the first ideas were created through a handful of sketches, the goal was to explore the design space to the fullest. Therefore, restrictions such as legislative issues and brand identities were not considered as much in the beginning of the process. This is something that needs to be considered for the final concept to better match Volvo Car's brand identity, and to ensure that it follows traffic safety rules and regulations. The screening and the mood board created did help to gain a brief understanding of Volvo Cars' brand identity even though it could have been analyzed more in depth. As the early concepts were created using a rapid prototyping approach, many ideas were formed and scrapped in a

relatively quick manner. Doing this helped generate many ideas and move on from one step to another. The downside however is that many interesting and good ideas may have been lost on the way. Having a set of clear criteria between each rapid session could have been considered to prevent this from happening. The guidelines were based on the previous concept from the San Francisco study. This may have inhibited many different ideas from being generated early in the process. Narrowing down the guidelines could therefore have been a better option for increasing the diversity of different ideas.

Unfortunately, the digital sketches that were created initially used confidential material as an outlined template to streamline the process of conveying different ideas. Therefore, these sketches could not be presented in this thesis. However, since different ideas were created in an efficient manner, various ideas could be merged into a storyboard which created a framework to work from in After Effects. After Effects enabled different ideas to be expressed and illustrated through different animations in a very powerful way. It allowed for concepts to be discussed and iterated on a deeper level, which would never have been the same for hand sketches. It also made it easier for participants in the Lo-Fi user study to understand and express their feelings with a more honest representation of the concepts.

The different Lo-Fi concepts were created with similar contexts like the Takeover-buttons and the environment around the car. Using animations enabled more qualitative data on emotions and feelings to be collected from users, compared to sketches being illustrated through storyboards and complicated descriptions. As some of the communication is missed in digital user studies, such as the body language and tonality of the voice, it is important to have clear and comprehensible illustrations. According to Lapakko (2007), body language and tonality of the voice stand for about 93 % of communication according to the 7-38-55 rule by Albert Mehrabian (1967).

Therefore, After Effects was used as a Lo-Fi representation as it would have been more difficult for users to both communicate and understand the concept of such a complicated and unfamiliar system like AP in AVs. By making the representation of the concepts as clear as possible, it made it easier to collect complicated data like emotions and feelings from the users through the digital user study. Regarding the Lo-Fi user study, the learning effect had to be considered as the experience from the first concept could influence the answers for the second concept, which may result in biased answers. The concepts were therefore presented in a manner to prevent this from happening, which was to present two concepts for each participant, and in a mixed order. No major differences were observed in the analysis of the answers which lead to the conclusion that the learning effect did not affect the user study as much. To avoid the learning effect completely, each participant would have to see only one concept each. This would be too time consuming and would require more participants to be involved.

One could argue that other software for creating the UI of the system could have been considered and that After Effects may have been too time demanding for the Lo-Fi representation. This would be true for new users as the learning curve for the software is quite steep. But since one person from this project had previous knowledge of using After Effects, this statement can be neglected, and it was rather an effective tool to use. Sadly, there were many software crashes along the way, which slowed down the process a lot more than anticipated as the project file were recreated several times. Consulting Adobe Help Center, a computer with better GPU (Graphics Processing Unit) would have been required and more specific recommendation specifications can be found in Adobe's homepage (Adobe, 2021). However, as this solution was not an option for this project, the software issue was countered by saving the project files frequently. The Lo-Fi concepts created in After Effects were created on a rather

detailed level. It can be questioned whether this was necessary or whether a simplified animation together with a more detailed description presented to the participants before the concept could have been sufficient. Perhaps the same level of data would not have been possible to extract from the users as it would be more difficult for them to interpret the concepts and imagine how it would really look like.

It is clearly the designer's responsibility to ensure that the concepts are being interpreted in the intended manner despite the level of fidelity. If a concept can be presented in Lo-Fi but still maintain a high level of understanding, that is excellent. But as the UI gets more complicated, it also gets harder to simplify a concept without losing important data along the way. The relation between the fidelity of the concept (X-axis) and the complexity of the system (Y-axis) can be seen as the concept representation in Figure 79.

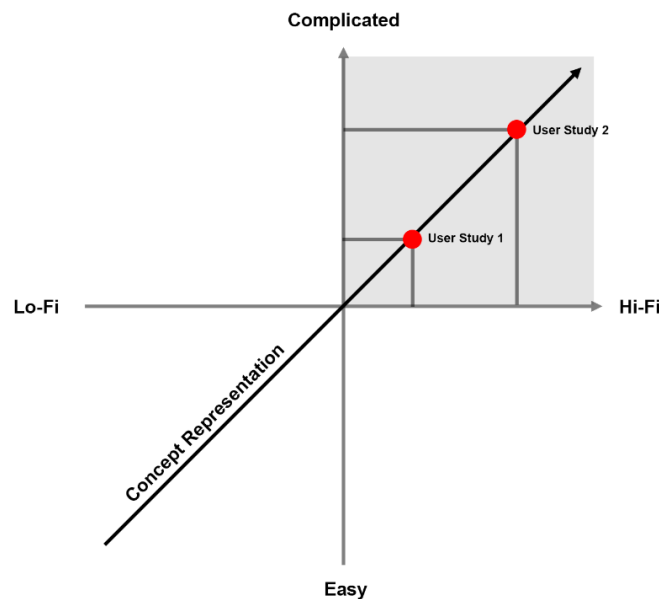


Figure 79. Concept representation in relation to the system complexity and the level of fidelity

The first quadrant is not preferable while the second, third and fourth quadrants work to illustrate different concepts. The diagonal line presents the optimal level of the concept representation. The automated system of this thesis project belongs to the second quadrant highlighted in gray in Figure 79. This model is not a fully accurate representation of a verified concept but rather demonstrates an essential discovery made in this thesis project. For instance, the interpreted complexity of the system varies depending on the participants, like the experts from user study 2 compared to the regular users from user study 1. As the UI of the transition is considered complicated, the concept representation in user study 1 belongs to the Hi-Fi representation, even if the first concept representation is considered lower in fidelity scale compared to the final concept.

Another important aspect to question is if the project could have been narrowed down earlier in the process. For instance, instead of having four concepts for the Lo-Fi user study, three concepts could have been used. This would have saved time and given room for a more thorough analysis of the user study as there would be less data to analyze and fewer concepts to evaluate. This would also have allowed for a more detailed extraction of data from the participants during the user study. The scope of

the transition could also have been narrowed down, for example by just focusing on the Pre-notification or the Post-notification. This would have resulted in a more uniformed concept development instead of focusing on each of the different phases and how they would correlate with each other throughout the transition. However, exploring all phases created a more coherent solution of the whole transition which could not have been possible if only one sequence were to be examined.

When creating the final concept in Unity, many issues were encountered like the inability to configure the Package Manager and confidentiality to important files. This made the whole process very strenuous and time consuming. Other issues along the way included incompatibility of certain video formats from After Effects, which resulted in a very complicated conversion process, to maintain the transparency of the videos. Despite being told that the process of working in Unity would be easy and modular with no coding involved, coding and scripting were still required from time to time. This was beyond the knowledge scope of this thesis project and made the whole learning curve a lot steeper for Unity. However, at this point, the project had reached a point-of-no-return. As Unity was concluded to be more difficult at this moment, more time had to be spent on creating the final concept than previously anticipated. Therefore, a compromise had to be made where the interactive part of the buttons had to be excluded from the expert test while continuing with Unity.

When configuring the VR set-up, the project had to be recreated from a high performing desktop as it was not possible to connect the VR set-up to the laptop. Transferring the project file from the laptop to the desktop was also not an option. Therefore, the project had to be recreated and configured with the Project Manager on the high performing desktop once again. This caused a lot of stress as this was realized the same day the project had to be configured for the final evaluation. Luckily, experts from the studio managed to help recreate and configure the project in the desktop, and set-up the VR in time for the expert study to start. One notable difference when previewing the project in Unity from the high performing desktop, was that the preview window started presenting the project right away instead of having to load for a long time as it did in the laptop. The preview was also much smoother and did not lag compared to the laptop. This verifies that a higher performing computer would have been needed in this project to streamline the efficiency of the process in VR. Furthermore, more coding experience is needed to work with Unity in general and it may not be a very suitable tool to use without such knowledge.

A better option, that would have resulted in a fairer comparison, would be to use a test car as in the San Francisco Bay study. The set-up would most likely be much easier and the comparison would have been more similar in terms of, e.g., external factors that may affect the UX in the transition. Even if VR gives the user a good representation of the concept compared to a 2D animation, it can never be compared to a real use scenario as there is not the same perception of risk involved in a VR environment. VR was however a very good alternative to using a real car as it was not possible to conduct such a test due to the Covid-19 pandemic. The final concept needs to be tested in real traffic and with people outside Volvo Cars once the pandemic of Covid-19 is over.

Furthermore, haptic feedback is another important aspect to consider as it appears to have a huge impact on the UX, as concluded from the San Francisco Bay study. The auditory cues used in the final concept also need improvements as the creation of both the VUI and SUI were mostly designed based on intuition. Some feedback regarding the audio was considered from the user study and discussions were held, but a thorough design guideline needs to be created for the audio, similar to how the design

guidelines for the visual cues were created. Even if the design process of the audio can be described as rapid with no iterations involved, the audio strongly affected the UX positively. This verifies that sound is needed as a supplement to the visual cues presented to the user during the transition. It is however not clear whether the visuals contributed to a positive experience of the audio or if it was a combination of both. Therefore, further research needs to be conducted for each separate information channel, the visual and the audio. The audio should also be used carefully as it may use a lot from the user's mental capacity and interfere with the other information channels in the vehicle.

Cognitive perception is an interesting topic and should be explored more as it could affect the UX of AV. Additionally, more research needs to be done to examine if VUI is appreciated in the long run, or if users would rather prefer to turn off the voice messages when becoming more familiar with the system. Moreover, alternative ways of turning off AP also need to be examined to allow for new and innovative solutions to be created. Both the user study and the expert study showed that pedagogic and distinct messages need to be considered to deactivate AP.

As for the report writing which was carried out in Microsoft Teams, synchronization errors did occur multiple times resulting in data being lost. This slowed down the process of writing as many parts had to be rewritten. To maintain a higher level of efficiency in report writing, more continuous documentation should have been made throughout the project. Working from home due to the Covid-19 have affected the way of working and new, untried, online methods have been used to limit physical meetings. The digital methods have been useful and have mostly worked well. However, working online made collaboration more difficult in some cases, for instance, for rapid prototyping and quick discussions. Therefore, some physical meetings were organized when necessary, which created a sense of belonging and community working together.

10.2 Ethical and Sustainability Considerations

Self-driving vehicles (AVs) could have a large advantage over human driven vehicles when it comes to safety, convenience, and energy efficiency (Rahman, Deb, Strawderman, Burch, & Smith, 2019).

AVs are consequently argued to increase traffic safety as human drivers can be replaced thanks to advanced sensing and communication technology. The risk of accidents may be reduced significantly when the human factor is removed from the driving, as distractions and erroneous decisions by humans are considered to be the cause of critical traffic situations and accidents (Bernhard, Oberfeld, Hoffmann, Weismüller, & Hecht, 2020).

AVs are also argued to contribute to increased sustainability. The introduction of AVs could have a substantial positive impact on sustainability, in terms of less negative land use, reduced energy use, reduced traffic, and improved public health. For example, AVs are argued to have great potential to reshape motorized transport in cities to a more sustainable way of traveling, by integrating green technology and flexible shared-mobility services (Acheampong & Cugurullo, 2019). Ride-sharing and autonomous mobility services could solve a rising demand in cities for flexible transport. Studies of a scenario in Singapore have showed that autonomous ridesharing can cover the current mobility needs in the city while reducing the number of vehicles to a third. This could lead to a reduction of CO₂ emissions, travel time, and cost due to the improved energy efficiency of AVs (Bernhard et al., 2020). However, for

AVs to transform transport in cities, the public needs to accept AVs and the associated services need to fulfil the expectations associated with people's daily travel needs.

The automotive industry has also given a lot attention to the implementation and use of AD in public transports, another shared resource, but it is still not certain that people are willing to use automated public transport (Bernhard et al., 2020). To examine that question the transport company of the city of Mainz, Germany, tested an autonomous minibus in a public space. Participants rated environmental friendliness and safety as important aspects for them to accept the vehicle. Participants who answered a questionnaire after they tested the bus rated their acceptance higher than the participants that answered before they tried it (Bernhard et al., 2020). This goes in line with the interviews in this study where people mentioned experience as a big influencing factor for them to trust and accept the new autonomous functions in the vehicle. As autonomous systems do not require the users to act continuously while in AP, it becomes easier for the users to appreciate the ADS after some experience using the AV because of their changed view of the ease-of-use (Bernhard et al., 2020).

The public's attitudes towards AVs are influenced, on the one hand, by perceptions, motivations, preferences, socio-demographic attributes and, on the other, mobility needs (Acheampong & Cugurullo, 2019). Perceived benefits have a positive impact on the acceptance of AVs. Fears and anxiety regarding automated driving are lower among people with technology-positive attitudes in general. When asking people about their attitudes towards AVs, people tend to worry about the safety of pedestrians, cyclists, and motorists, together with a fear of failing technology (Acheampong & Cugurullo, 2019). However, in studies by Acheampong and Cugurullo, most interviewees expect positive benefits from the implementation of AVs. The adoption rate of AVs is also influenced by bigger socio-economic forces such as socio-cultural, economic, and political forces.

Trust in technology is an important factor for the intention to use and rely in AVs (Liu, Guo, Ren, Wang, & Xu, 2019). Another factor that influences the acceptance of AVs in different contexts is performance expectancy, and it has been proven that the driving behavior of AVs affect the trust and acceptance of users (Bernhard et al., 2020). This correlates with the results from this project, that if the driving behavior of the AV lives up to the personal expectations and preferences of driving, trust towards the AV will increase.

It has not yet been sufficiently investigated whether people are willing to pay extra for self-driving vehicles and what demographic and psychological factors that influence the willingness to pay (WTP) for autonomous driving (Liu et al., 2019). Demographic determinants of WTP can be age, gender, education, and income, and psychological factors can be perceived benefits and risks of AVs, anticipated dread for riding AVs, and trust. Results from a survey conducted on the topic showed that 39 % of the participants were willing to pay less than 2900 US dollars, 34 % were willing to pay more than 2900 US dollars, and about 26 % were unwilling to pay extra (Liu et al., 2019). Younger participants with high income and high education were willing to pay more. Another positive predictor was if the participants had heard about AVs before which then resulted in more positive perceptions such as higher trust, perceived benefits, lower risk, and lower dread of AVs.

AVs could offer new mobility to people that cannot drive, like people with medical issues, and the older population (Rahman et al., 2019). The ones expected to benefit the most from self-driving vehicles are older adults who will benefit from the increased mobility that AVs could offer them. However, using new technology may be a challenge for them due to their potential physical and cognitive limitations (Liu et

al., 2019). Older adults seem to have a generally positive attitude towards self-driving vehicles from a user perspective, together with perceived usefulness, trust, social norm, and acceptance. However, from a pedestrian point of view, the older adults had a less positive or negative perception except for the perceived usefulness. If older adults are familiar with AVs, they show a more positive perception of them. This makes it important to educate older adults about the benefits of AVs and how to interact with them (Rahman et al., 2019).

There are also possible downsides of AVs. According to Foster and Konca (2007), there are three distinct professions which the introduction of AVs could greatly affect. These are shipping, taxi service and public transport. All these professions need a person to control the vehicle at some level. As AVs get more integrated into society, fewer people will be needed for driving. As a result, companies could save both time and money as the labor costs will be decreased, and vehicles could run more efficiently. On the other hand, unemployment for these services would rise and these people could have a hard time finding a new job. This may be more cumbersome for older employees as they may have a harder time learning a new skill and getting a new job. These issues need to be stressed and empathized before fully integrating these automated systems into society (Forrest & Konca, 2007).

CONCLUSION

11. Conclusion

UX consists of both hedonic and pragmatic attributes. Both are important to consider when enhancing the UX for autonomous vehicles. The previous user study from the San Francisco Bay area showed a negative UX tendency when deactivating AP. By breaking down the system, rebuilding it and adding two essential components to it, a new concept has been created. These components consist of a Pre- and a Post-notification, to allow for a more pleasant transition and hence a more positive UX, by reducing the level of stress and confusion before and after the transition. This was verified by user studies.

