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MASTER THESIS

Creating a Foundation for Interactive Heads-Up Displays

or: How I Learned to Stop Worrying and Love the HUD

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Thesis for the Degree of Master of Science

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Abstract

Level 2 automation has been shown to lower the cognitive workload needed to operate vehicles. As a result, drivers may experience a cognitive underload while driving. This may incentivize the driver to use their phone, resulting in unsafe situations. This thesis lays a foundation for creating interactive heads-up displays (HUD) that may replace the need for using a phone. The focus is put on the user experience of the HUD specifically implemented in cars and trucks. In order to do so, several aspects within the scope of this research are investigated.

User research, through cultural probes and context mapping, explores current use of phones. The results show the need for staying connected, and the development potential of an interactive HUD.

A previously untested method, called the Blur method, is shown to be a better representation of HUD use than the industry-standard Occlusion method. It is further shown to be a valuable method for qualitatively evaluating interface designs. The look-down angle from the driver's line of sight is shown to be essential in task performance, with an optimal angle being between 2.5° and 5° below the line of sight.
A human-machine interface concept with level 2 Wizard-of-Oz automation is created based on the research in this thesis. The concept shows significantly positive results ($p<0.05$, $n=12$) on the attractiveness, perspicuity, efficiency, and simulation scales of the User Experience Questionnaire.

This thesis presents 32 guidelines in the categories of HUD content, HUD interface, physical implementation and relations to the phone. The guidelines serve as a basis for designing a HUD that combines a safe, efficient interaction with an enjoyable user experience. The guidelines create a foundation for designing interactive HUDs, and the authors recommend a holistic approach into further research and development of the interactive HUD and potential guidelines.

Keywords: interactive heads-up display; level 2 automation;
cognitive underload; blur method; look-down angle; user experience

Acknowledgements

WITH THE CONCLUSION of this thesis an important chapter of our lives is also concluded. We look back on a period of both personal and professional growth and would like to acknowledge several people who have helped us get to where we are now.

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Daniel Roeven, as you know we're terrible developers, and through your assistance with Framer we were able to build user interfaces for our tests. We're especially grateful for your help with implementing the Blur method, one of the cornerstones of this thesis.

We want to thank Oskar Schymberg for lending us his racing game controller. The controllers were highly unpredictable and having two of them saved our tests at numerous occasions.

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Billy Astorsson

Paul van Sommeren

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List of Abbreviations

ADAS	Adaptive Driver Assist Systems
CSD	Center Stack Display
DIM	Driver Information Module
GPS	General Positioning System; navigation device
HDD	Heads-Down Display
HMI	Human-Machine Interaction
HUD	Heads-Up Display
IC	Information Cluster
L0	SAE Level Zero Automation
L1	SAE Level One Automation
L2	SAE Level Two Automation
LCT	Lane Change Test
LDWS	Lane Departure Warning System
LKAS	Lane Keep Assist System
MDev	Mean Deviation
MVP	Minimum Viable Product
NHTSA	National Highway Traffic Safety Administration
SID	Secondary Information Display
TCT	Task Completion Time
UCD	User-Centered Design
UEQ	User Experience Questionnaire
UI	User Interface
UTF	User Task Flow
UX	User Experience
WoZ	Wizard of Oz (Testing)
ΔMDev	Mean Deviation from Baseline

Background

THE INTRODUCTION OF systems that offer SAE level 2 automated driver assistance systems (L2, and SAE level 0: L0)(On-Road Automated Driving committee, 2014) has changed people's behavior and needs while driving. RISE Viktoria has identified a higher demand on vehicles infotainment systems and has therefore initiated 'SEER - Seamless, Efficient and Enjoyable inteRaction (RISE Viktoria, 2018), a project that aims to investigate how secondary tasks should be designed for to allow a seamless and efficient interaction which is safe and enjoyable at the same time. With less mental workload needed to actively maneuver the vehicle, the driver is more likely to use secondary systems, like in-vehicle infotainment (Winter, de Winter, Happee, Martens, & Stanton, 2014).

To stay connected with one's social media flow and being able to take in and respond to notifications and other information while driving is a presumptive rising need (RISE Viktoria, 2018). To have an enjoyable, safe and efficient interaction with the vehicle's infotainment system as well as a seamless interplay with nomadic connected devices, like smartphones or laptops, is another (RISE Viktoria, 2018). If the in-vehicle systems fail to meet these rising needs, chances are that people will use their nomadic devices while driving instead, resulting in decreased situational awareness and potentially dangerous driving behavior (NHTSA, 2018; RAC, 2016).

A heads-up display (HUD) is a type of transparent display placed close to the user's normal viewpoint. An automotive HUD is typically projected, either directly on the vehicle's windscreen, or on a separate screen mounted in front of it. The automotive HUD enables a display position that is perceived to be closer to the road view than other in-vehicle displays. The position enables a faster focus switch between the display and the road view and brings an opportunity for interaction within the driver's peripheral vision.

A study has recently been conducted at Semcon with the aim to "find a way to allow drivers to interact with non-driving related notifications without picking up their phone." This study has resulted in insights, design suggestions and guidelines specifically on heads-up display (HUD) information priority and notification suppression. The HUD has become especially interesting since its position allows for presence in the peripheral vision.

Automotive HUDs have been well-researched, for example by Yoo et al. (1999), the Alliance of Automobile Manufacturers (2006), NHTSA (2014), and Campbell et al. (2016). Organisations such as NHTSA have provided standards and guidelines regarding physical properties and acceptable content for automotive HUDs. The existing standards and guidelines are comprehensive but typically only cover aspects for a passive HUD, presenting drive-related information such as warnings, speed, and navigation.

During the literature pre-study of this thesis it was found that very little research covering aspects for interactive HUDs in cars with L2 automation has been published, indicating a need for further research and expanding on knowledge in this area.

Aim

THIS THESIS AIM is to enhance the user experience through the HUD with the goal of making especially physical and visual interaction with nomadic devices while driving obsolete. The main approach is to move functionality from the nomadic devices to the HUD and enable a safer interaction. Displaying and interacting with notifications from messaging and social media that would normally be sent to the phone is in focus.

The thesis delivers added knowledge on the current user behavior and attitudes regarding phone use while driving and explores the anticipated change between L0 and L2 autonomy. It also delivers added knowledge on automotive HUD interaction and generates a tested Human-Machine Interface (HMI) concept based on the collected results and insights.