An analysis of the system based on the results of the UX-curve has shown that each sequence of the transition is connected and needs to be conceptualized in relation to each other. The guidelines created for the concepts indicate that the UX of the transition can be improved in many ways. Through the creation of the concept, a set of fundamental conclusions have been made. To make the distributed information of the concept as clear and coherent as possible, different information channels need to be coordinated with each other. The cognitive limitation of users also needs to be considered as it may lead to incomprehensibility due to information overload. This study has also shown that experience is needed for the users to familiarize themselves with the system regardless of what system is presented to them.

Using a multimodal system is also important to improve the HMI in AVs. Using visual cues is essential to convey a message, but insufficient if no additional modality is added to the automated system. Adding audio cues, such as VUI and SUI, is therefore needed to support the visual cues presented to the user. It is nevertheless important to use the audio carefully, as it can be interpreted as either too intrusive or too urgent. Haptic cues also need to be considered as it greatly affected the UX in the San Francisco Bay study. However, it is important to use haptics carefully, as many participants from the San Francisco Bay study interpreted the haptic signal as negative.

There are many reasons why the final concept was the most appreciated concept out of the four tested concepts. One of the most obvious reasons was the usage of the HUD, which was placed in the user's field of view to make it more cognitively perceivable. Nevertheless, the final concept showed great success in both internal and external evaluations, the latter of which was conducted using VR. By using Pre- and Post-notifications to prepare and understand the Takeover through visual and auditory cues, understanding and predictability have been improved.

Furthermore, more research needs to be done regarding the audio and the haptic signals. The final concept also needs to be tested in a real case scenario with interactive buttons, to evaluate or example errors while interacting with the system. Alternative ways of turning off AP also need to be explored to create a larger diversity of the concepts. As many guidelines were formulated for this project, the ones with the lower priority could also be examined to explore new and interesting ideas. As the MRM has not yet been explored, more research needs to be considered to explore how the system responds when the driver fails to deactivate the system.

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Appendices

- A.** Summary of the Inter-rated reliability test
- B.** Full comments from the thematic analysis of the San Francisco Bay Study
- C.** All design guidelines for phase 1, 2-6, and 7 of the transition
- D.** Ideas from the first Brainwriting session
- E.** Ideas from the second Brainwriting session
- F.** Links and QR codes to the 4 animated concepts
- G.** GDPR consent form for the user study
- H.** The online user study evaluation plan
- I.** Take-aways and comments from the user study
- J.** A summary of the takeaways from the user study
- K.** Scripts used for Unity
- L.** Links to the final concept in Unity
- M.** Interview template for final evaluation
- N.** Questionnaire used in the final evaluation
- O.** GDPR consent form for the expert study

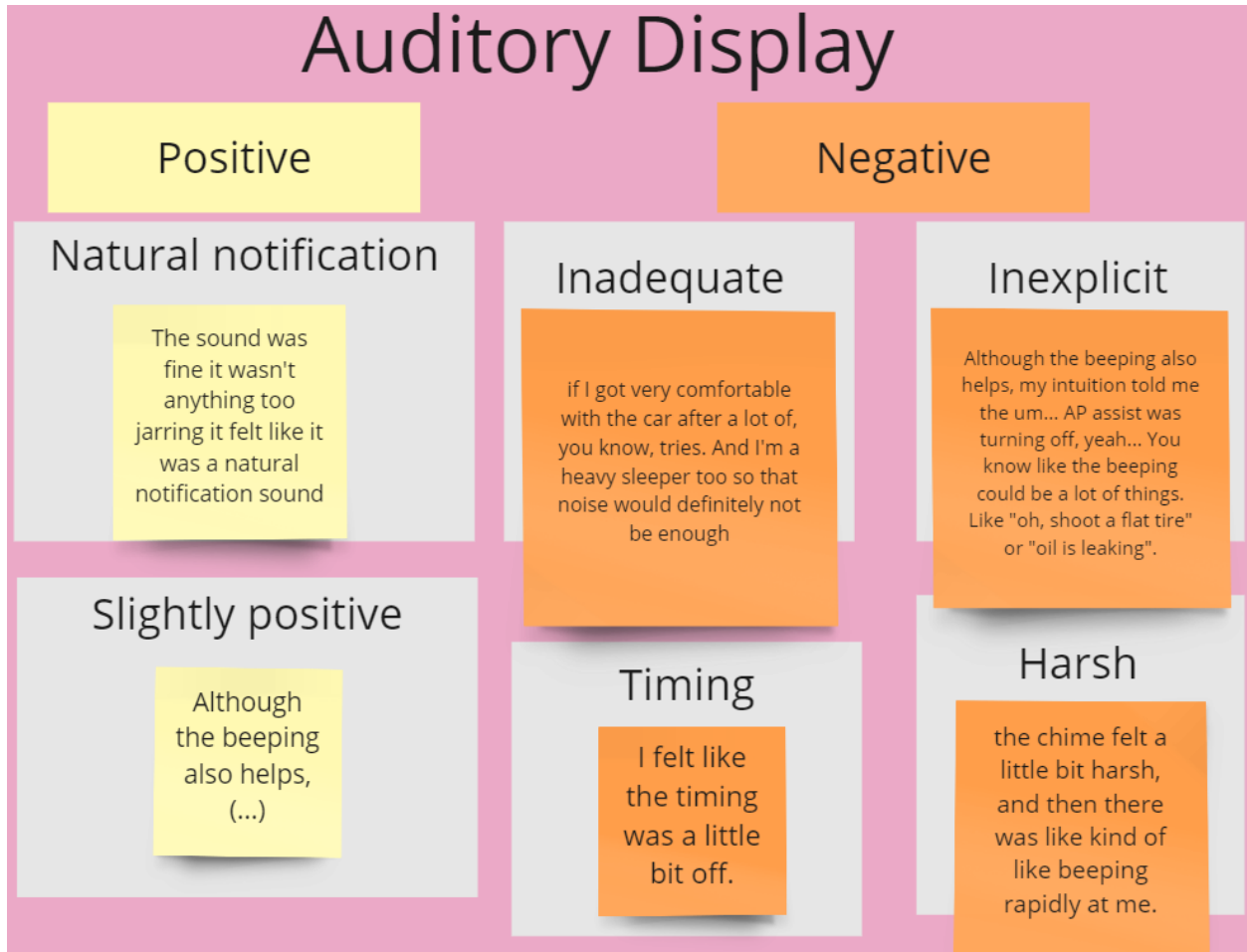
Appendix A

Summary of the Inter-rated reliability test

	Kappa	Agreement (%)	A and B (%)	Not A and Not B (%)	Disagreement (%)	A and Not B (%)	B and Not A (%)	ΣEF	TA	TU
Trust & Trans	0.6827	98.40	1.79	96.61	1.60	0.70	0.90	94.96	98.40	100.00
JW & JF	0.6659	98.68	1.36	97.32	1.32	0.57	0.76	96.04	98.68	100.00
AK & AS	0.6351	98.69	1.18	97.51	1.31	0.78	0.53	96.40	98.69	100.00
AS & JW	0.5920	98.47	1.15	97.32	1.53	0.56	0.97	96.24	98.47	100.00
AS & JF	0.6216	98.65	1.14	97.51	1.35	0.57	0.78	96.43	98.65	100.00
AK & JW	0.5935	98.38	1.23	97.15	1.62	0.73	0.89	96.00	98.38	100.00
AK & JF	0.6025	98.49	1.19	97.30	1.52	0.78	0.74	96.19	98.49	100.00
Average	0.6184	98.5566	1.2070	97.3496	1.4435	0.6647	0.7788			

Appendix B

Full comments from the thematic analysis of the San Francisco Bay Study



Auditory Display

Interpreted Cues

Suggestions

Attention

The signal caught my attention,

Tone

And it was the tone.

(...) you heard a signal

The car is letting me know by (...) playing sound to let me know (...)

And it was beeping at me a lot, the car.

(...) the noise in the back

Louder

if someone's maybe snoozing or dazing off. Maybe if the seatbelt doesn't work, I don't think that'll be loud enough to wake somebody.

(I): What do you think would happen?(TP): It would probably be louder. What's the plan b if someone doesn't respond?

I think maybe the sound should be a little louder though.

Hierarchy

The audio made me take a look at the visual, which told me that I should prepare to take over.

The beeping kind of forewarned me that it was trying to tell me something.

Auditory Voice

Positive

Positive

I do like the voice command. I think that is a good feature.

Mindful

(...)but I liked the whole "hey please take over" more mindful I like that. (...)

Appreciation

But it's amazing I just did what it said

Negative

Timing

I felt like the timing was a little bit off.

Interpreted Cues

Attention

Drops me in and says "Take over" (...) it grabs your attention immediately.

Okay. That was really-, I liked that because it-, it was like all senses, "it said drive the car" and pulling on the seat belt, otherwise I would be like "la la la".

Voice

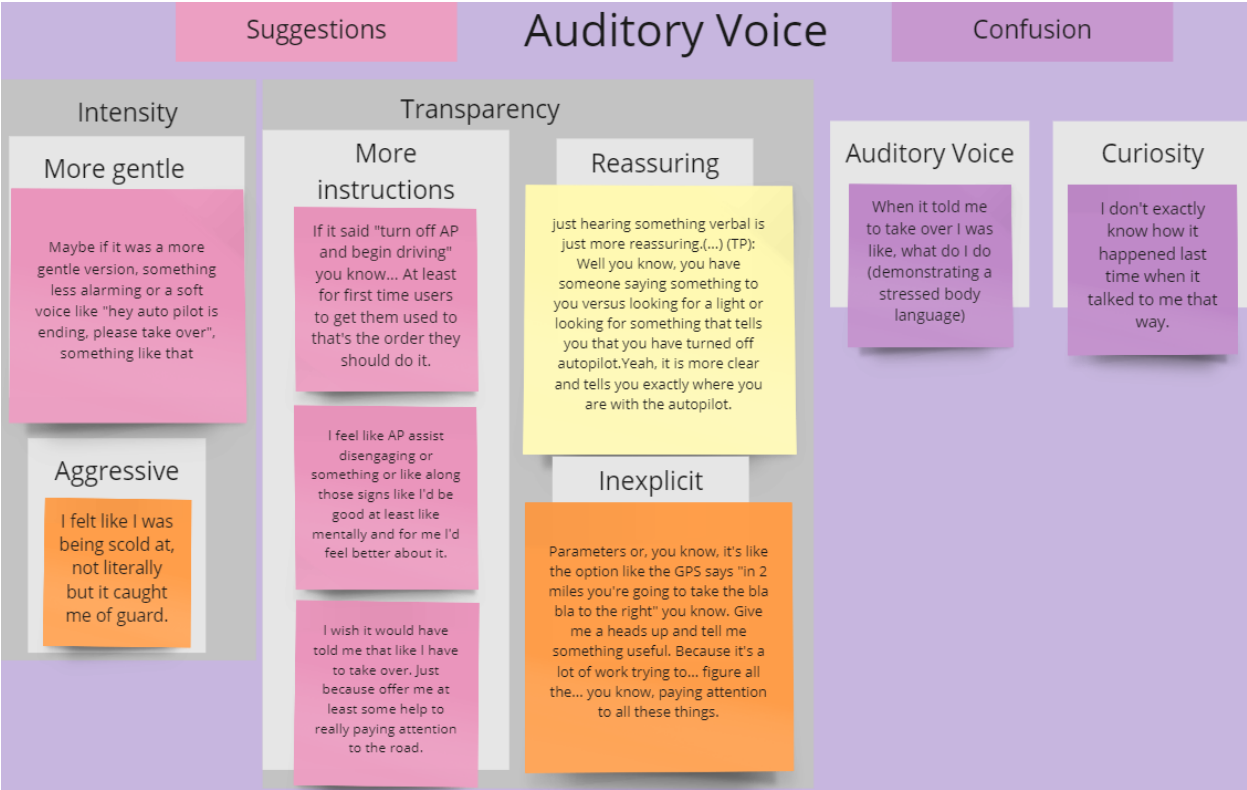
She told me to drive the car so I started driving the car

it told me verbally

(...) and the voice.

Memory Loss

It told me, I can't remember what it said now. Can you tell me what it said? It was commanding me to take over but I don't remember the words



Center Stack Display (CSD)

Interpreted Cues

Attention

AP ending,
thank you iPad
tablet thing.
Ok, I'm taking
over.

Hierarchy

It was fine, for some reason
I looked over at the
infotainment first for some
notification and then that
was when I saw the
information here (at the
display behind the steering
wheel)

Visual

The car is
letting me
know by both
displaying
visual

just because this is
bigger I think it would
be easier to read, that's
how I feel I like the fact
that it also show up
here, the notification

Instrument Cluster Display (ICD)

Interpreted Cues

Visual

The car is
letting me
know by both
displaying
visual

Color

It was
yellow

I know the
colour
changed on
the screen.

I remember it to be
yellow on the
screen. It was
commanding me
and telling me what
to do and I did
exactly what it said

I just
remember
it being
yellow,

Hierarchy

the audio made
me take a look at
the visual, which
told me that I
should prepare to
take over.

(TP): With the
seatbelt as well
as the visual on
the screen
giving you a...

(...) or some reason I looked over
at the infotainment first for
some notification and then that
was when I saw the information
here (ICD)(..) Yea, just because
this is bigger I think it would be
easier to read, that's how I feel I
like the fact that it also show up
here, the notification

Relief

It was the screen. The beeping
kind of forewarned me that it
was trying to tell me something.
But because the seatbelt
happened first, for a second I
actually thought we were in
some kind of danger, like a car
got too close and that's why it
had to anticipate again.
[Laughter] But, then when I saw
the screen I realised that ok...

Instructions

The instructions
that was given,
because it had
the buttons and
visual on that.

Seatbelt

Positive

Impressed

Oh, that is cool! It is like "hello, wake up", that is really cool.

Attention

(TP): the signal caught my attention, but what really got me was the seat belt. It was like "hello, hands back on the wheel".

...the seat belt is another-, it grabs your attention immediately.

It's good the seatbelt got my attention because otherwise I would keep talking.

Okay. That was really-, I liked that because it-, it was like all senses, "it said drive the car" and pulling on the seat belt, otherwise I would be like "la la la"

I think that's pretty good, something happened to my strap, it was like it buzzed tighter, I was like okay. It's obviously telling me something. It kind of actually made me nervous, like there is something about to happen

(...)And I'm a heavy sleeper too so that noise would definitely not be enough but I think that seatbelt would..

It felt good, it was... A bit of, kind of jolted me awake. Big thing.

Seatbelt

Negative

Negative Feelings

Insecurity

Personally for the first time being in this car I'm not sure how I would feel about that.

Nervous

I think that's pretty good, something happened to my strap, it was like it buzzed tighter, I was like okay. It's obviously telling me something. It kind of actually made me nervous, like there is something about to happen

Unnecessary

I could do it without the strap

Fear

(TP): Yes. It was the seatbelt. Or initially the seatbelt made me feel like something was wrong. That's usually what happens in a car, the seatbelt locks before you break heavily. So that's what that brain association was. But now...

But because the seatbelt happened first, for a second I actually thought we were in some kind of danger, like a car got too close and that's why it had to anticipate again.

It was alarming! It was an alarming like "oh, shoot, I had to hit the break!" Like the only time my seatbelt locks like that is if I hit the breaks suddenly and like I haven't had to do that in a long time. So I'm like "oh, God!".

Because I'm like "oh gosh!" like for one this one, seatbelt locking startles me a lot. I'm like "oh, shoot! What's going on?"

Seatbelt

Interpreted Cues

Feedback

Also there is kinetic feedback on the seat belt that is like "Hey, just in case your ears and eyes are not working, there is also this feedback on the skin, so if you can get back on there that would be great".

Overwhelmed

The seatbelt alerts you, in case you fall asleep maybe. This is all a lot to take in

Warning

Um... It was getting a little tighter. Like something, kind of like a warning.

Interpreted cue

It did that thing [pulls the seatbelt]

So the tug on the seatbelt let you know, huh?

With the seatbelt as well as the visual on the screen giving you a...

Um... The seatbelt tightened right before.

The colour changed on the screen and the seatbelt touch and there was beeping.

Oh, all of it. The pulling of the seatbelt, the lifebelt,(...)

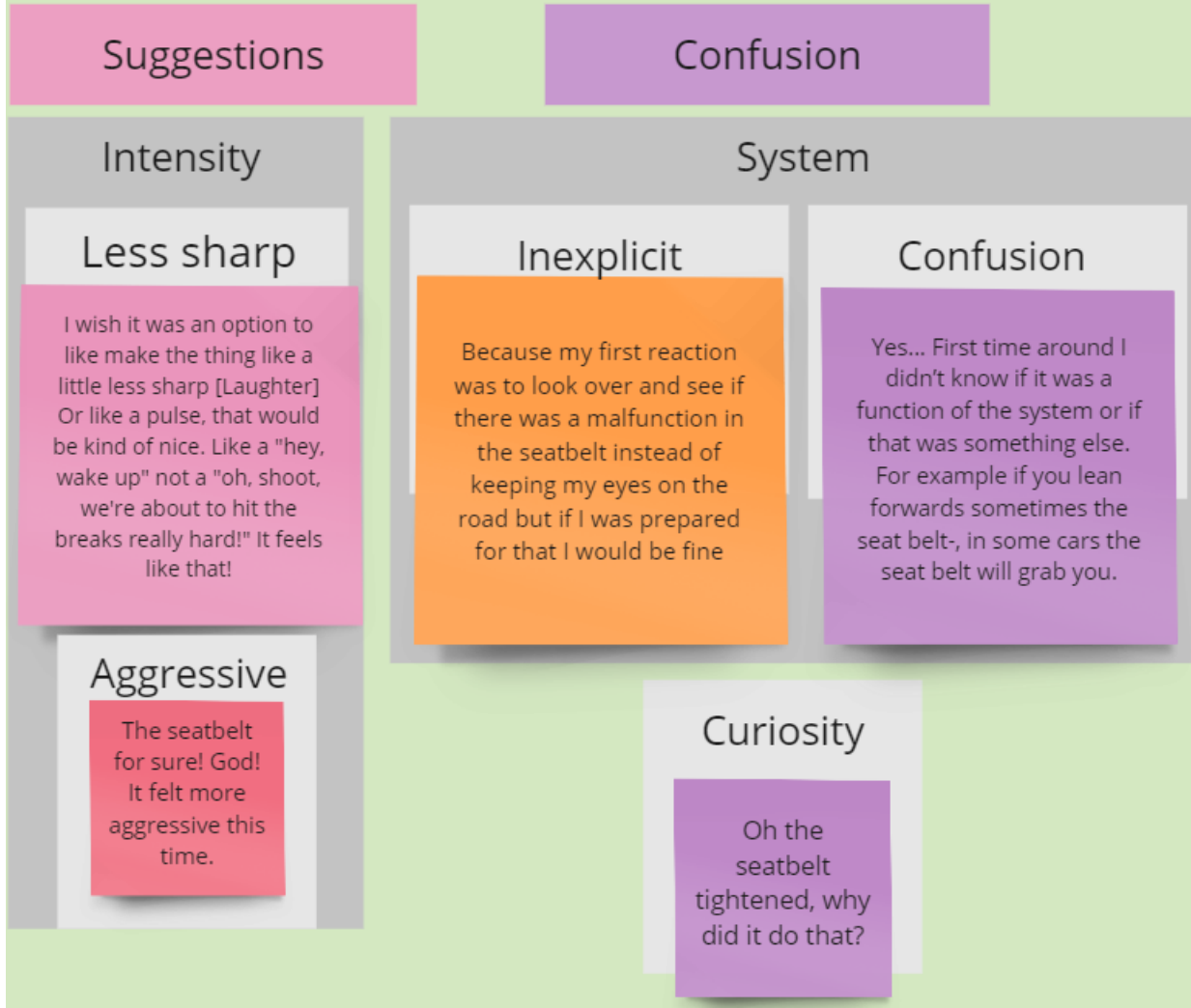
So, the seatbelt jiggles and it tells you to take over.

Experience

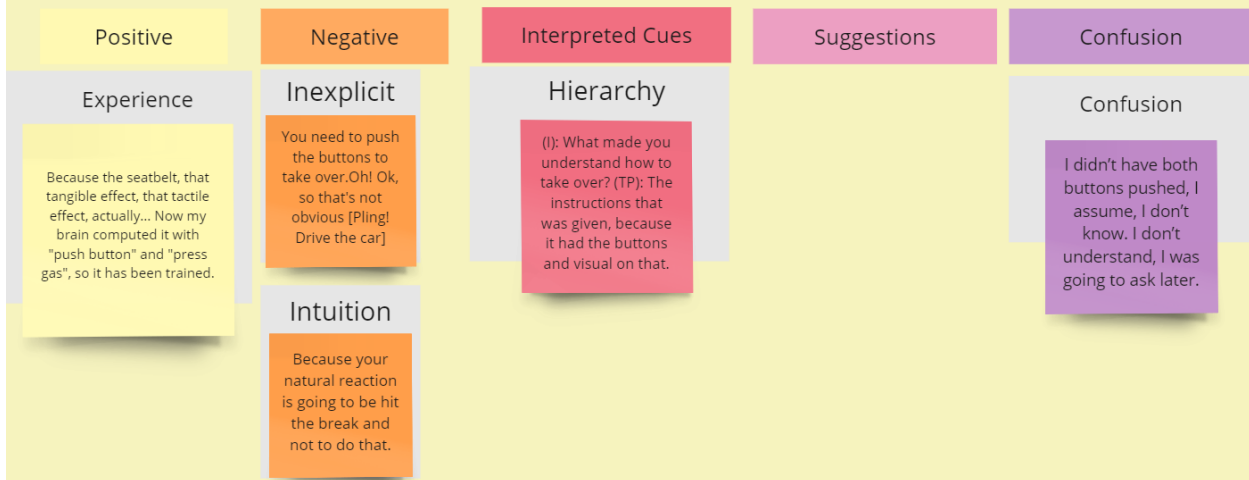
(TP): Because the seatbelt, that tangible effect, that tactile effect, actually... Now my brain computed it with "push button" and "press gas", so it has been trained.

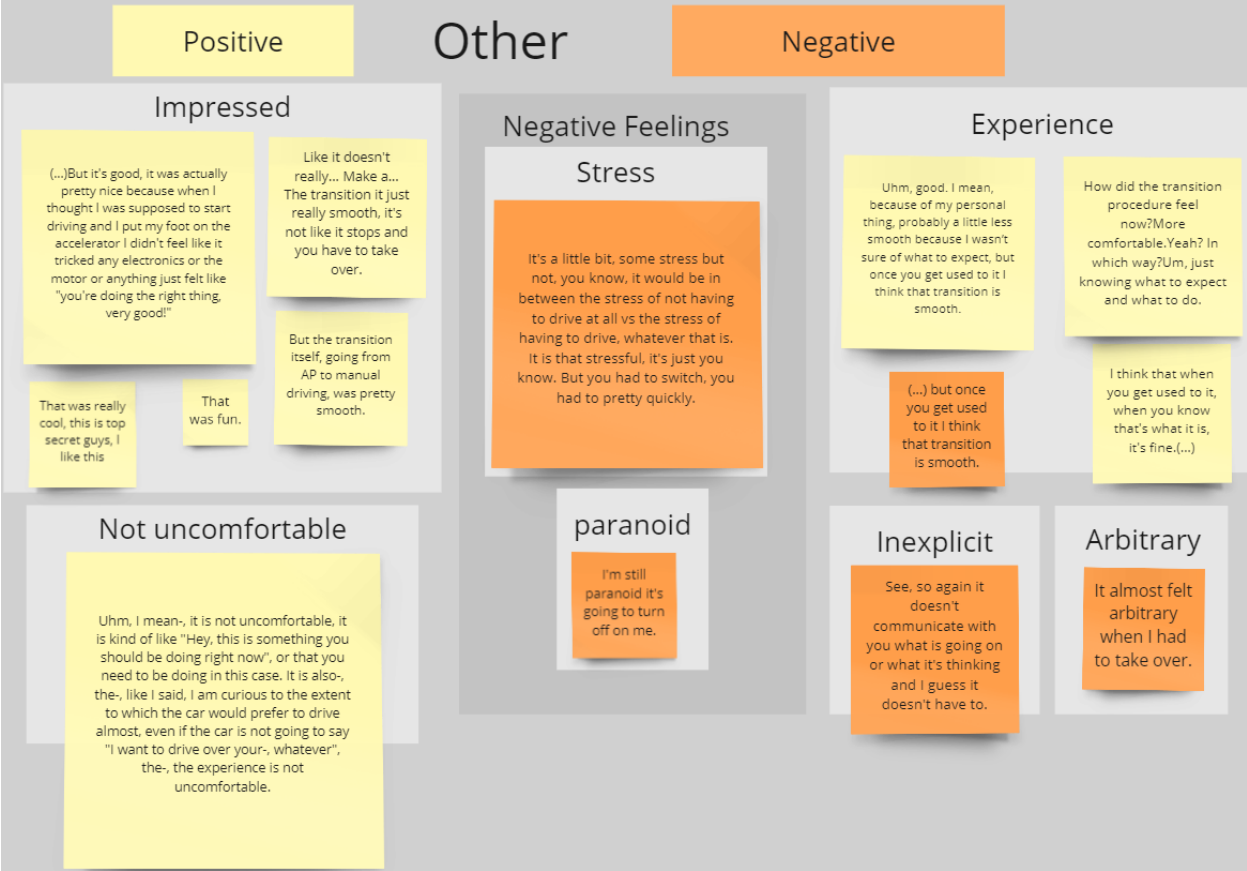
Because the seatbelt, that tangible effect, that tactile effect, actually... Now my brain computed it with "push button" and "press gas", so it has been trained.

Seatbelt



Take-over Buttons





Other

Suggestions

Pre-notification

Yeah, a little bit. A little bit stressed. And it says here is this shrinking time where you can, you know... So I guess, it would be nice to know like what the margin of like transition or if the timeline for transition should be that was it like quickly shrinking on you. You know what I mean? I wish it was wider, like a longer period, you know? It just flashed all of a sudden, like "prepare!". Oh, what?! And then, you know what I mean, like it told me like "Ey, you've got a little bit to go to switch back to driving" would be nice.

Auditory Voice

If it said "turn off AP and begin driving" you know... At least for first time users to get them used to that's the order they should do it. Because I'm pretty good at remembering anyway
[Laughter]

Automatic off

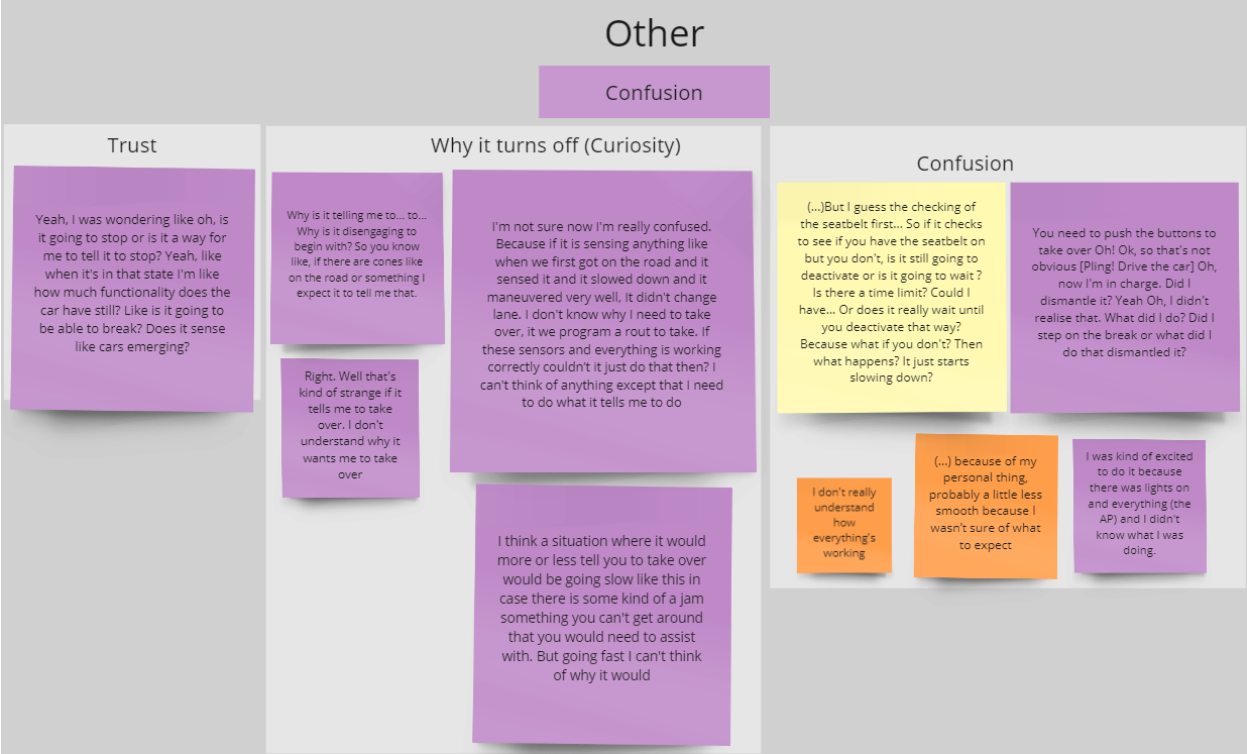
Yeah, I wish like when it ended it would have like a countdown and it ended itself because now I'm like ok, I do not only have to worry about taking over I have to turn it off first too. Like I wish it could just turn off. Because like if AP is ending, it's just like if I never turn it off does that mean it's constantly going to just be ending and freak out or..?

Suggestions

Talk or vibrate, seatbelt, loud music or something like that

Vibration

more mindful I like that, gentle vibrations would be nice



Positive Reactions Transcript



Negative Reactions Transcript

Frustration, Auditory display,
understanding, curiosity

Confusion

So your mind goes from like feeling relaxed, I guess, to a little bit of "what's going on? What do I have to do to take over?"

Please take over, so how do I do that? by pressing these (audio: "drive the car").

It took me a while to respond, right? I think like I had to... like get my mind out of what I was doing with "oh, what's going on? Oh, I have to do this thing".

Oh the seatbelt tightened, why did it do that?

I don't really understand how everything's working [Pling! Pling! Pling!] Ok... [Pling! Pling! Pling!]

(TP): What? What am I not doing? Isn't it off? (I): No (TP): Press it again? (I): Yes

I don't know these signals, I don't know what that means.

(I): You need to push both. (TP): Oh, to turn it off? [Beep!]

Oh, is that AP ending? Ok! Please take over and... Do I have to deactivate it? (I): Yes

[Pling! Pling! Pling!] Do I press the buttons? That's right.. [Pling! Drive the car]

[deactivates AP] Oh I did? Oh I got it.

[Pling!] Should I take over? [Pling!] Will it tell me when or..?

Negative Reactions Transcript

Negative Feelings

Seatbelt, driving behaviour,

Stress

(TP): Yeah, a little bit. A little bit stressed. And it says here is this shrinking time where you can, you know...

I was getting a little stressed out there

I can't really tell when it's going to turn off so I'm kind of on the edge right now. If I knew exactly at what speed it turns off at or something, because now it's kind of unpredictable. Almost like the traffic speeding up I think it might turn off, in a few miles.

(TP): [Beep!] Oh, gosh! Please take over, I am taking over! [Pling!] Drive the car! Ok!

(TP): [Pling!] oh [Pling! Pling! Pling!] I don't know these signals, I don't know what that means.

When it told me to take over I was like, what do I do (demonstrating a stressed body language)

Scared

but it also felt like when you go too fast and then you brake very hard and the seatbelt locks, it just felt like I was getting in to an accident. I was like, wow am I getting in to an accident? But then I was like, no the seatbelt just locked

It's kind of scary, it almost feels like the engine is in this mode that it's not ready for it.