The thesis further delivers guidelines on how interactive HUDs can be designed with a maintained user's perspective to ensure a good experience. User interface (UI) prototypes are created for trying out various concepts and should meet functionality and fidelity levels suitable to the goal of the specific test/simulation.

Additionally, the project evaluates the suggested Blur method by applying it on produced concepts and benchmark it to the Occlusion method and simulated driving. These tests are implemented with the goal of evaluating proposed designs/guidelines. They are not developed to the extent of general implementation and proving test procedure. Recommendations for tests based on the results and experience is included.

Objectives

The objectives are split into a primary objective, and secondary objectives which function as a means to the primary objective.

Primary objective

— To formulate guidelines for interactive HUDs

Secondary objective

— To evaluate methods for measuring task performance on HUDs, including benchmarking the Blur method with the Occlusion method
— To identify phone-related needs regarding messages and social media of users while entering, being in and after exiting a car.
— To identify how activated L2 affects how notifications should be presented with respect to different situations
— To generate, test and validate an HMI concept based or the proposed guidelines

Research Approach

This project is performed from a UX perspective with emphasis on the holistic driver's experience in contrast to purely functional information display. The thesis applies a User-Centered Design (UCD) approach according to Norman's definition:

> *"User-centered design, a philosophy based on the needs and interests of the user, with an emphasis on making products usable and understandable." (Norman, 2016)*

Since very little published research could be found on interactive HUDs, the project work had to be built on the findings of own research - often on the results of ongoing tests. This required a process structure that allowed for simultaneous tracks where knowledge gaps could be filled continuously, regardless if they originated in user research, method development or research on the technical or physical principles of the heads-up display.

To accomplish this, the three phases User research, HUD research and UI development were performed simultaneously through the majority of the project. Results and insights from activities belonging to each of the three phases were then used to support successive activities when needed.

During a Semcon study (Bång & Hillding, 2018a) it was identified that the current way of testing HUDs, such as through the Eye-Glance Measurement (EGM)(Seaman, Hsieh, & Young, 2016) or the Occlusion method (ISO, 2017a), may be limited. These methods are developed for testing regular interfaces and might be less applicable to HUDs as these are transparent, close to the line of sight, and only have a virtual location. As a response to that, the Semcon study suggested a new method for evaluating HUD interfaces, called the Blur method.

During the concluding part of the project, the tracks merged together, and an HMI concept was created and evaluated during the Concept evaluation phase. The total outcome of all phases was then summarized into a set of design guidelines—creating a foundation for interactive HUDs.

The process is illustrated in Figure 1 below.

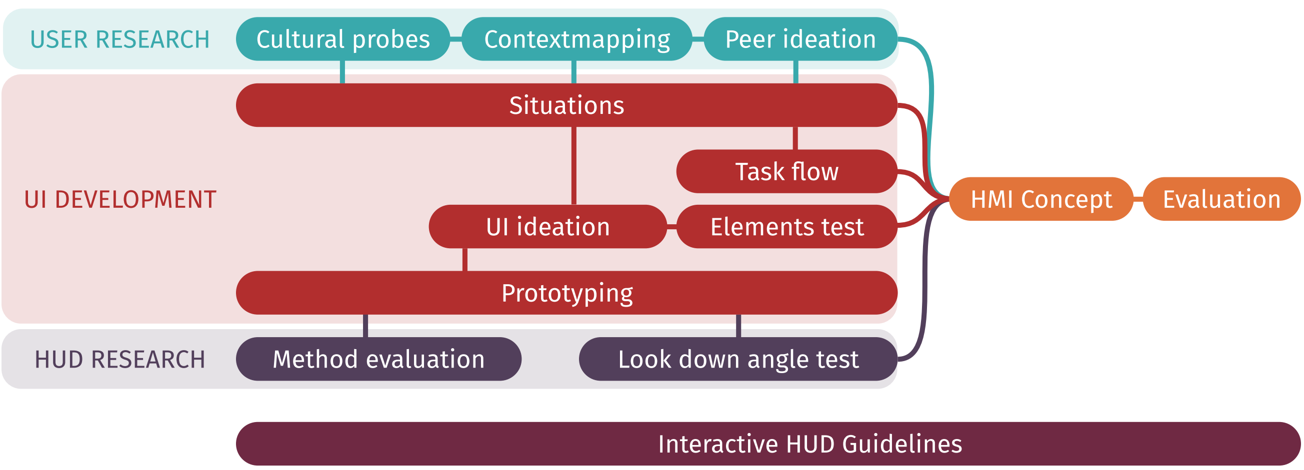


Figure 1 – Illustration showing the process of the project work

Demarcations

Although the HMI is experienced by the user through several interaction points (Driver Information Module/ Information Cluster, Center Stack Display/Secondary Information Display [DIM/IC, CSD/SID and HUD]), this study will focus on displaying information on the HUD and user interaction with this system.

The study acknowledges the implications of using certain simulators and the effects that the simulator's limitations may have on the results. The opportunities to improve the existing testing environments will be continuously investigated and changes made where appropriate. It should be noted that the influence of the simulator software was limited to the existing settings and configurations.

Structure

THE REPORT CONSISTS of six sections; User Research, HUD Research, UI Development, Final Concept, Guidelines and Ending, see Figure 2. All design and research activities are sorted within the first four sections and the last two describes the thesis deliverables, in form of a set of design guidelines, and ending conclusions, discussions and recommendations for future work.

'User Research' covers all studies connected to user insights, consisting of a diary probes session, a context mapping workshop and a peer ideation session.

'HUD Research' covers two studies meant to fill the gaps within current research on interactive HUDs. The studies consist of one test for evaluating the Blur method as a method for evaluating HUD interfaces, and another test for evaluating and defining an optimal look down angle. These chapters can be seen as standalone parts, with outcomes setting the basis for the following work.

'UI Development' covers the activities during the development, including situational restrictions, ideation sessions, UI element testing, user task flow, and defining the proposed navigation structure.

'Final Concept' describes the developed HMI concept, which can be seen as the implemented summary of all collected insights. It also contains a study where the HMI concept was evaluated for usability and user experience in a L2 Wizard-of-Oz user test.

'The Guidelines' are the final deliverables of this thesis and are meant to aid designers and researchers when designing for interactive HUDs. This is a standalone chapter based on all collected findings.

Finally, 'Ending' consists of the thesis' conclusion and discussion together with recommendations for future work.