Um... It choked me a little bit [Laughter] Um... Yeah, that kind of really startled me to be honest [Laughter]

It's easier, but I always feel like "take over or I'm going to crash"

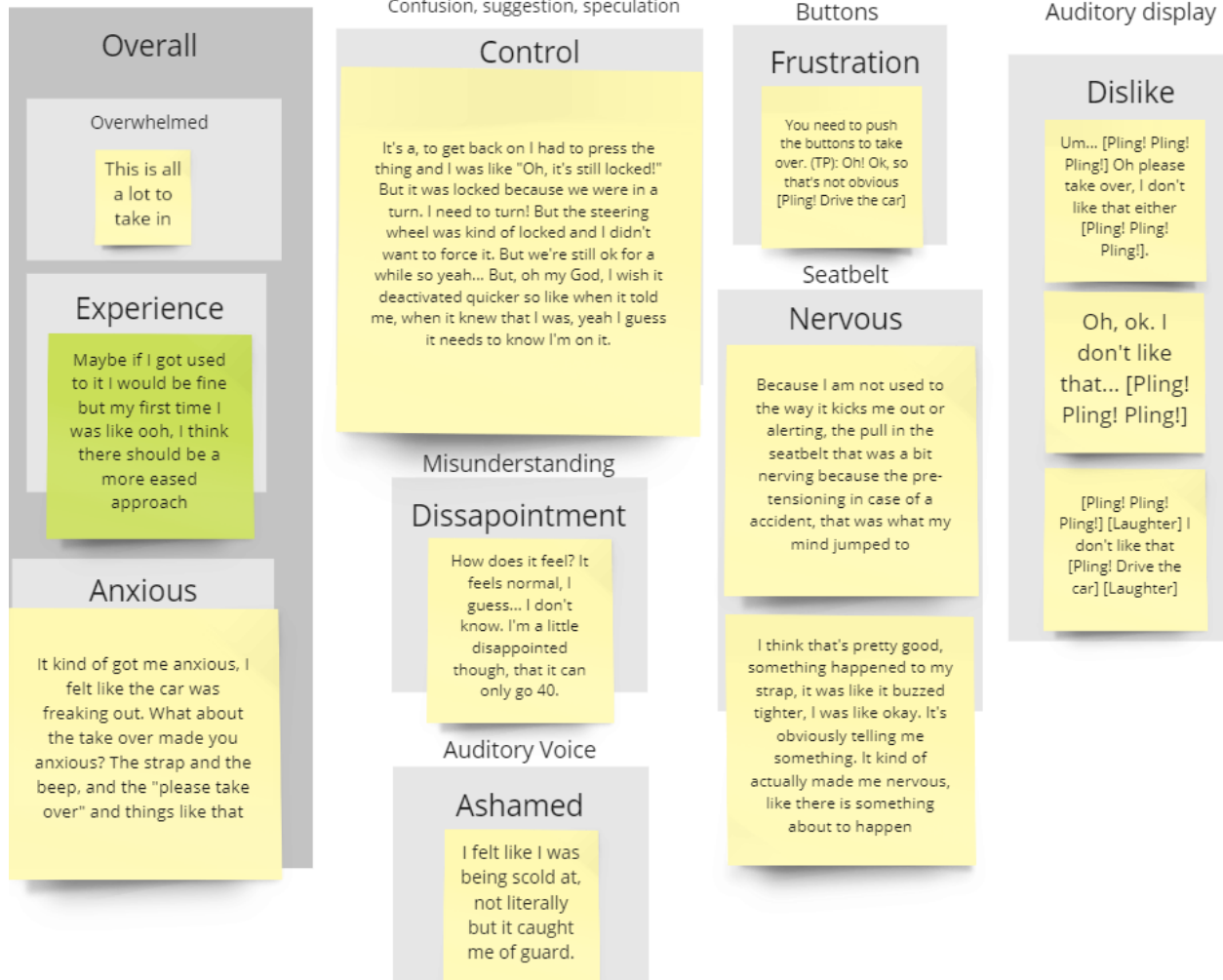
(TP): Oh! God! It just like choked me! [Pling! Pling! Pling!].

Although, if it turned off right before like a stop I'd be a little freaked out because then it's like "is it actually going to stop? Is it still engaged?" Like that part where it says, where it's like the AP like disengaging, please take over.

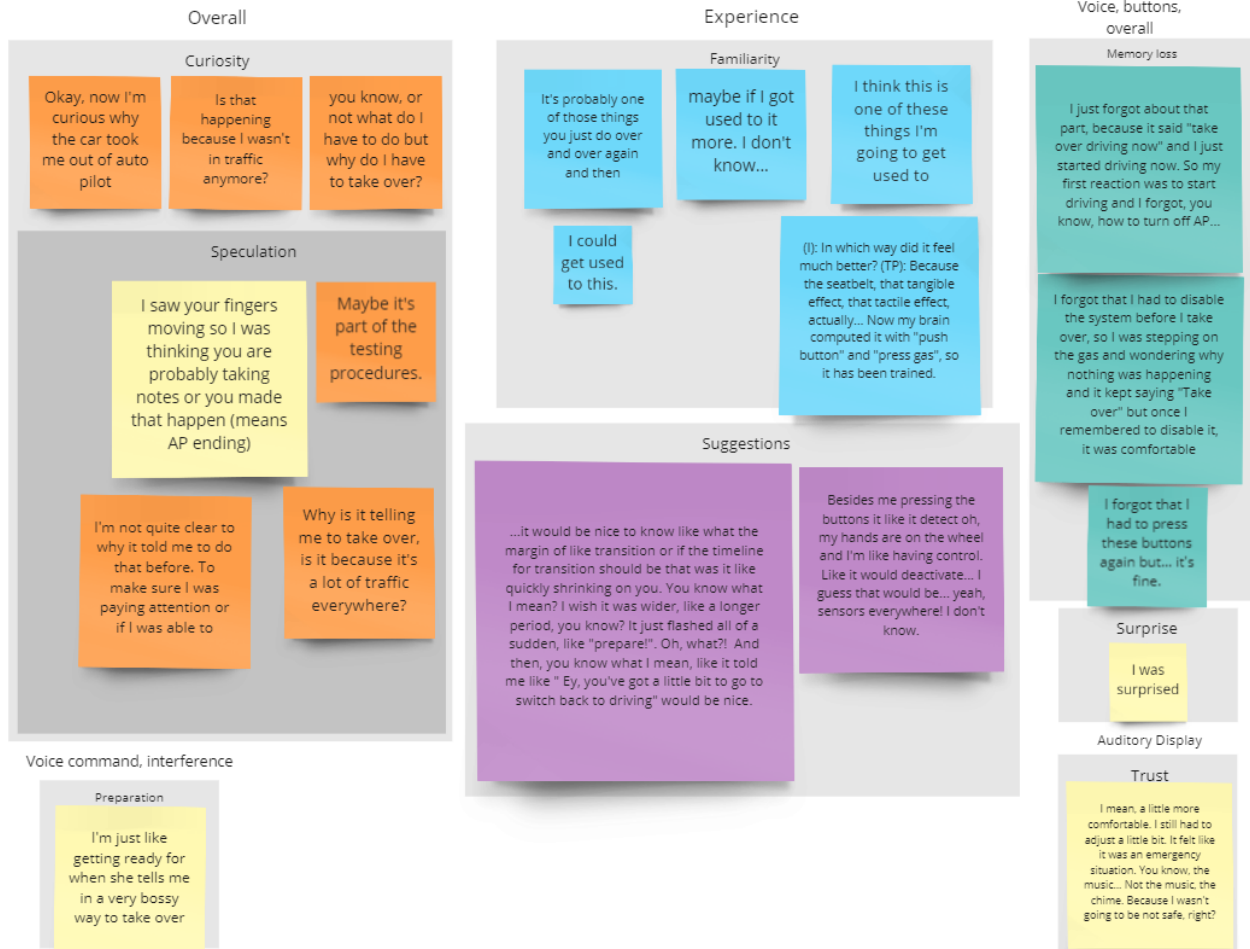
[Pling! Pling! Pling!] [Pling! Drive the car] So it's 40 mph... Wow! Yanks on you too. It scared the crap out of me! [Laughter]

Oh, I thought we were going to blow up or something! [Laughter] It always makes me freak out when it's beeping. It makes me feel like something is wrong.

Negative Reactions Transcript



Mixed Reactions Transcript



Reactions Video

Attention

Surprised

[1:00:19,7 - 1:00:36,9] Looks surprised when the car signals for takeover.

[15:20,4 - 15:58,8] Looks a bit surprised when the signal comes and then grabs the steering wheel(TP): Okay...

[19:19,5 - 20:01,5] Makes a surprised body movement.

Scared

[Pling! Pling! Pling!] [Holds her hands for her heart, Laughter] I don't like that [Pling! Drive the car] [Laughter]

[16:11,8 - 16:14,5] Gets jump-scared when take-over notification shows up

[1:05:28,0 - 1:05:30,1] Gets jump-scared when take-over notification shows up

[28:38,3 - 28:41,1] Gets jump-scared when take-over notification shows up

[15:46,0 - 16:13,3] Looks really surprised. body react by a small jump and then freezes.

[1:21:47,5 - 1:21:55,3] Gets jump-scared when take-over notification shows up

Interruption

[31:13,0 - 31:17,1] Stops talking,

[24:22,8 - 24:32,9] Sitting in a phonecall when the car alarms for takeover.

[18:45,2 - 18:50,9] Interrupted when using the phone. (TP): oh, oh, oh.

Interrupted when using phone.

Reactions Video

Memory loss

Holding the steering wheel and finally remembers to push the buttons

[1:12:28,8 - 1:12:32,2] Holding in the steering wheel and dont know what to do. Needed a reminder and then he remembered it.

[22:09,4 - 22:11,7] OH okay, so how do I take over?

[1:12:33,0 - 1:12:43,6] Holding the steering wheel and dont know what to do. Needed a reminder and then he remembered it.

Instructions

[16:54,2 - 16:57,1] Needed instructions to push both buttons for takeover.

[1:04:55,9 - 1:05:03,1] Needs to be remembered to push the buttons.

[19:11,4 - 19:58,4] Needed instructions for pushing both buttons for takeover.

Needed instructions for pushing both buttons for takeover

[22:11,4 - 22:33,8] Needed instructions for pushing both buttons for takeover,

Needed instructions for pushing both buttons for takeover

[18:52,4 - 18:58,8] [Beeping from AP] (TP:)Oh, well, oh, okay. (I:)You have to take over by pressing the buttons.Long press. (TP:)Oh

[1:06:25,3 - 1:06:30,2] Reacts on the signal but does not know what to do

[15:53,6 - 16:09,7]Needed instructions to push both buttons for takeover. (TP:)When It told me to take over I was like, what do I do (demonstrating a stressed body language.

[27:27,3 - 28:37,8]Needed instructions for pushing both buttons for takeover, Holding the steering wheel and does not understand what to do.

Auditory Voice

Joy

[19:55,5 - 20:34,6] Laugh about the bossy voice command.(TP): haha so bossy!

Curiosity

I wonder why it tightened my seatbelt? To make sure I'm hanging on.

[Pling! Drive the car] Ok, who's in charge here? Why is it telling me when to drive and then to take over

Error

and released the buttons for deactivation too early.

and released the buttons for deactivation too early.

released the buttons for deactivation too early.

Released the buttons for deactivation too early.

Confused

Looks a bit confused at first before figuring out how to end tip and pushes the buttons

(TP):[Pling, pling, pling] So does it... So if I took over I just... [Pling! Drive the car] Alright.

(TP): oh, that was interesting

try to interprete the messages of taking over.

[1:04:38,0 - 1:04:54,6] Mode confusion. IF AP is available and active or not.

Appendix C

All Design Guidelines for phases 1, 2-6, and 7 of the transition

DESIGN GUIDELINES [1]				
Criterion	Theme	Based on	Comments	Priority
Convey the message soothingly	Auditory	VC		High
Minimise distracting noise outside ODD	Auditory	VC	ANC, block radio, surrounding distractions.	High
Allow the user to prepare for the take-over	Overall	VC	Timespan, timing	High
Minimise stress in relation to the transition	Overall	VC	Timing of the cues, intensity	High
Minimise the association with danger and fear	Overall	VC	Crash, hard break	High
Provide secondary information	Overall; Information	FMT	Backup system, Visual, Audio	High
Catch the attention without evoking negative feelings	Overall; Feelings	HTA	Smooth, increasing and decreasing intensity	High
Minimize surprising notifications	Overall; Communication	VC	Passive communication: Haptic, visual, auditory	High
Interrupt the users secondary tasks in a comfortable manner	Overall; Attention	HTA	Tricking through ex light in periferal, magic	High
Direct the attention to important functions	Overall; Attention	FMT		High
Block NDRT content	Overall; Attention	FMT	Attention?	High
Show clearly visible communication	Vision	HTA	Distance from text, contrast, color etc.	Medium
Be bright enough to catch the attention	Vision	HTA	Spec from Volvo	Medium
Should be logically timed in relation to the users interpretation	Auditory	VC		Medium
Clear auditory communication	Auditory	VC		Medium
Communicate for deactivating the system	Auditory	VC	With different cues	Medium
Provide more information from the voice	Auditory	VC		Medium
Use colors as a way to direct the attention	Auditory	VC		Medium
Provide clear instructions and visuals from the ICD	Auditory	VC		Medium
Be loud enough to catch the attention	Auditory	HTA	Spec from Volvo	Medium
Allow familiarization with the system	Overall	VC		Medium
Avoid creating an overwhelming experience	Overall	VC	avoiding information overflow	Medium
Provide the driver with sufficient instructions	Overall	VC		Medium
Increase the transparency	Overall; Understand	HTA	Easy to understand	Medium
Clarify the intention of the signals	Overall; Understand	HTA		Medium
Avoid confusion	Overall; Understand	VC	Which mode the driver is currently in, what actions to make, Error	Medium
Avoid evoking negative feelings	Overall; Feelings	HTA	Whole process	Medium
Provide accessible cues	Overall; Accessibility	HTA		Medium
Confirm the status of the system	Overall; Feedback	FMT	AD MD etc.	Medium
Can be used by users with no experience of AD	Usability; Intuitiveness	HTA		Medium
Communicate function, (semantics)	Usability; Intuitiveness	FMT	Symbols,animations,guiding lights,text?, audio cues, guiding audio sound,picture:	Medium
Avoid the sensation of guilt	Overall	VC	"not your fault" feedback	Low
Minimise the risk of taking the wrong action	Overall; Risk	HTA		Low
Minimize the danger when taking the wrong action	Overall; Risk	VC		Low
Explain the reason behind the transition	Overall; Understand	HTA		Low
Support correct action	Overall; Understand	HTA	Bigger buttons?	Low
Enable feedback on interactions	Overall; Feedback	HTA, FMT	Active communication: Haptic, visual, auditory	Low
Provide intuitive instructions for the user	Usability; Intuitiveness	HTA		Low
Provide an intuitive take-over maneuver	Usability; Intuitiveness	HTA	Buttons bigger?	Low

DESIGN GUIDELINES [2-6]




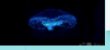
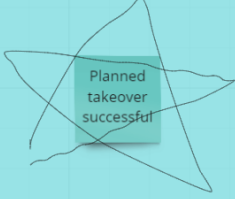
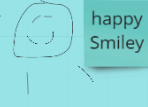
Criterion	Theme	Based on	Comments	Priority
Show clearly visible communication	Vision	HTA	Distance from text, contrast, color etc.	High
Clear auditory communication	Auditory	VC		High
Communicate for deactivating the system	Auditory	VC	With different cues	High
Provide more information from the voice	Auditory	VC		High
Provide clear instructions and visuals from the ICD	Auditory	VC		High
Minimise distracting noise outside ODD	Auditory	VC	ANC, block radio, surrounding distractions.	High
Minimise stress in relation to the transition	Overall	VC	Timing of the cues, intensity	High
Avoid creating an overwhelming experience	Overall	VC	avoiding information overflow	High
Provide the driver with sufficient instructions	Overall	VC		High
Minimise the association with danger and fear	Overall	VC	Crash, hard break	High
Provide essential information	Overall; Information	FMT	How? Visual, Audio	High
Support correct action	Overall; Understand	HTA	Bigger buttons?	High
Avoid confusion	Overall; Understand	VC	Which mode the driver is currently in, what actions to make, Error	High
Avoid evoking negative feelings	Overall; Feelings	HTA	Whole process	High
Catch the attention without evoking negative feelings	Overall; Feelings	HTA	Smooth, increasing and decreasing intensity	High
Provide accessible cues	Overall; Accessibility	HTA		High
Enable feedback on interactions	Overall; Feedback	HTA, FMT	Active communication: Haptic, visual, auditory	High
Direct the attention to important functions	Overall; Attention	FMT		High
Block NDRT content	Overall; Attention	FMT	Attention?	High
Can be used by users with no experience of AD	Usability; intuitiveness	HTA		High
Provide intuitive instructions for the user	Usability; intuitiveness	HTA		High
Communicate function, (semantics)	Usability; intuitiveness	FMT	Symbols, animations, guiding lights, text?, audio cues, guiding audio sound, pictures	High
Be bright enough to catch the attention	Vision	HTA	Spec from Volvo	Medium
Should be logically timed in relation to the users interpretation	Auditory	VC		Medium
Convey the message soothingly	Auditory	VC		Medium
Use colors as a way to direct the attention	Auditory	VC		Medium
Be loud enough to catch the attention	Auditory	HTA	Spec from Volvo	Medium
Allow the user to prepare for the take-over	Overall	VC	Timespan, timing	Medium
Provide secondary information	Overall; Information	FMT	Backup system, Visual, Audio	Medium
Minimise the risk of taking the wrong action	Overall; Risks	HTA		Medium
Minimize the danger when taking the wrong action	Overall; Risks	VC		Medium
Increase the transparency	Overall; Understand	HTA	Easy to understand	Medium
Clarify the intention of the signals	Overall; Understand	HTA		Medium
Confirm the transition	Overall; Feedback	FMT		Medium
Confirm the status of the system	Overall; Feedback	FMT	AD MD etc.	Medium
Minimize surprising notifications	Overall; Communication	VC	Passive communication: Haptic, visual, auditory	Medium
Interrupt the users secondary tasks in a comfortable manner	Overall; Attention	HTA	Tricking through ex light in periferal, magic	Medium
Provide an intuitive take-over maneuver	Understanding; Intuitiveness	HTA	Buttons bigger?	Medium
Increase the understanding of using the buttons	Haptic	VC	Some cue that leads to the buttons	Medium
Allow familiarization with the system	Overall	VC		Low

DESIGN GUIDELINES [7]




Criterion	Theme	Based on	Comments	Priority
Avoid the sensation of guilt	Overall	VC	"not your fault" feedback	High
Provide secondary information	Overall; Information	FMT	Backup system, Visual, Audio	High
Increase the transparency	Overall; Understand	HTA	Easy to understand	High
Explain the reason behind the transition	Overall; Understand	HTA		High
Confirm the transition	Overall; Feedback	FMT		High
Show clearly visible communication	Vision	HTA	Distance from text, contrast, color etc.	Medium
Clear auditory communication	Auditory	VC		Medium
Convey the message soothingly	Auditory	VC		Medium
Provide more information from the voice	Auditory	VC		Medium
Minimise stress in relation to the transition	Overall	VC	Timing of the cues, intensity	Medium
Avoid creating an overwhelming experience	Overall	VC	avoiding information overflow	Medium
Minimise the association with danger and fear	Overall	VC	Crash, hard break	Medium
Avoid confusion	Overall; Understand	VC	Which mode the driver is currently in, what actions to make, Error	Medium
Avoid evoking negative feelings	Overall; Feelings	HTA	Whole process	Medium
Catch the attention without evoking negative feelings	Overall; Feelings	HTA	Smooth, increasing and decreasing intensity	Medium
Confirm the status of the system	Overall; Feedback	FMT	AD MD etc.	Medium
Can be used by users with no experience of AD	Usability; Intuitiveness	HTA		Medium
Be bright enough to catch the attention	Vision	HTA	Spec from Volvo	Low
Should be logically timed in relation to the users interpretation	Auditory	VC		Low
Communicate for deactivating the system	Auditory	VC	With different cues	Low
Use colors as a way to direct the attention	Auditory	VC		Low
Provide clear instructions and visuals from the ICD	Auditory	VC		Low
Be loud enough to catch the attention	Auditory	HTA	Spec from Volvo	Low
Minimise distracting noise outside ODD	Auditory	VC	ANC, block radio, surrounding distractions.	Low
Enable feedback on interactions	Overall; Feedback	HTA, FMT	Active communication: Haptic, visual, auditory	Low
Minimize surprising notifications	Overall; Communication	VC	Passive communication: Haptic, visual, auditory	Low
Direct the attention to important functions	Overall; Attention	FMT		Low

Appendix D

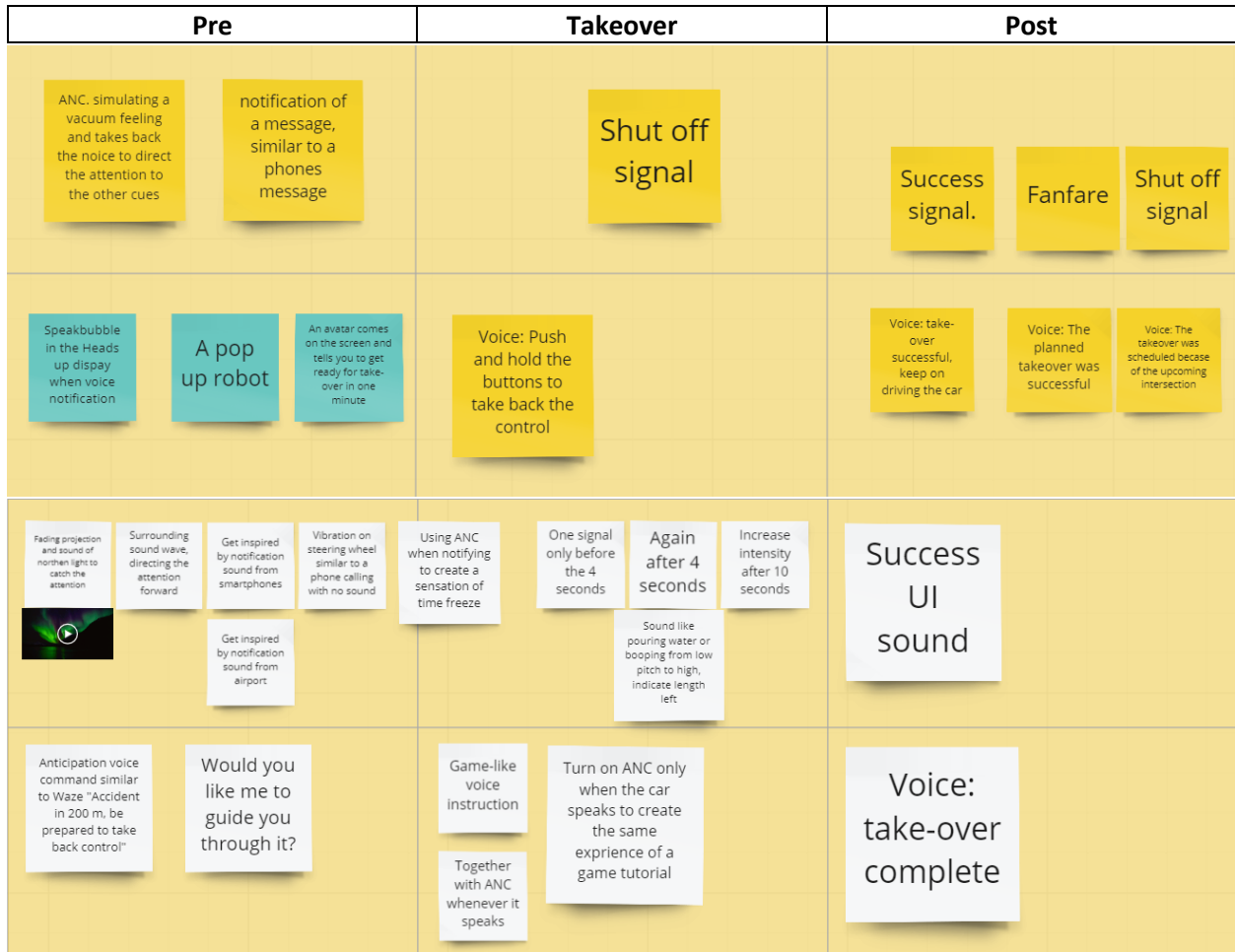
Ideas from the first Brainwriting session

Pre	Takeover	Post
<p>Sound wave circle appears</p>  <p>Sound wave line appears</p> <p>Smooth transformation from interface of TJP on</p> 	<p>Use colors with no association with warning or danger</p> 	<p>Morfing transformation back to normal interface</p>
<p>Breathing pulse animation on the screen</p>  <p>Circle</p> <p>Line</p>	<p>Clearly turn off NDRT content, only show Volvo logo</p>	<p>Back to drive mode interface, adjust temp, radio etc, basic apps only</p>
<p>illustration of time left before the takeover starts</p>	<p>Text that says push and hold both buttons</p> <p>Animation of pushing the buttons procedure</p> <p>A circle that gets closed</p> <p>3...2...1... .Drive the car</p>	 <p>Planned takeover successful</p>
<p>close the CSD fully to direct focus on the ICD</p> <p>Blocked secondary tasks content</p> <p>Hologram</p> <p>Robot</p> <p>Transparent screen</p> <p>Pop up screen</p> <p>New notification that says prepare or get ready for the takeover in one minute or similar</p> <p>Stop youtube or similar content and show the GPS with a message like Get ready to drive the car.</p>	<p>Text: push and hold the buttons and drive the car.</p> <p>Stop youtube or similar content and show the GPS with a message</p> <p>Direct the attention towards the ICD with an eye and arrow at an illustration of the ICD</p> <p>circle that gets smaller until push of buttons is done</p> <p>Hologram</p> <p>Robot</p> <p>Transparent screen</p> <p>Pop up screen</p>	<p>Happy "avatar" tamaguchi</p>  <p>happy Smiley</p> <p>Hologram</p> <p>Robot</p> <p>Transparent screen</p> <p>Pop up screen</p>

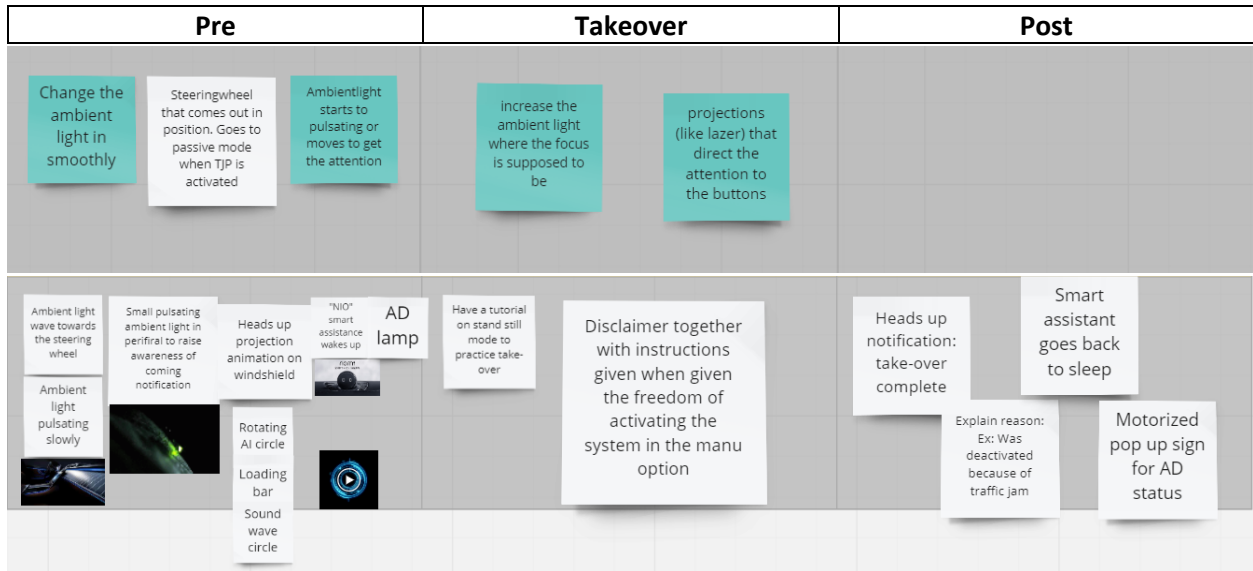
Visual cues using ICD and CSD

Pre	Takeover	Post
<p>Buttons changes colors</p>	<p>Use minimalistic but clear icons</p> <p>Pulsate with light on the buttons where the driver should push</p> <p>Projection in the car to indicate where to push</p> <p>Buttons pulsates to indicate something is about to happen</p> <p>Animated symbols on the buttons, digital display</p> 	<p>Lights turns off</p> <p>Or switches back to stationary white</p> <p>Always on display animation to symbol</p>
<p>Pulsating light on steering wheel</p> <p>On the logo</p> <p>Behind the steering wheel</p> <p>Animation in the middle of the steering wheel</p> 	<p>Animation of time left for pushing on the steering wheel</p>	<p>Animate the logo of Volvo in the middle</p>
<p>The buttons start to luminate and then flicker or a light that goes around it</p>	<p>Light behind the buttons</p> <p>The buttons start to luminate like a firefly</p> <p>Pulsating lights on the steering wheel that direct the attention towards the buttons</p> <p>Flipping buttons that appear when it is time to press them</p> <p>Big buttons with only one function, maximize the chance of finding the buttons</p> <p>Screen on buttons that simulates filling a glass of water when pushing</p> <p>The buttons start to luminate and then flicker or a light that goes around it</p>	<p>lid over the buttons to show that the takeover is done</p> <p>Flipping buttons that enable other functions like drive assist etc., and flips over again when AP is activated</p>
<p>Screen in the middle of steering wheel that starts "come alive" by some animation</p>	<p>buttons on the edges of the steering wheel that lights up where your supposed to put your hands</p> <p>Screen on steering wheel, ball that gets smaller and smaller until pulsating in another color, arrow towards the buttons</p> 	