USER RESEARCH	1	Cultural Probes
	2	Context Mapping Workshop
	3	Peer Ideation Session
HUD RESEARCH	4	Blur Method Evaluation
	5	Look Down Angle Evaluation
UI DEVELOPMENT	6	Situational Restrictions
	7	UI Ideation
	8	UI Elements Testing
	9	User Task Flow
FINAL CONCEPT	10	HMI Concept
	11	HMI Concept Evaluation
	12	The Interactive HUD Guidelines
ENDING		Conclusions
		Discussion
		Recommended Future Work

FIGURE 2 - ILLUSTRATION OF THE REPORT STRUCTURE

User Research

User research has been performed to help understand the expected users of a heads-up display. This section contains the three studies performed, namely the Cultural Probes study, the Contextmapping Workshop, and the Peer Ideation session.

From this, a better understanding of the users was created. Additionally several guidelines were stated, as well as input generated for the consecutive studies.

1 Cultural Probes Study

Collecting insights on people's driving behaviors was the goal of the conducted study in this chapter. The study explored people's phone use while driving, together with their attitudes connected to it. Since some of these aspects could be seen as sensitive, the study was set up as a cultural probes study—offering full anonymity as a mean for gathering the wanted insights in an unobtrusive way.

1.1 Aim

The aim of the study was to gain insights about driver's phone use behavior before, while and after driving. The goal was to explore people's behavior and their attitudes concerning it. It was also of interest to see how the use of driver assistance systems affected the participants' behavior and attitudes towards phone use while driving.

1.2 Method and Design

In order to fulfill to goal of gaining user insights, Cultural Probes were selected as a method. This section describes the method and design of the study.

1.2.1 Cultural Probes

Cultural Probes is a method to get to know intended users in a explorative and mostly inspirational way (Gaver, Boucher, Pennington, & Walker, 2004). They are valuable tools in the early design stage to gain insights in the behavior of expected users (Van Boeijen, Daalhuizen, Van Der Schoor, & Zijlstra, 2014) and can be used to test preconceptions about the to-be-investigated context.

The method provides a way to look deeper into the user's context without being too intrusive. For this study it is likely that the taboo of discussing phone use in cars will be encountered and users are likely aware of the illegality and safety aspects of using a phone while driving. It is therefore not unlikely that users will be hesitant in being completely honest about their behavior. By using Cultural Probes in contrast to shadowing, and offering full anonymity, the users will likely feel safer and less judged to disclose activities that they otherwise might have withheld.

1.2.2 The KJ Method

The KJ method, after its author Kawakita Jiro, is an analysis technique used to organize ideas, problems, and solutions into related groups (Curedale, 2016). It helps categorize and organize a large number of fragmented information into logical cohesive groups. The goal of the method is to produce a better idea selection or a problem that is better understood. The method is also known an affinity diagram.

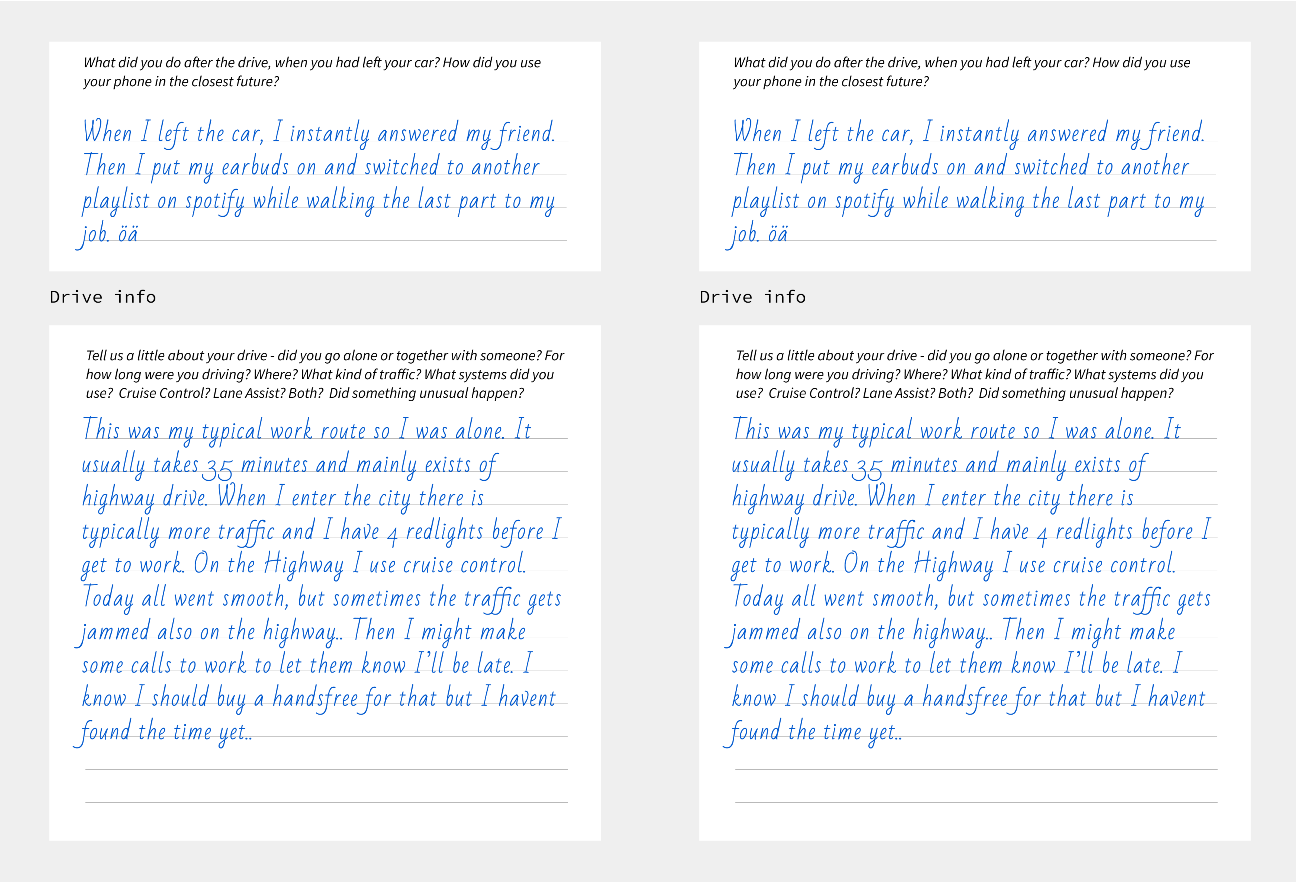
1.2.3 Sample

In total 23 probes were sent out, 17 targeting cars and 6 targeting trucks. They were sent to people that drive daily, either through commuting or for work. The use of driver assistance systems was an important criterion, 3 people drove cars with L0 functionality and 14 with L1 or L2. The sample consisted of 18 male and 5 female, ages 27-60 (M=45.5, SD=11.1). 18 people were from Sweden and 5 from the Netherlands.

1.2.4 Study Setup

Probes were created in the form of diaries along with small assignments regarding phone use in cars and trucks, see Figure 3. Participants were asked to keep track of their drives and their phone use during these drives, and to tell freely about their experiences in this context.

Figure 3 - Picture of the printed diaries



What did you do after the drive, when you had left your car? How did you use your phone in the closest future?

When I left the car, I instantly answered my friend. Then I put my earbuds on and switched to another playlist on spotify while walking the last part to my job. öä

Drive info

Tell us a little about your drive - did you go alone or together with someone? For how long were you driving? Where? What kind of traffic? What systems did you use? Cruise Control? Lane Assist? Both? Did something unusual happen?

This was my typical work route so I was alone. It usually takes 35 minutes and mainly exists of highway drive. When I enter the city there is typically more traffic and I have 4 redlights before I get to work. On the Highway I use cruise control. Today all went smooth, but sometimes the traffic gets jammed also on the highway.. Then I might make some calls to work to let them know I'll be late. I know I should buy a handsfree for that but I havent found the time yet..

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Figure 4 - Example Page

Questions were specifically asked about situations occurring before, during, and after the drive. As example, see Figure 4. Additional assignments were giving that asked participants to think about their car systems, phone use in general and at the end of the diary to reflect on how they would want their car interior to look like with respect to their experiences through the probe.

Two pilots were held with employees of the Semcon UX department, one of which had experience with creating probes before. The probes were adapted after these tests to elicit more open writing. The final design can be found in Appendix I.

1.2.5 Analysis

Cultural probes are typically used on an inspirational level and are not necessarily applicable for qualitative data. To gain a clear view of different activities an adapted version of the KJ analysis was used. Entries were coded with their diary number and colored according to triggers, L0, L1 (cruise control), and L2 (cruise control and lane assist) respectively, see Figure 5. Entries were then grouped into observations, attitudes, and activities, of which the latter implemented a flowchart-like diagram.

1.3 Results

The following section describes the results of the probes. Different attitudes and activities were observed and will be discussed.

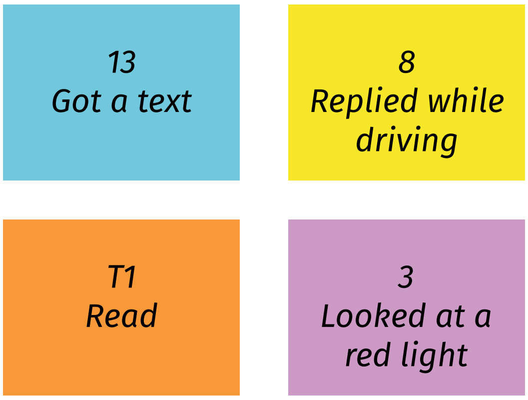

Figure 5 - Example of coded entries

1.3.1 Observations

People expressed a high awareness of the risks of phone use while still admitting doing so. This means that there are quite strong needs or habits in play, and as a result the behavior is not likely to be changed solely by laws and regulations. A majority of the triggers comes from the phones themselves but not all of them. Some can be traced to external factors or an urgent need to communicate in certain situations.

1.3.2 Attitudes

Phone use while driving is clearly a conflicting subject. A lot of entries reflect upon the risks and dangers while also admitting that it is something they still tend to do at times. The criticism gets more intense when observing others, but most participants also criticized their own behavior. There were several entries with statements such as “Small triggers, like notifications, lead to more” or “It’s really dangerous but I do it anyway.” One entry also pointed at a possible hypocrisy in laws where legal systems like GPS systems and the CSD might be at least as distracting as conventional phone use.

While most people believed that handheld phone use is dangerous behavior there were some variations in views of what is an acceptable behavior or not. Many believed that making calls through hands-free is acceptable but there were also participants remarking that an intense phone call can be quite distracting as well, making it hard to judge safety. In contrast, one person thought it was more about the situation than the actual behavior. Handheld phone use could be acceptable during highway drives but not in the cities, and shorter text messages could be acceptable dependent on the situation.

Though not being stated as an acceptable behavior, handheld phone use during red lights and queues was a frequently noted activity. Another was to stop the car at a bus stop or similar to send texts or make urgent calls.

The use of social media apps like Facebook or Instagram was rarely mentioned as an activity during the actual drive but some entries indicated that their notifications could work as triggers.

1.3.3 Activities

The most activities were found to be in three categories: calling, messaging and using navigation functions, followed by a fourth miscellaneous category. Activities were divided into a before, during, and after the drive section. The most common triggers of phone use were being texted (reported by 10 participants) and being called (reported by 9 participants, of which 8 reported answering). Self-initiated interaction was mostly due to calling (reported by 7 participants) and navigation (reported by 5 participants). Calling was done both handheld and hands-free. Some examples are given below, the full results can be found in Appendix II.

Figure 6 below shows possible interaction flows after receiving a text message. The participants were split in the behaviors of reading during the drive or postponing until after. A single participant said to reply while driving, and another said to specifically stop to reply to texts.

Using navigation while driving showed a higher variety of interactions, see Figure 7. An unknown route may be looked up before the drive, while traffic jams triggered participants to use their phones during the drive.

One specific entry, see Figure 8, showed a more complex series of interaction. This participant read an article before the drive but withheld himself from reading while in a traffic jam. Receiving a text later on became a gateway trigger to read the article after having read the text at a red light.

1.4 Discussion

The sample indicated a possible limitation, as more mentions of social media such as Instagram were expected (Hardison & Cochran, 2016; NHTSA, 2018), a problem that is acknowledged by these companies themselves (AdCouncil, n.d.). This may be due to the lack of young participants, who are more likely to use their phone while driving (NHTSA, 2018). Since this behavior is established, it will be taken into account. Additionally, a majority of participants had either L1 or L2 autonomy, but no clear differences were found between the levels.