Haptic cues using buttons and steering wheel



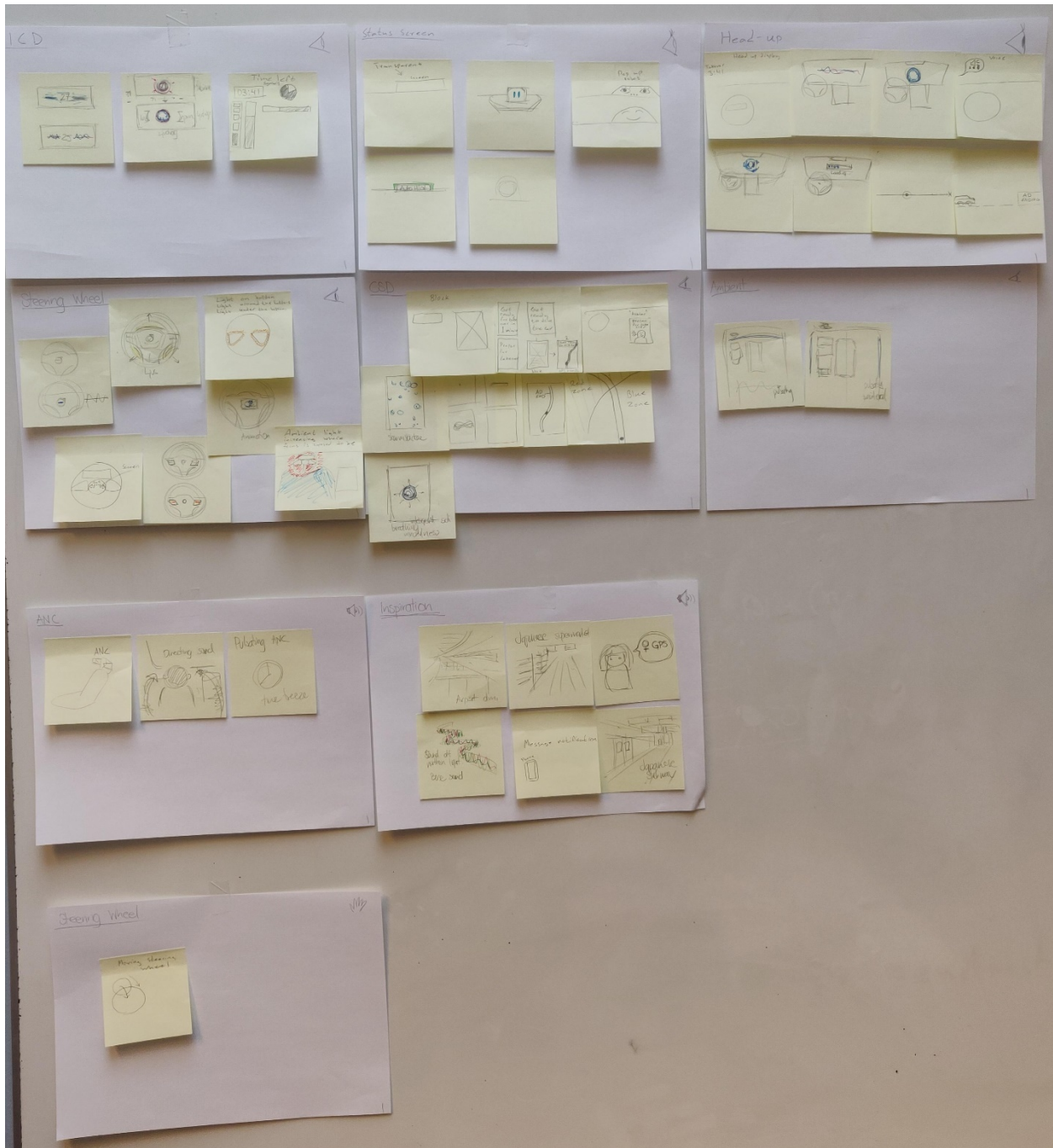
Audio cues using VUI and SUI



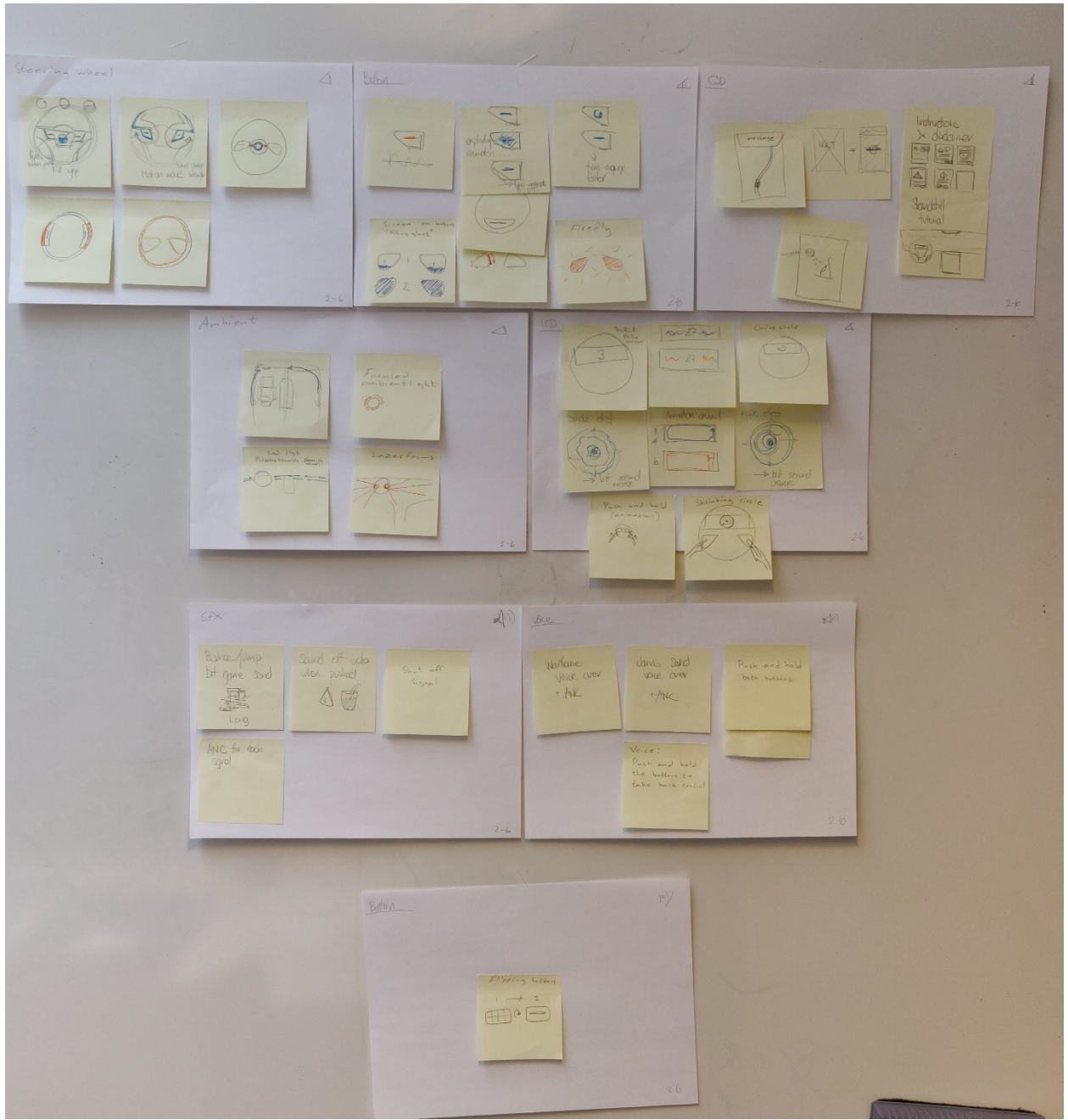
Other cues

Appendix E

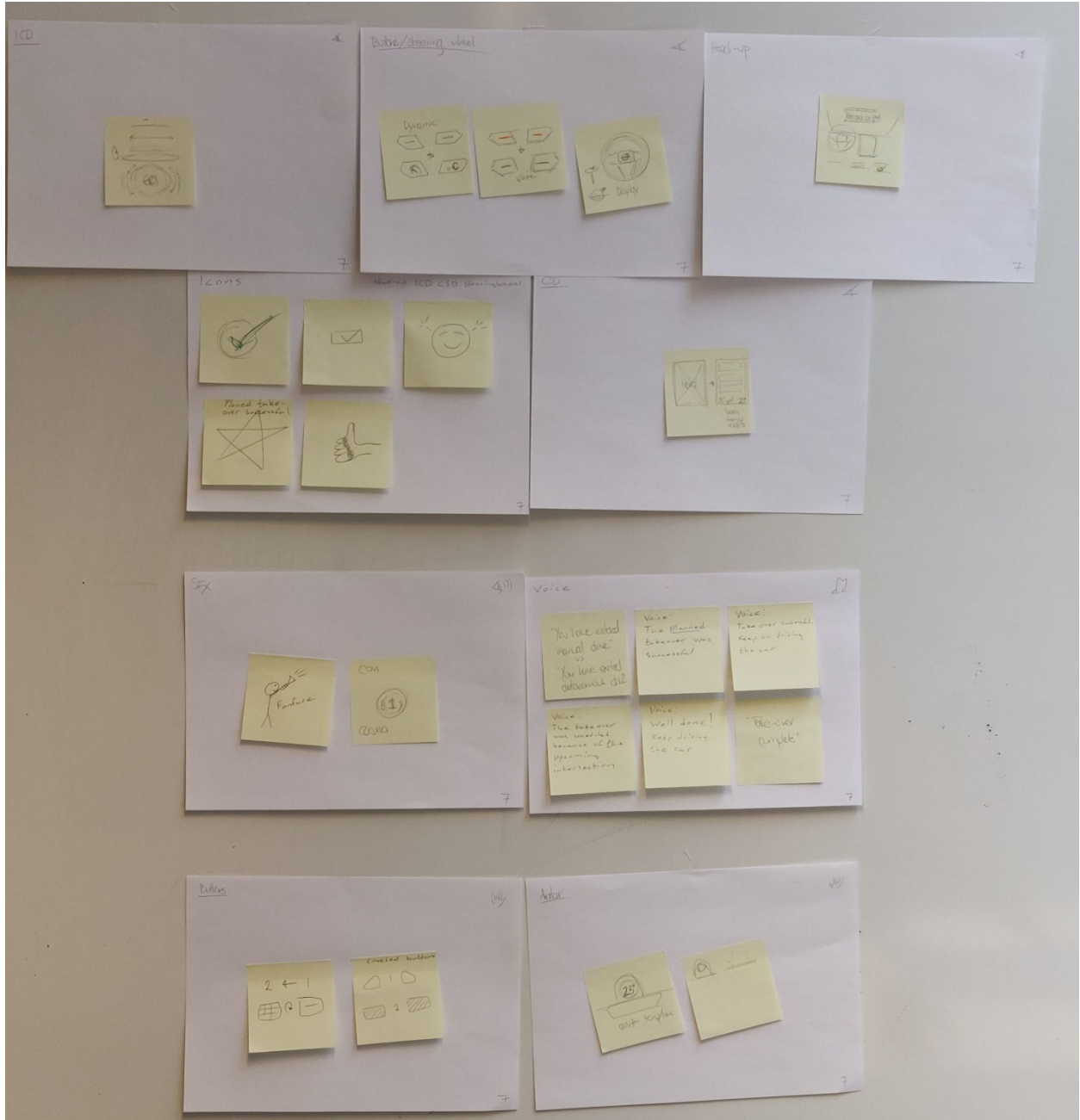
Ideas from the second Brainwriting session



Pre-notification



Takeover-sequence



Post-notification

Appendix F

Links and QR codes to the 4 animated concepts



Concept A; Lightning

<https://youtu.be/AyaVmwTb7-A>



Concept B; Firefly

<https://youtu.be/DEIVjdHxYCU>



Concept C; Lightning

<https://youtu.be/922FBNC-CFw>



Concept D; Firefly

https://youtu.be/LjF7e_N8DXs

Appendix G

GDPR consent form for the user study



User Study for Volvo Car Corporation

Test leaders

Alexander Karlsson
Master Thesis, Volvo Torslanda PV
405 31 Gothenburg

Alfred Sävervall
Master Thesis, Volvo Torslanda PV
405 31 Gothenburg

Dear Participant,

Thank you for taking the time and participating in our user study. This user study is performed by Alexander Karlsson (alex.karlsson@volvocars.com) and Alfred Sävervall (alfred.savervall@volvocars.com) on behalf of Volvo Car Corporation to collect information about how drivers understand and experience the interaction with an automated car. The results from this user study will generate important input to future development of the concepts for the master thesis report.

The user study consists of online video interviews where the participant watches videos of the concepts. In addition, a short interview will be conducted to gain a better understanding of the experience and thoughts of the proposed concepts. The test session will take approximately around 30 minutes.



Consent to media documentation & processing

During the test session and the following interview we are going to conduct audio- and video recordings. Hereby the focus lies on the Interpretation of the signals from the car, the instrument cluster and other control panels of the vehicle and not on the participant. However, a recognisability on the recordings cannot be fully eliminated.

The material is relevant for the analysis of the session and the evaluation of the interview. It will only be used internally and sole for the stated purpose. You will stay anonymous and the collected data will be handled confidentially.

Please, check the boxes you agree with.

- I hereby agree to audio recordings during the session.
- I hereby agree to video recordings during the session.
- I hereby agree that the recorded files may be used for research and demonstration purposes.

I hereby declare that I have read the information notice and understood the conditions and purpose on media documentation and processing of my personal data.

Date and Place Name in Print Signature



Information Notice

Controller

Volvo Car Corporation, hereinafter referred to as “VCC”, “we”, “our” and “us”, will as controller process your personal data as described below.

Purpose and legal basis for processing

VCC will process the personal data that you provide to us in connection with you signing up for participation in the study such as contact details for administration of your participation. VCC will furthermore process the personal data that we collect as a result of your participation in the study (audio and video recordings) for research and development of autonomous functions including evaluation and improvement of our products and services and for contributing to research questions.

The legal basis for our processing of your personal data for administering your participation is that this processing is necessary for the performance of our contract with you concerning your participation in the study. The legal basis for our processing of your personal data for research and development and for contributing to research questions is that this processing of your personal data is necessary for the purposes of legitimate interests pursued by us.

Disclosure / Recipients of your personal data / Transfer

Your personal data may be disclosed to the general public as part of the publication of the research report. Furthermore, your personal data will be transferred to companies within the same group of companies as Volvo Car Corporation which are located outside of the EEA with the basis of Standard Contractual Clauses adopted by the European Commission- safeguarding your personal data.

Retention time

We will process your personal data in relation to study for a period of 8 years.

Your rights and contact information

You have the right to request a copy of the personal data that we store about you. If you would like a copy of some or all of your personal data, please send us an e-mail to alfred.savervall@volvocars.com.

We want to make sure that your personal information is accurate and up to date. Please do not hesitate to ask us to correct or remove information you think is inaccurate. You also have the right to have your personal data deleted and to have our processing of your personal data restricted in certain

circumstances.

In addition, you have the right to object to our processing of your personal data as well as to receive your personal data, which you have provided to us, in a structured, commonly used and machine-readable format and to have these transmitted to another controller. For more information on your rights please contact our Data Protection Officer by sending an e-mail toglobdpo@volvocars.com or sending a letter to Volvo Car Corporation, Attention: The Data Protection Officer, HB3S, 405 31 Göteborg, Sweden.

Appendix H

The online user study evaluation plan

Online User study Evaluation Plan

A (Lightning)		B (Firefly)		C (Galaxy)		D (Game)	
TP1	AB	TP4	BA	TP7	CA	TP10	DA
TP2	AC	TP5	BC	TP8	CB	TP11	DB
TP3	AD	TP6	BD	TP9	CD	TP12	DC
Alfred				Alex			

GDPR

"You will now conduct a user test together with me. In short, the thesis we are working on is about the transition from autonomous to manual driving in self-driving cars. The entire test takes just over 1h and during the test you will experience 2 concepts in different scenarios. After each scenario, I will ask questions about how you experienced the scenario and the information presented. It is important that you are honest and tell us exactly as you feel throughout the test as no answers are wrong. If you have any questions, we can answer them after the test. During the test, it is important that you both see and hear well and have a good connection to the network throughout the test. During the test, we will record the call in order to be able to take notes afterwards which you have approved in the GDPR form. If you have any questions about this afterwards, you can reach us by email or phone."

Background context

"You are about to watch a simulation where you drive in an autonomous car. The car drives completely autonomously but requires you as a driver to drive manually on certain occasions. In this simulation, the test starts with the autonomous function activated and you can sit back and relax until you get more instructions or signals from the car. We will ask questions about your experiences with the concepts. As I said before, you will see 2 concepts. The first concept you will see it three times, and the second concept twice. Firstly, the concept, I will first pause the video once and ask a question. For both concepts, you will see the concept in its entirety once and afterwards in different sequences. In between, we will ask questions after each sequence."

Demography

Age	
Sex	
Native Language	
English Level	

Turn off cellular noise. Don't forget to record.

First concept; Concept A

Part i) Play video until the push of a button.

(Ask if they see before. Ask if the image is sharp before play. Replay at lag.)

1. How do you interpret the situation right now?

Part 1) Play the entire sequence and ask the user to think aloud after the video.

1. Can you describe the course of events and what you felt while you saw this?

Part 2) Play the sub-sequences and ask questions.

Pre-notification

1. How do you interpret the signals?

a. What do you think the car wants to tell you? *(Use for short answer)*

Takeover

1. Did you understand what the car was trying to tell you? (Why?)

(If no, go to question 2. If yes, go to a and b)

a. What made you realize that you were going to *(take back control/press the buttons)*?

b. What made you understand how to act to take control?

2. Why do you think the car showed you these signals? *(What made you think that? Ex warning etc)*

Post-notification

1. Why do you think the car wanted you to take control?

2. Can you explain what happened after you took control with the buttons?

3. Do you feel like you got enough information from the car to understand why you had to take back control?

4. Do you feel like you got enough information from the car to feel safe with the takeover?

Second concept; Concept B

Part 1) Play the entire sequence and ask the user to think aloud after the video.

1. Can you describe the course of events and what you felt while you saw this?

Part 2) Play the sub-sequences and ask questions.

Pre-notifications

1. How do you interpret the signals?

a. What do you think the car wants to tell you? *(Use only for short answers)*

Takeover

1. Did you understand what the car was trying to tell you? (Why?)

(If no, go to question 2. If yes, go to a and b)

a. What made you realize that you were going to *(take back control/press the buttons)*?

b. What made you understand how to act to take control?

2. Why do you think the car showed you these signals? *(What made you think that? Ex warning etc)*

Post-notifications

1. Why do you think the car wanted you to take control?

2. Can you explain what happened after you took control with the buttons?

3. Do you feel like you got enough information from the car to understand why you had to take back control?

4. Do you feel like you got enough information from the car to feel safe with the takeover?

Final thoughts

1. Which of the concepts do you think was easiest to understand? *Why would you do that?*
2. Which concept do you like most between the two concepts you just saw? *Why would you do that?*
3. Which concept appealed to you most aesthetically?
4. Would you feel comfortable using a similar interface in a real-world situation where you are going to take control in a self-driving car? *Why would you do that?*
5. Is there anything specific about the interfaces you saw that you thought were good and less good?
6. Do you think sound signals to the concepts would have become clearer? Where and what?

Do you have any questions?