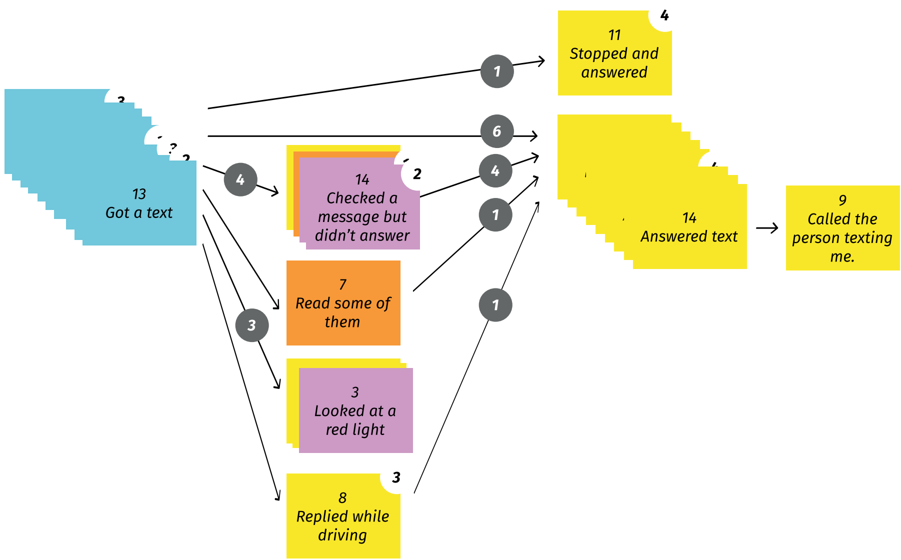

FIGURE 6 - INTERACTION FLOW - RECEIVING A TEXT MESSAGE

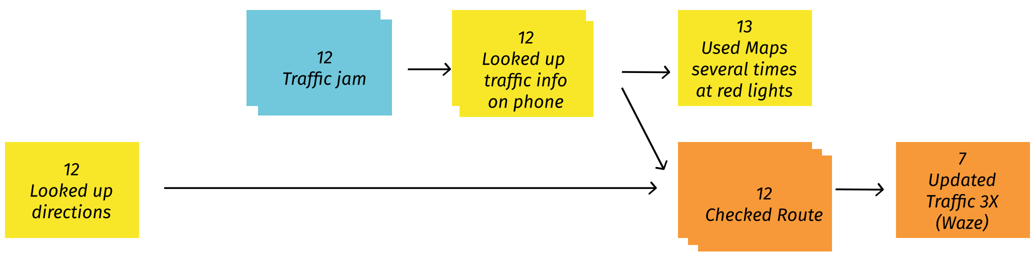

FIGURE 7 - INTERACTION FLOW - USING NAVIGATION

FIGURE 8 - INTERACTION FLOW - READING AN ARTICLE

2 Contextmapping Workshop

TO FURTHER THE knowledge found in the cultural probes, a contextmapping workshop was held. This chapter describes the aim, method and design, and results of this hands-on workshop.

2.1 Aim

A workshop was held with the aim to get further insights and a deeper understanding of the results from the cultural probes session (Chapter 1). The participants in this session also participated in the cultural probe study as to sensitize them - making them aware of their everyday experiences and creating more grounded results. (Pettersson, 2018; Van Boeijen et al., 2014)

2.2 Method and Design

The background and method for the contextmapping session is discussed in the section below.

2.2.1 Method

Contextmapping (Sanders & Stappers, 2012) is an approach with the purpose of informing and inspiring designers for ideation. “Contextmapping is a user-centered design approach that involves the user as the expert on his or her experience” (Van Boeijen et al., 2014). It provides a better insight into the user’s context and is a way to “step into the user’s shoes” (van der Burg, 2010). In a workshop session, generative tools are provided to elicit the users’ experiences in a playful and engaging way. Some of the materials used in the sessions can be seen in Figure 9 below.

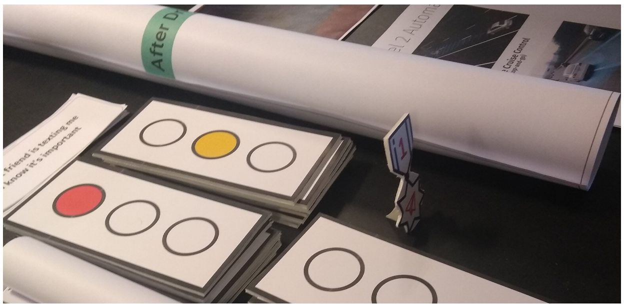

FIGURE 9 - PICTURE OF ITEMS USED IN THE CONTEXTMAPPING WORKSHOP

Within this project the tools and topics are divided into three parts, with the goal of moving from surface point of view to a deeper understanding. This is supported by applying a past–present–future structure to the parts, as also shown in Figure 10 below.

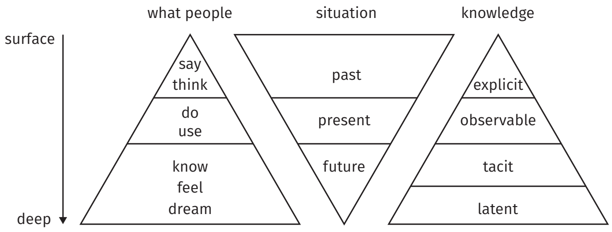

FIGURE 10 - ILLUSTRATION OF THE PAST-PRESENT-FUTURE CONCEPT, ADAPTED FROM SANDERS & STAPPERS (2012)

The method was selected to work well together with the aforementioned Cultural Probes. The probes have the additional purpose of sensitizing the users - making them aware of their everyday experiences and creating more grounded results (Pettersson, 2018; Van Boeijen et al., 2014) .

2.2.2 Sample

The sample consisted of three females and three males, ages 20-63. None of the participants had a background in industrial design or a creative field, so the session was shaped to focus more on finding experiences and attitudes than to co-create. Five of the six participants drove on a daily basis, and used their phones at some point while driving, as found during the probe study (Chapter 1).

2.2.3 Setup and Procedure

The workshop started with an introduction of the project and some lighter activities to get conversations started. The session in itself was divided in three main sessions named Probe Quotes, Timeline and Situations. The sessions represented the past, the present and the future within the context mapping method. After each session there was a break where food, coffee and sweets were served. In the first break the participants were also introduced to the previously used HUD drive simulator and were given some time to experience using a HUD interface while driving. The authors of this report acted as moderators during all sessions, steering the discussion and taking notes when needed.

Probe Quotes

In the probe quotes session, the participants were presented with selected quotes from the design probes. For each quote the participants were instructed to use voting cards to show how much they agreed on the quote. The cards were made in the form of traffic lights, with green light indicating yes, red no and yellow that they could not decide or that it depended on the situation. Example of a probe quote:

> *"I don't like it when I see other people holding their phone when driving"*

After each vote there was a short discussion where the participants explained their opinions a bit further. The quotes were then placed on a chart together with added comments on post-it notes, see Figure 12. After all quotes had been placed a discussion was held whether the participants agreed with the collected picture.

Timeline

In the timeline session, the participants were placed in front of a printed timeline of a driving scenario (Figure 11). The scenario was divided into the following parts: before driving, entry, highway drive, traffic jam, city drive, exit, and after driving. The moderator then presented event cards and placed them at different positions on the timeline. Example of an event card:

> *"My best friend is texting, and I know it is important." (placed on highway drive)*

For each event, the participants were asked to write down their initial feeling and reaction on post-its and place them next to the presented card. After going through everyone's post-its, a discussion was held regarding if the car should help the user in any way during the presented event. After going through all cards, a discussion was held on which of the events would differ the most in another situation on the timeline.

Figure 11 - Picture taken during the Timeline session at the Contextmapping workshop

Situations

In the situation session, the participants were presented with different future situations and were again instructed to use the traffic light vote cards to show their opinions regarding the presented situation. In this case green light indicated the situation was ok, red that it was not ok and yellow that they were unsure or felt that it depended on the situation. Example of a situation:

> *"Reading the news on the HUD"*

After each vote, a discussion around the following questions were held: Is the situation okay? If not, can we make it okay? If okay, where is the limit? What should the HUD look like in this situation? Notes were taken continuously during the session.

2.3 Results

The three different workshop activities led to their own insights. What they are and how they relate to the context can be found below.

2.3.1 Probe Quotes

The results from the probe quotes session, as shown in Figure 12, confirmed many of the findings from the cultural probes study. There is a strong need to stay reachable, but people are also very aware of the risks connected to phone use while driving, resulting in a highly divided chart. The participants were positive towards the Swedish law against handheld objects while driving and very critical towards others' behavior. They were negative towards sending messages while driving but did not want too much restrictions either. Even though many expressed that they normally did not check their phones after a notification few wanted to have their notifications silenced while driving. This indicates that it would be stressful not to know if someone needed to contact them. Similarly, the urgency of contact was seen as a much bigger trigger than monotony.

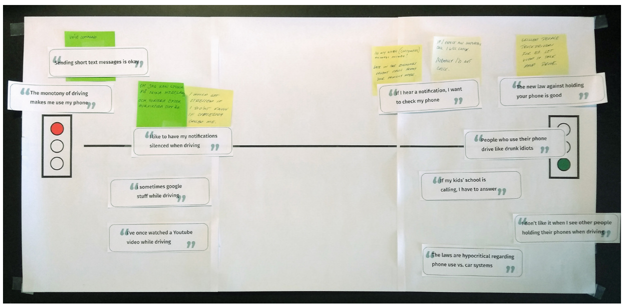

Figure 12 - Picture showing the produced Probe quotes chart

When presented with the planted quotes, "I sometimes google stuff while driving" and "I've once watched a YouTube video while driving", the participants were generally negative. There was some recognition of this behavior in the group, which led to participants confessing on occasionally doing other 'stupid things' while driving.

2.3.2 Timeline

When presented with urgent text messages or emails during highway drive, the participants expressed feelings of anxiety and stress and wanted to be able to both read and reply to them in some way. When asked what would happen if the same messages were presented during a city drive instead, they were less interested in reading, mainly since they felt the driving would be too demanding. It was also noted that city driving provides with more opportunities to make a quick stop for reading and replying to messages if necessary. In Figure 13, a picture of the produced timeline chart can be seen.

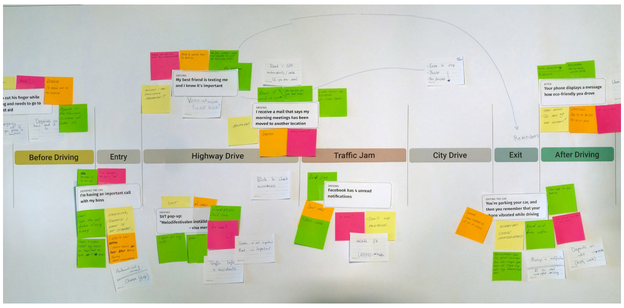

Figure 13 - Picture showing the produced Timeline chart

When discussing the entry, it was found that a method is needed to transfer the phone's functions to the car, even during for example a call. Participants indicated that they were not necessarily interested in receiving news messages on the HUD, Information related to traffic or accidents would be of interest, as they were familiar with the traffic information through the radio.

As mentioned before, the participants were not very interesting in integrating social media into the car system. No need was found to integrate these services and it was even requested to be able to uninstall or suppress apps or services. Additionally, participants wanted to be able to install additional apps for specific types of traffic information.

When participants would soon exit the car, but realized they received a message, some would want to read immediately. Others said that the car should be aware of getting parked, and notifications could be suppressed until parked or after the car has been exited. It was also mentioned that they would like to receive a reminder of unread messages they'd received once they left the car. Participants were very positive to receiving information on their drive afterwards, especially regarding eco-friendliness. One participant found that such a message could be suppressed until the next drive, as to incentivize better driving immediately after.

2.3.3 Situations

The 'Situations' session tried to explore future scenarios. It was found that for the participants it was hard to place themselves in this scenario, as well as finding it difficult to assume trust of L2 cars. This yielded mostly negative reactions to the scenarios, but some participants noted that they could accept reading short messages or parts of the news if they could trust the car fully. Other participants mentioned that you would always lose too much concentration, even in the L2 scenario. Opinions were divided on whether it was okay to have your hands off of the steering wheel while driving, but it was mentioned that drivers will have to get used to more automation, and it could become okay. It was said that no matter how good the car gets, there will always be situations that it cannot handle.

The participants reacted positively to an explicit hand-over from L2 to L0 and mentioned that how this is handled should depend on the driving situation and the driver. Suggestions were given on sound (including muting the radio), visual warnings, and vibrations.

2.4 Discussion

The participants were highly engaged in all sessions and eager to contribute throughout the workshop. Participants were comfortable with sharing their experiences despite any existing taboos, as was experienced similarly in the probe study.

Since the sample was selected from the probe study it has similar limitations with the lack of young participants who are more likely to use their phone while driving (NHTSA, 2018). The absence of social media activity in the probes was linked to the rejection of social media use that was discussed in this session. A more conservative attitude towards driving behavior in general was found, with a tendency to rather avoid secondary tasks while driving than trying to perform them in a safer way.