Appendix I

Take-aways and comments from user study

Pre	Take-over	Post	General	Part i
Concept A; Lightning				
<p>+ Signals came through and was noticed. Steering wheel symbol, push and hold, prepare</p> <p>+ Noticed and understand static change in ICD, understands to hold the steeringwheel</p> <p>+ Understood the intentions of the car. Noticed windshield light, prepare, and that CSD went OFF,</p> <p>+ felt safe. Noticed and understood steeringwheel symbol, noticed shining lights, CSD video confusing.</p> <p>+ Was clear with illustrations and coordinating lights. Understood they had to take back control</p> <p>- Felt overwhelming while offering too little information.</p>	<p>0 Noticed push and hold. The signals was missed completely one time, focus on the road</p> <p>+ Understand reason of signals. Noticed color change and instructions to hold steeringwheel and push buttons</p> <p>+ Noticed push and hold and color change from blue to orange. Noticed flash around the buttons. Understand instructions of how to take control.</p> <p>- do not understand why the signals came. Dont understand that they should take control and drive.</p> <p>+ Felt intuitive and clear how to take over</p> <p>+ A bit confusing but still understood how to handle it</p>	<p>- Noticed ICD. Did not understand reason why. Wants audio signals. Understand AP status</p> <p>- Feel safe, nice instructions, do not understand why, to little information</p> <p>- felt safe. Noted message on CSD. Do not understand why. Not enough time to read.</p> <p>- Noticed drive the car and speed indicator, Understand how to take over. Dont understand why. Dont understand to use the buttons. Missinterpreted flashing lights with "blinkers". Unclear information.</p> <p>- Felt less intuitive and lacked AP Status even if they understood. Do not understand, not enough info of why.</p> <p>- Confusing and dont understand why it happened even though they understand they have to drive.</p>	<p>Wants audio signals.</p> <p>Wants instructive gps voice or beep. Would have liked to know before about the buttons.</p> <p>Wants instructions before about system and how to use it. Do not trust the system. A>B-aesthetics. Traffic lanes confusing.</p> <p>Felt more clear than C. Felt intuitive with text and illustrations. Would feel safe using it. Looks nice and futuristic. Would be nice with pling sound</p> <p>Felt like A had too much text. Would feel safe using this UI. Would like a voice assistance.</p>	<p>0 Noticed push and hold. Frist the screen, then the symbols. Think they should take over. Wouldn't notice without audio if watching something else.</p> <p>0 Thinks they should switch to manual driving they should do something to confirm.</p> <p>- That it is exciting but difficult because you want to look at the steering wheel, the screen, and the road at the same time. Not entirely safe. I wonder where it was going now. Thought you'd move the steering wheel, but nothing happened.</p>
Summary				
<p>4 5 out of 6 people understood they had to prepare for taking back control. They understood the signals and especially the steeringwheel symbol, prepare and the lights. Noticed the windshield light, that CSD turned off and the static change in ICD. Understood to hold the hand on the steeringwheel. One person felt safe.</p> <p>One felt overwhelmed and that the car offered too little information.</p>	<p>3 4 out of 6 people understood the signals and how to take over control. It felt clear and intuitive how to take over. Noticed the color change and flash around buttons. They noticed push and hold and instructions to hold steeringwheel.</p> <p>One person did not understand why the signals came and did not understand that they were supposed to take back control and drive.</p> <p>The signals were missed completely one time because of focus elsewhere.</p>	<p>-6 Noticed ICD, drive the car and message on CSD. Nice instruction. Two people expressed that they felt safe.</p> <p>None of the TP understood the reason of the transition. One person noticed the message on the CSD but did not have enough time to read it. The info was unclear and insufficient. Wants clearer AP status. One person missinterpreted the flashing buttons with turning lights.</p>	<p>A Two people feel safe about using the UI. Most people wants audio signals, both instructive gps voice and bling sounds. Felt intuitive with text and illustrations. Also nice futuristic looking aesthetics.</p> <p>One do not trust it. One felt like A had too much text.</p> <p>Some wants instructions before about the system and how to use it.</p>	<p>-1 2 out of 3 understands that they should take over but none mention that they should push the buttons. Wants audio to ensure better focus. Feeling difficult since they want to look at the steering wheel, the screen, and the road at the same time. Not entirely safe.</p>

Concept Lightning

Concept B; Firefly							
0	Noticed the gps light on the csd, the "light" on the ICD. Liked the moving dot on the CSD aesthetically. Good contrasts, less good on the ICD. Need more information channels(audio). Wanted instructions before to know where to pay attention. Wants earlier warnings	-	understand hands on steeringwheel. Did not understand to push buttons. Dont understand why. Questioning capability of cars attention.	-	Unclear message of speed(did not really understand). Focused most on traffic. Did not understand why.	Elderly would have difficulties with the multitasking or multiple screens. Wants earlier warnings. Suggests a picture of traffic stop as a pre-notification. The surroundings more interesting. More information channels wanted like audio to feel comfortable with the system. Audio signal, earlier signal, text and symbols suggested.	
0	Noticed get ready and steeringwheel symbol. Saw dot in CSD but did not understand what it meant. Confused about reason of get ready, reason of takeover	0	understood how to take act, steeringwheel and push buttons. Noticed lights on buttons, push and hold, steeringwheel symbol,, push and hold, picture showed to push the buttons. Confused about both buttons lit up (mixed it up with blinkers). Did not understand orange color change in ICD. confused about lanes. Dont understand why to push both buttons(reason of signals).	-	Feel safe when it said drive the car. Dont understand reason of takeover. Not enough time.	Dont know the limit of the AP, dont understand the system. Video in CSD confusing.	The car urged me to hold the steering wheel and press the brake, I thought at first. Not sure it was right. I had time to see push and hold. I think I'd have slowed down if it stood like that. Hold the steering wheel and press the brake.
+	Noticed get ready. Did not understand push and hold, looked nmore on the road by habit. Noticed the steeringwheel flashing and assumed that something should be corrected.	-	Dont understand the signals. Dont understand why. Dont understand to push both buttons.	-	Need instructions before driving to understand.	Wants a voice that tells you what to do, voice signal.	0 (Lane confusion.). Then I saw the steering wheel coming up on the little screen. I don't know what that means, but maybe I should drive myself then and turn.
+	understand what to do, push and hold. Correct interpretation to take over control. Understand to push buttons.	+	Noticed push and hold. Understand intention of the car. Understood hand/steeringwheel symbol, how to act. Uncomfortable with AP on, alot going on and less focus on road. Understood they should take back control. Don't know why. Realised how through text and glowing buttons	-	Noticed drive the car. Confused about reason, insufficient info given on why. Unsafe, to fast info/transition		+
+	Understood they should prepare.	+	Understood the text in ICD. Understood through glowing buttons. Realised through text, glow and orange color in ICD.	0	Felt safe. Didn't remember the post-text but noticed glow. Don't know why it happened	B Prefer B over C as it was easier and more clear. Pling sound would make a difference.	
0	Understood take-over. Noticed the illustration in CSD and the text in ICD. Didn't understand the map and the yellow dot properly.	+		-	Felt safe, don't get why it happened and don't they the information was enough. Thinks the car went back to AP. Think it should appear earlier in pre.	B Strong pre. Weak post prefer this over D, clearer, cleaner, easier. Would like a pling sound.	
Summary							
3	4 out of 6 Understood they should prepare for take-over. Noticed get ready, steeringwheel symbol, illustration in CSD, text in ICD and flashing on steeringwheel. They saw steeringwheel symbol and get ready, but it was mixed level of understanding of the reason of the signals. 3 of 6 people saw or mentioned the Gps map with the yellow dot. One liked it because of clear contrasts but most people did not understand the gps map properly.	1	3 out of 6 people understood how to act to take back control because of the glowing buttons, the steeringwheel symbol and the text. One person did understand to hold the steeringwheel but not to push the buttons. One person did see the signals but were confused about that both button lit up and mixed it up with turning lights. Did not understand the color change and why they were supposed to push the buttons.	-5	3 out of 6 mention they feel safe. Noticed glow and drive the car. None of the TP understood the reason of the transition. Not enough information given and some felt that the transition went to fast. They want mor time and earlier sinals in Pre. One do not feel safe. Dont rememer post text. One thought the speed indicator was unclear and did not really understand it. Wants instructions before to understand	B Liked Pre. B Post not so good. Earlier signals wanted. Audio signals wanted to get attention when looking at the surroundings. Elderly would have a hard time because of multiple screens Most people wants an audio signal. Both instructive GPS sound and bling sound mentioned. Prefer B over C and D because clearer, easier, cleaner.	0 1 out of 3 understands how to act. One assumes they should drive manually. 3 out of 3 saw the steeringwheel symbol. 2 out of 3 did not understand the symbols fully. One interpreted the signals with pushing the brake.

Concept Firefly

Concept C; Galaxy									
+	It tells you to wake up and pay attention to overtaking car.	+	Understand to push buttons and drive manually. The visual symbols made me understand.	0	sufficient info to understand reason why. Felt safe, clear communicatoin what to do. Missunderstood reason why.	C	C>A-clearer communication and easier, less messy. Wants a mix of the two concepts. C>A, easier, better colors, better looking and generally better. C more volvo and clean. Felt safe using it, clear and good signals		
0	Noticed and likes the Yellow windshield light. Clear with steeringwheel and when it flashed it made me understand to hold the steeringwheel. Lanes confusing. Confusion about changing color in the windshield. Overtaking car reason.	-	Did not understand the signals. Do not understand the windshield lights. Missunderstood change of colors. Missunderstood color on pulsating ring on ICD. Did not understand to push the buttons. Did not understand the importance of the signals.	-	dont understand why.	?	wants voice signal. For example, warning of ice. Traffic. Tapered lanes. Tunnel down the front. Satisfied with the system if used to it. need instructions and experience,sufficient info if undrestood. Understood steeringwheel symbol. Like blue clear aesthetics. not sufficient information to feel safe. Needs testing. ICD movie bad and disturbing, attention from road and ICD		
0	Interpreted it as warning (not necessary bad). Not sure if AP was off. Would prefer red colors like red.	+	Understood they should push the buttons. Think the ambient light was coordinated and directed the focus towards the steering wheel.	0	Felt MD was obvious throuh the Avatar. Felt safe. Don't think they got enough information why it happend. Assumes the overtaking car was the reason.	?	Liked the color change that made them aware. Would feel comfortable using it as it looks nice and futuristic. Prefer this over A due to look. Did not notice ambient light first. Unclear with just prepare. CSD unclear. Would like sound.	0	Thinks AP turned off due to overtaking. Thinks the car went back to AP ON.
0	Know they should be prepared but not for what	-	Did not understand what the car was saying and why it wants them to take over.	-	Don't know why it happened. Would probably take back control but wouldnt know why. Think they need to familiarize themself to understand and feel safe.	?	Don't understand. Felt overwhelming. Would feel comfortable using it, easy procedure. Buttons and lights helped. Sound would be preferred. Felt good and natural. Reacted mostly on ICD. Would like a HUD to know where danger comes from. (Video distracting) Prefer this more than D due to look and clarity. Would like sound of danger like City Safety.	-	Did not understand push and hold.
+	Noticed the ambient light, steering, CSD, ICD. Understand they should take over.	+	Noticed orange color from ambient light, and the display. Understand they should take over. Orange color and illustartion in ICD made them understand.	-	Think it happend due to overtaking. Don't think they got enough info why it happended. Think it went back to AP. Don't feel safe. Would like a clearer illustration of hands on steering.	C	Think the car wants to check alertness. Do not understand AP ON in pre. Noticed ambient light in pre. Understand they have to take over. Like this more than D, annoying but clear. Think too many screens. Like the colors in ICD and guiding light. Would like to see the whole speedometer marks. Would like sound.	-	Reacted to the car on the left side. Didn't know if the car registered it in the system. Analysed the traffic situation.
+	Understand they should prepare to hold steering. Noticed text in ICD.	+	Understand hold and push in ICD. Understood through ambient light as well as text and illustration in ICD. Didn't notice the avatar.	0	Noticed the avatar, green and AP off. Felt safe. Think they went back to AP. Don't think info was enough to understand why. Think it glows too much. Annoying. (General?)	C			
Summary									
3	Many of the participants noticed the signal, especially the ICD. Even if they understood they should prepare, they didn't know why and for what. Many also expressed the signals as confusing especially the color change and the AP status.	2	Here 4 out of 6 understood they should take over. What was noticeable was that many participants understood through the illustartion and text in the ICD. The amient light also made them aware of the situation. 2 out of 6 participants didn't understand at all and misunderstood it completely which is not very good. Many didn't notice the avatar as it was flooded with other informations from the other screens.	-3	The Avatar was appreciated in this concept. Hinted about them entering MD. The reason why didn't come through. 5 out of 6 thought the information was not enough and many assumed the overtaking car triggered the event. One expressed the glow as annoying and intense. As one participant mentioned, it would feel more safe if they familiarized themselves with the system	C	Many preferred this concept over A. As it looked nicer, was more intuitive and was clearer. One expressed this concept as futuristic because of the look. The glow, colors, illustartion and the buttons was also appreciated in this concept. Simple procedure. Some thought the CSD and the text was a bit unclear. Some also thought there were too many screens and created a sense of overwhelming experience. Many interpreted the situation as the car wanting to check alertness and not give back control. Many would appreciate sound to this concept as it would make it clearer	-2	1 out of 3 understood somehow. First time users assumed AP turned off due to overtaking car. Thought the push and hold was a bit unclear. Payed more attention to the road than the inside of the vehicle.

Concept Galaxy

Concept D; Game						
	<p>Blue glowing car very great, positive, clear warnings. Understood. Noticed Get ready, AP end, blue car. Likes spinning lights on buttons. Likes blue windshield light. Lue car made it feel more urgent.</p> <p>+</p> <p>Understand intention of signals. Noticed and understood get ready, AP end on head-up display.</p> <p>+</p> <p>Like the HUD glow, CSD illustration. Understand take-over. Hard to tell if AP was on. Would like CSD more clearly.</p> <p>+</p> <p>Understood to be aware. Confused of why.</p> <p>0</p> <p>Reacted to HUD line. Understood they had to take over with glow. Didn't see the text in the end of the blue line. Think the car wants to check alertness. Think it was due to overtaking car.</p> <p>+</p> <p>Think its a warning. Think it happened due to overtaking or merging lane.</p> <p>0</p>	<p>Noticed flashing and lights buttons. Understand push and hold, and reason of color change. The glowing buttons made them understand how to act. Change of color in car and ICD increases focus. Steeringwheel symbol needs more time. Missinterpreted countdown</p> <p>+</p> <p>Understand instructions, hands on steingwheel and push and hold buttons. Understand has to take over driving. The info on ICD and CSD made them uderstand how to act.</p> <p>+</p> <p>Understood take-over and how to act. The orange color and the CSD illustration made them aware. Steering wheel as well</p> <p>+</p> <p>Understood how to take over. Noticed the illustration. Understood they should hold during countdown. Could me misunderstood for pushing 3 times.</p> <p>+</p> <p>Think they should hold the steering wheel. Noticed the ICD and the illustration. Understood through glow. Didn't remember the text.</p> <p>0</p> <p>Don't understand what the car is telling. Think it could be due to alertness check.</p> <p>-</p>	<p>head-up display, interpreted positive and understood. Understood why. Felt stable, appreciation of explanation(Head-up display). sufficient information provided to understand reason, shining car, head-up display, text</p> <p>+</p> <p>Noticed head up diaplay, cars were driving faster. Sufficient info to understand why, late info, wants that info in pre. Dont feel safe, wants a sound signal to feel safe.</p> <p>+</p> <p>Felt like information was enough. Felt safe, it showed where and how to act. Confused over AP status. Think they entered AP mode again. Assumes it was triggered by danger.</p> <p>0</p> <p>Understood they had to drive after push. Felt safe as they got enough time. Think they went back to AP when hands disappeared. Don't think they know why it happened. (Didn't like the post-notification as there will always be cars driving faster?) Would like a GPS voice</p> <p>0</p> <p>Noticed the glow. Felt safe and enough time. Think they entered AP again. Don't remember the text. Don't think they got enough info why it happened.</p> <p>-</p> <p>Noticed the countdown. Felt safe and had enough time. Think its good they have to use both hands. Think they entered AP again. Don't show actively how they should do it.</p> <p>-</p>	<p>D>A explaining reason of takeover. ring on ICD not as clear as (A) ? Felt safer, trust in the car because of sufficient information. Much information happening. (A) better looking, aesthetics, cooler.</p> <p>D</p> <p>Suggestions: text closer to steeringwheel, head up. Maybe an audible beep when you start reacting. Higher if you do not react and more frequent beeps the more dangerous the situation is.</p> <p>alot going on, information overload, CSD, ICD Window and traffic. D>B, clear and explanation of why, more info given,better aesthetics. Not safe, wants clearer explanation of why, earlier warnings, more time. Liked the light around the buttons. Dislike head up, wants less screens, to many information screens. wants audio signals early.</p> <p>D</p> <p>Really liked how HUD registred the overtaking and caught attention. Liked this more than C, easier, clearer, futuristic. Liked the color and illustration. Missed AP status. Would like sound similar to City Safety.</p> <p>D</p> <p>Like this over A, cleaner and less info to process. Not so much text and the symbols spoke for themselves. Felt more intuitive. Liked the countdown and the color change. Would feel safe using this. Would like a voice. Interpreted this as danger. Didn't like the idea of having to read after taking over. Should have gotten my attention earlier</p> <p>D</p> <p>Noticed the HUD post message. Think the car wants them to hold the steering wheel. Felt safe and was clear what to do. Would like a sound</p> <p>?</p> <p>Noticed HUD post message. Less intense than C but less clear. Like this look more than C. Like the color change and guiding light.</p> <p>=</p> <p>Would like to see the whole speedometer. Think it could be clearer with sound. Also why you should do it. Do not understand why pushing the buttons.</p>	<p>Illustration was too distracting. Didn't see push and hold until it turned orange.</p> <p>0</p> <p>Think it happened due to overtaking. The steering wheel was glowing and told me to prepared.</p> <p>0</p> <p>Think they should hold the buttons to take over. Too many screens and videos showing the ICD.</p> <p>+</p>	
Summary						
<p>4</p> <p>The participants expressed a great appreciation towards the HUD display, highlighting the overtaking car on the road. Some also noticed the text in ICD saying "Get Ready". The buttons. It made them aware.</p> <p>Some thought it was confusing if AP was ON. Some also expressed a sense of confusion of why it happened.</p> <p>Some thought overtaking var was the reason while others thought the car wanted to check your alertness.</p>	<p>3</p> <p>5 out of 6 participants seems to understand the takeover sequence. Notable cues were buttons, ambient light and text in ICD and CSD. The color change and glowing buttons seemed to work effectively to watch the attention.</p> <p>Some claimed they didn't get enough time. Some also found the countdown to be confusing. Some didn't remember the text in the ICD even if they understood through text and illustrations. 1 didn't understand at all, thought it was an alertness check.</p>	<p>0</p> <p>3 out of 6 thought the information given was enough to understand why it happened. Even if not everyone out of the 3 got it right, they still felt safe getting a notification about it afterwards. Some appreciated the HUD and the post text. Everyone felt safe during the transition. They noticed the countdown, the glow and the text.</p> <p>Some still didn't know why it happened even after reading the post. Some thought it didn't show actively how to take over. Another didn't remember the text in the HUD.</p> <p>Nearly everyone would appreciate sound in the system.</p>	<p>D</p> <p>Many recognized the HUD and found it helpful. They preferred this concept over the other they saw. Felt clear, intuitive and cleaner. Most would appreciate sound to feel more safe.</p> <p>Some felt like it was information overload, too many screens to look at, while other thought it was unclear why they had to push.</p> <p>Most suggested having sound.</p>	<p>1</p> <p>Thought it was distracting, didn't notice the text until it turned orange. Think it happened due to overtaking. Understand they should hold the buttons to take over. Too many screens showing.</p>		