For this sample, being reachable was seen as more important than staying connected to a social media platform or being able to initiate contact. It is expected that this changes for a different demographic.

Another limitation was the difficulty of describing L2 functionality without the participants being able to try it, which resulted in less acceptance of the safety of such as system. Only one person within the sample used L2 and only with a lane departure warning system (LDWS) as opposed to lane keep assist systems (LKAS). It is possible that people with more experience of LKAS driving would have a different attitude.

3 Peer Ideation Session

DESCRIBED IN THIS chapter is an additional ideation session that was held with peers from the Industrial Design Engineering faculty.

3.1 Aim

Since the results from the cultural probes study and the context mapping session indicated limitations in the sample, additional inputs were gathered through a peer ideation session. The goal of this ideation session was to expand on insights and attitudes that the probe study and the contextmapping session may have missed.

3.2 Method and Design

The method, sample and setup of the ideation session are described in this section.

3.2.1 Method

Brainwriting and Braindrawing (Van Boeijen et al., 2014) are two ideation methods with similar procedure and outcomes. In a Brainwriting session a number of questions is presented to a group of participants. They then write down their ideas on a specific question on a piece of paper. The papers are then passed on the other participants and ideas can be elaborated on or serve as inspiration. Braindrawing is similarly performed, with the difference that the ideas are drawn or sketched instead of being written down.

3.2.2 Sample

There were eight participants in the workshop including one of the authors of this report. All participants were industrial design engineering students at a master's level. There were three females and five males, ages 24-31.

3.2.3 Setup

The session was set up as a creative workshop. During the session, the project's scope and current progress was presented together with explanations of L2 automation and different implementations of vehicle HUDs. When all participants had expressed that they had understood the project and context, a Brainwriting session was held where the participants wrote down ideas and reactions towards a number of predefined questions, see Figure 14.

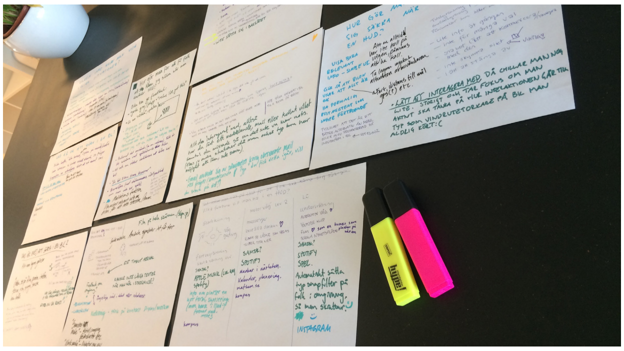

FIGURE 14 - PICTURE SHOWING THE RESULTINGPAPERS FROM THE PEER IDEATION SESSION

Questions:

- What should be ok to do in a car?
- What should absolutely not be ok to do in a car with a HUD?
- How can the car make people feel safe when using the HUD?
- What information/functionality would you like to have in a vehicle HUD and when?
- What type of information/functions can be shown in the following situations; highway drive, city drive, traffic jam?
- How should the phone handle information that has previously been interacted with through the cars system?

3.2.4 Analysis

The results were analyzed through clustering, sorting and collecting the most important findings. Examples are the limitation of allowing only one hand for single tasks, entertainment systems switching off in demanding situations, and provide warnings about high-risk areas such as roads with wildlife. Additional tasks lists were generated for functions and services that should be allowed in different situations. For the full list of generated ideas, see Appendix VIII.

3.3 Results

The results from the peers showed differences from the user studies before. There was a much higher level of acceptance of using (social media) services in the peer group compared to the probe study and context mapping. Additional activities are also regarded as okay, with the notion that they should be (mostly) legal.

Input on available functions for different driving situations were gathered and general comments on UI design were given.

HUDs should communicate a feeling of safety, and make sure that the driver is not overloaded with information. The HUDs content may be adapted to show information regarding safety. There should be a clear line of activities that would draw too much attention such as games, and entertainment should be turned off in high-risk situations.

The user research provided with a better understanding of the users needs and expectations. It gave rise to several guidelines and generated input for the consecutive studies.

As a result of the user research, it has been shown that people do a lot of phone related activities while driving. It was also found that the phone itself often becomes a trigger, where one type of phone use, like reading a notification, can trigger other type of phone use as well.

The participants showed a high awareness to the potential dangers connected to phone use while driving but also admitted that they did it themselves - displaying a conflict between attitude and behaviour. The participants were generally positive towards situationally dependent phone restrictions while driving. That the car could control when, or when not to, present information from the phone was also appreciated as long as it increases the perceived driving safety.

HUD Research

This section discusses the two studies that relate directly to the heads-up display. These two studies are the Blur method evaluation, and the Look-down angle test.

At the start of this thesis, a new method was proposed for researching HUD behavior. This method, called the Blur method, is an HUD alternative to the industry-standard Occlusion method. In Chapter 4, this method is evaluated.

Chapter 5 discusses the Look-down angle test. This test measures the performance of driving together with performing secondary tasks, and shows what angles are ideal for the best performance in both driving safety and secondary tasks.

4 Blur Method Evaluation

THIS CHAPTER DISCUSSES the evaluation of the Blur method, as proposed in an earlier study. The aim, background and setup, as well as the results, can be found here.

4.1 Aim

The Blur method (O. Bång & Hillding, 2019) has been suggested as a improved tool for testing HUD interaction compared to the Occlusion method (ISO, 2017a). However, this method has not been put to use or had its validity proven. In order to test its validity for implementation in this thesis project, a test was set up to compare the Blur method to simulated driving and the Occlusion method.

The test is set up with two questions in mind, namely:

- Is the Blur method a better alternative to the Occlusion method for evaluating HUDs?
- What task completion time is acceptable and how does this compare to simulated driving?

Additionally, the results will be compared to results found by Kujala (2007) to benchmark test validity and compare both objective and subjective observations.

4.2 Method and Design

In order to set a proper baseline, the Blur method is compared to the industry-standard Occlusion method. A simulator setup was built, and software and UI developed for the test. Furthermore, the procedure is described, and the results of the test are discussed.

4.2.1 Methods

The Occlusion Method

The Occlusion method is a well adopted, cost-efficient method for measuring the visual demand of in-vehicle interfaces. No driving simulator is required for using the method. There are set protocols provided by NHTSA (2014) and ISO (2017a).