Concept Game

Appendix J

A summary of the takeaways from the user study

	Concept A; Lightning	Concept B; Firefly	Concept C; Galaxy	Concept D; Game
Pre	5 out of 6 understood they had to prepare for taking back control. They understood the signals and especially the steering wheel symbol, prepare and the lights. Noticed the windshield light, that CSD turned off and the static change in ICD. Understood to hold the hand on the steering wheel. One person felt safe. One felt overwhelmed and that the car offered too little information.	4 out of 6 understood they should prepare for Takeover. Noticed get ready, steering wheel symbol, illustration in CSD, text in ICD and flashing on steering wheel. They saw steering wheel symbol and get ready, but it was mixed level of understanding of the reason of the signals. 3 of 6 people saw or mentioned the GPS map with the yellow dot. One liked it because of clear contrasts but most people did not understand the GPS map properly.	Many of the participants noticed the signal, especially the ICD. Even if they understood they should prepare, they didn't know why and for what. Many also expressed the signals as confusing especially the color change and the AP status.	The participants expressed a great appreciation towards the HUD display, highlighting the overtaking car on the road. Some also noticed the text in ICD saying, "Get Ready". The buttons. It made them aware. Some thought it was confusing if AP was ON. Some also expressed a sense of confusion of why it happened. Some thought overtaking var was the reason while others thought the car wanted to check your alertness.
Takeover	4 out of 6 understood the signals and how to take over control. It felt clear and intuitive how to take over. Noticed the color change and flash around buttons. They noticed push and hold and instructions to hold steering wheel. One person did not understand why the signals came and did not understand that they were supposed to take back control and drive. The signals were missed completely one time because of focus elsewhere.	3 out of 6 understood how to act to take back control because of the glowing buttons, the steering wheel symbol and the text. One person did understand to hold the steering wheel but not to push the buttons. One person did see the signals but were confused about that both buttons lit up and mixed it up with turning lights. Did not understand the color change and why they were supposed to push the buttons.	4 out of 6 understood they should take over. What was noticeable was that many participants understood through the illustration and text in the ICD. The ambient light also made them aware of the situation. 2 out of 6 participants didn't understand at all and misunderstood it completely which is not very good. Many didn't notice the avatar as it was flooded with other information's from the other screens.	5 out of 6 understands the Takeover-sequence. Notable cues were buttons, ambient light and text in ICD and CSD. The color change and glowing buttons seemed to work effectively to get the attention. Some wanted more time. Countdown confusing. Some didn't remember the text in the ICD even if they understood through text and illustrations. 1 didn't understand at all, thought it was an alertness check.
Post	Noticed ICD, drive the car and message on CSD. Nice instruction. Two people expressed that they felt safe. None of the TP understood the reason of the	3 out of 6 mention they feel safe. Noticed glow and drive the car. None of the TP understood the reason of the transition. Not enough information given, and	The Avatar was appreciated in this concept. Hinted about them entering MD. The reason why didn't come through. 5 out of 6 thought the information	3 out of 6 thought the information given was enough to understand why it happened. Even if not everyone out of the 3 got it right, they still felt safe getting a

	<p>transition. One person noticed the message on the CSD but did not have enough time to read it. The info was unclear and insufficient. Wants clearer AP status. One person misinterpreted the flashing buttons with turning lights.</p>	<p>some felt that the transition went to fast. They want mor time and earlier signals in Pre. One does not feel safe. Don't remember post text. One thought the speed indicator was unclear and did not really understand it. Wants instructions before to understand</p>	<p>was not enough and many assumed the overtaking car triggered the event. One expressed the glow as annoying and intense. As one participant mentioned, it would feel safer if they familiarized themselves with the system</p>	<p>notification about it afterwards. Some appreciated the HUD and the post text. Everyone felt safe during the transition. They noticed the countdown, the glow and the text. Some still didn't know why it happened even after reading the post. Some thought it didn't show actively how to take over. Another didn't remember the text in the HUD. Nearly everyone would appreciate sound in the system.</p>
<p>General</p>	<p>Two people feel safe about using the UI. Most people want audio signals, both instructive GPS voice and bling sounds. Felt intuitive with text and illustrations. Also, nice futuristic looking aesthetics. One does not trust it. One felt like A had too much text. Some wants instructions before about the system and how to use it.</p>	<p>Liked Pre. Post not so good. Earlier signals wanted. Audio signals wanted to get attention when looking at the surroundings. Elderly would have a hard time because of multiple screens. Most people want an audio signal. Both instructive GPS sound and bling sound mentioned. Prefer B over C and D because clearer, easier, cleaner.</p>	<p>Many preferred this concept over A. As it looked nicer, was more intuitive and was clearer. One expressed this concept as futuristic because of the look. The glow, colors, illustration, and the buttons were also appreciated in this concept. Simple procedure. A bit unclear text in the CSD. Too many screens created an overwhelming experience. Many interpreted the situation as the car wanting to check alertness and not give back control. Many would appreciate sound to this concept.</p>	<p>Many recognized the HUD and found it helpful. They preferred this concept over the other they saw. Felt clear, intuitive and cleaner. Most would appreciate sound to feel safer. Some felt like it was information overload, too many screens to look at, while other thought it was unclear why they had to push. Most suggested having sound.</p>
<p>Part i</p>	<p>2 out of 3 understands that they should take over, but none mention that they should push the buttons. Wants audio to ensure better focus. Feeling difficult since they want to look at the steering wheel, the screen, and the road at the same time. Not entirely safe.</p>	<p>1 out of 3 understands how to act. One assumes they should drive manually. 3 out of 3 saw the steering wheel symbol. 2 out of 3 did not understand the symbols fully. One interpreted the signals with pushing the brake.</p>	<p>1 out of 3 understood somehow. First time users assumed AP turned off due to overtaking car. Thought the push and hold was a bit unclear. Payed more attention to the road than the inside of the vehicle.</p>	<p>Thought it was distracting, didn't notice the text until it turned orange. Think it happened due to overtaking. Understand they should hold the buttons to take over. Too many screens shown.</p>

Appendix K

Scripts used for Unity

```
C:\WINDOWS\system32> cd C:\FFMPEG\bin
```

```
C:\FFMPEG\bin> ffmpeg -i Name.mov -c:v libvpx -pix_fmt yuva420p -b:v 1M -auto-alt-ref 0  
-metadata:s:v:0 alpha_mode="1" -c:a libvorbis OutVideo.webm
```

Commands in CMD for converting QTFF to WebM.

```
using System.Collections;  
using System.Collections.Generic;  
using UnityEngine;  
using PathCreation;  
  
public class Follower : MonoBehaviour {  
    public PathCreator pathCreator;  
    public float speed = 5;  
    float distanceTravelled;  
  
    void Update() {  
        distanceTravelled += speed * Time.deltaTime;  
        transform.position = pathCreator.path.GetPointAtDistance(distanceTravelled);  
    }  
}
```

Script for the trajectory of the overtaking car.

Appendix L

Links to the final concept in Unity



The final concept in Unity
<https://youtu.be/guUkwTvb6wc>



The final concept in VR
https://youtu.be/_JkXnfeo95c

Appendix M

Interview template for the final evaluation

Preparation

- Sanitize equipment's.
- Greet participant. Give them facemask if they do not have it.
- Ask them if they filled in the GDPR form, if not, give them time to fill it in.
- Guide them towards the test rig.

Introduction

- “You are most likely familiar with the study we have conducted already. We have created our final concept that we want to evaluate together with you. What you are going to see is the final concept in VR. Unfortunately, the concept is not interactive meaning that you cannot push the buttons to turn off the system. First you will see the concept, then we will give you a form and questionnaire to fill out to evaluate your experience. Finally, we will ask you a few questions. Any questions?”
- Offer VR face protection covering the upper part of the face.
- Mount the VR to their head and the headphones.

After VR

- Help them take it off
- Quantitative data
 - Give them the UX-curve to fill out and explain it briefly.
 - Give them the QR code for them to scan with their phone and fill in the questionnaire.
- Qualitative data
 - Guide them to a room and start the interview.
 - Start voice recording.

Interview

Emotions

- What emotions did you experience during the transition?
- Do you want to elaborate a little on the experience curve? The peaks and the dips?

Usability

- How did you experience the information that was presented to you?
- Did you feel like the information was easy to understand? (If short answer → Why?)

Pre-notification

- Did you feel prepared enough to push the buttons?
- How did you experience the first cues when the car wanted your attention?

Post

- Why do you think the car requested you to take control?

Overall

- What did you appreciate about the concept?
- What did not appreciate less in the concept?
- Would you be comfortable using the concept in a real context?

End

- Stop recording and thank them for coming. Ask if they have any further questions.

Appendix N

Questionnaire used in the final evaluation

Final concept Questionnaire

The following statements are asked to collect your honest opinions about the concept that was presented. Your answers are anonymous and will only work as an evaluation of the final concept for the thesis report.

1. I got sufficient information to understand what the car wanted me to do

Not at all ☆ ☆ ☆ ☆ ☆ ☆ Absolutely

2. The visual and audio signals felt coherent and logical

Not at all ☆ ☆ ☆ ☆ ☆ ☆ Absolutely

3. I appreciated the voice messages

Not at all ☆ ☆ ☆ ☆ ☆ ☆ Absolutely

4. I appreciated the audio signals

Not at all ☆ ☆ ☆ ☆ ☆ ☆ Absolutely

5. The visual information was clear and easy to interpret

Not at all ☆ ☆ ☆ ☆ ☆ ☆ Absolutely

6. I felt safe

Not at all ☆ ☆ ☆ ☆ ☆ ☆ Absolutely

7. Define your experience with three words

Enter your answer

Submit

Appendix O

GDPR consent form for the expert study



User Study for Volvo Car Corporation

Test leaders

Alexander Karlsson
Master Thesis, Volvo Torslanda PV
405 31 Gothenburg

Alfred Sävervall
Master Thesis, Volvo Torslanda PV
405 31 Gothenburg

Dear Participant,

Thank you for taking the time and participating in our user study. This user study is performed by Alexander Karlsson (alex.karlsson@volvocars.com) and Alfred Sävervall (alfred.savervall@volvocars.com) on behalf of Volvo Car Corporation to collect information about how drivers understand and experience the interaction with an automated car.

The user study consists of a virtual reality (VR) test where the participant tries the concept in a VR environment. In addition, a short interview will be conducted to gain a better understanding of the experience and thoughts of the proposed concepts. The test session will take approximately around 15 minutes.



Consent to media documentation & processing

During the test session and the following interview, we are going to conduct audio- and video recordings. Hereby the focus lies on the Interpretation of the signals from the car, the instrument cluster and other control panels of the vehicle and not on the participant. However, a recognisability on the recordings cannot be fully eliminated.

The material is relevant for the analysis of the session and the evaluation of the interview. It will only be used internally and sole for the stated purpose. You will stay anonymous and the collected data will be handled confidentially.

Please, check the boxes you agree with.

- I hereby agree to audio recordings during the session.
- I hereby agree to video recordings during the session.
- I hereby agree that the recorded files may be used for research and demonstration purposes.

I hereby declare that I have read the information notice and understood the conditions and purpose on media documentation and processing of my personal data.

Date and Place Name in Print Signature



Information Notice

Controller

Volvo Car Corporation, hereinafter referred to as “VCC”, “we”, “our” and “us”, will as controller process your personal data as described below.

Purpose and legal basis for processing

VCC will process the personal data that you provide to us in connection with you signing up for participation in the study such as contact details for administration of your participation. VCC will furthermore process the personal data that we collect as a result of your participation in the study (audio and video recordings) for research and development of autonomous functions including evaluation and improvement of our products and services and for contributing to research questions.

The legal basis for our processing of your personal data for administering your participation is that this processing is necessary for the performance of our contract with you concerning your participation in the study. The legal basis for our processing of your personal data for research and development and for contributing to research questions is that this processing of your personal data is necessary for the purposes of legitimate interests pursued by us.

Disclosure / Recipients of your personal data / Transfer

Your personal data may be disclosed to the general public as part of the publication of the research report. Furthermore, your personal data will be transferred to companies within the same group of companies as Volvo Car Corporation which are located outside of the EEA with the basis of Standard Contractual Clauses adopted by the European Commission- safeguarding your personal data.

Retention time

We will process your personal data in relation to study for a period of 8 years.

Your rights and contact information

You have the right to request a copy of the personal data that we store about you. If you would like a copy of some or all of your personal data, please send us an e-mail to alfred.savervall@volvocars.com.

We want to make sure that your personal information is accurate and up to date. Please do not hesitate to ask us to correct or remove information you think is inaccurate. You also have the right to have your personal data deleted and to have our processing of your personal data restricted in certain circumstances.

In addition, you have the right to object to our processing of your personal data as well as to receive your personal data, which you have provided to us, in a structured, commonly used and machine-readable format and to have these transmitted to another controller. For more information on your rights please contact our Data Protection Officer by sending an e-mail to toglobdpo@volvocars.com or

sending a letter to Volvo Car Corporation, Attention: The Data Protection Officer, HB3S, 405
31 Göteborg, Sweden.

Master of Science Thesis

Enhancing the User Experience in Transitions from Highly Automated to Manual Driving

Master of Science Thesis in the Master Program Industrial Design Engineering

In collaboration with Volvo Car Corporation

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