The Occlusion method tests UIs through intermittent viewing and measures the user's performance in Task Completion Time (TCT) or Total Shutter Open Time (TSOT). The measures indicate the visual demand of the task. Any device that follows the standard can be used to achieve the intermittent viewing. The UI should switch between occluded and unoccluded mode in a set interval where both the occluded and unoccluded viewing-time should be set to 1.5 seconds. The switch must not take longer than 20 milliseconds. The UI should be fully operational in both modes. ISO states that at least 10 participants should be tested while NHTSA recommends 24. According to NHTSA a task is considered to be acceptable if the mean TSOT is 12 seconds or less for at least 21 of 24 test participants.

Some adaptations of the Occlusion method standards were made to improve comparability between tests. The standards regulate that both the visual interface and the controls should be occluded. For this test that would have required occlusion goggles or similar, but since occlusion goggles would negate the effect of the blur test, it was chosen to occlude solely through the HUD screen, allowing the controls to be visible during occluded mode. The TV screen behind the HUD was set to be on during all tests to have a similar amount of contrast and luminance to not affect the HUD's legibility.

The Blur Method

The Blur method is a suggested method for measuring the visual demand of interfaces on vehicle HUDs. It is meant to follow the same protocol as the aforementioned Occlusion method, but instead of completely occluding the interface it blurs it instead. The idea is that a blurred interface can simulate HUD interaction more accurately since a driver is typically able to see both the HUD and the road view at the same time. The blurred mode would then mimic the situation of a driver interacting with the interface in their peripheral view. The amount of blur used should be set to match the visibility in peripheral view for an interface in a similar position. A visual representation of the used blur amount can be seen in Figure 15.

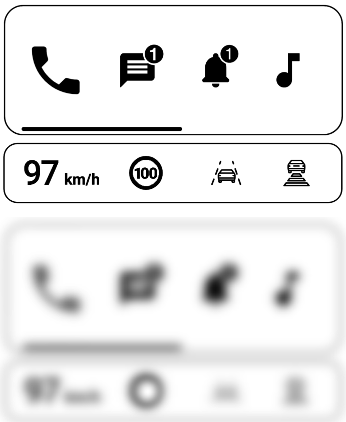

Figure 15 - Illustration showing the difference between the clear and blurred UI state

Driving simulator testing

The purpose of driving simulations is to provide a safe way of performing the primary driving task in various tests. Driving simulators exist in different levels of fidelity, from low-end setups using gaming controllers to extremely high fidelity setups featuring actual production vehicles on a moving rig (National Highway Traffic Safety Administration, 2014).

NHTSA produces standards on the minimum level of fidelity but also acknowledges that the acceptable fidelity level is situation dependent and that acceptance testing should be performable also with very simple, inexpensive driving simulators.

A general rule for all driving simulator testing is that the setup should generate "a pattern of eye glances similar to that seen when performing the same secondary task while driving an actual motor vehicle" (National Highway Traffic Safety Administration, 2014). A direct consequence is that the road display must be positioned at a far enough distance from the driver to simulate proper focus accommodation.

"...the roadway display should be far enough in front of the simulator's driver that visual accommodation must occur when the driver switches her gaze between the device interface and the roadway. In other words, the driver's eyes should be focused approximately at infinity when looking at the roadway and at the correct, much closer, distance when looking at the device display." (National Highway Traffic Safety Administration, 2014)

NHTSA (2014) currently recommends a minimum eye-point to screen distance of 2 meters based on depth of field calculations for the focal length of the human eye.

4.2.2 Sample

The sample was a convenience sample with the requirement of having a valid driver's license for cars and normal or corrected vision. In total 14 people participated, 6 females and 8 males, ages 25-45. The first two tests were permorfed as pilots.

4.2.3 Setup

The simulator used for this test was placed in a small office room, see Figure 16.

Figure 16 - Pictures showing the simulator setup from two different views

The setup consisted of the following:

- A 49” TV screen (LG 49UF675V)
- A driving simulator software (Euro Truck Simulator 2 + Scandinavia expansion)
- A racing game controller consisting of a steering wheel and pedals (Logitech G27)
- A separate controller with a joystick controlling the HUD
- A thin plastic screen mounted on a wooden frame, reflecting the HUD interface.
- A monitor placed below the plastic screen, displaying the HUD interface.
- A laptop running the HUD software
- A laptop running the simulator game
- An office table and a chair
- Equipment for recording video, audio and timing.

The chair and HUD were adjusted for each participant and then fixed during the test. A benefit of using a one-screen fixed view is that it minimizes the risk of simulator sickness. It does come with limitations since it does not allow looking out the side windows. This was compensated through choosing highway traffic routes and avoiding lane changing, minimizing the need of a side view.

To ensure consistent and repeatable test conditions, the following configurations were set for the software:

- The surrounding traffic was turned off.
- The camera view was set to be the same for all participants and fixed during each test.
- A game session was saved and reloaded for each participant making sure all tests followed the same path with the same conditions. The chosen path was E6 S Gothenbug - Malmö.

4.2.4 User Interface

The UI was running through Framer Classic, a UI prototyping software. Different presentation modes were created for the three different methods.

For the Drive test, the UI was presented in standard mode and operated through the joystick.

For the Occlusion test, the UI was programmed to switch between occluded (black screen) mode and unoccluded (showing UI) with a set time interval. The occluded and unoccluded time were both set to 1.5 seconds according to regulations (ISO, 2017a). The interaction worked independent of occlusion, meaning that the user could navigate the UI during the occluded time as well.

For the Blur test, the UI was programmed to switch between blurred and unblurred mode with a set time interval. Both blurred and unblurred time were set to 1.5 seconds, mimicking the occlusion test. The blur used was set to a gaussian blur of 15px on a 1920x1080px screen. This value was selected through a comparison with pictures taken with camera settings matching the theoretical aperture of the human eye. For more information see Appendix IV. The user could interact with the interface independent of blur modes.

The UI produced for this test was based on the results of an internal study (Bång & Hillding, 2018a). It is two-colored, presenting text and icons in white, within a white frame with a blue color indicating UI position and action. The frame had various grid layouts for presenting different functions. For navigation through the UI, a physical joystick was used. The joystick has two-axis functionality but only the vertical axis is being used for up-down navigation (see Figure 17), because internal findings at Semcon (Bång & Hillding, 2018b) indicate that unidirectional navigation is the most efficient for in-vehicle HUD interaction.

Figure 17 - Illustration of the UI navigation

Tasks

Two types of tasks were constructed with the goal of having both long and short UI interactions. For each test the short task consisted of making a call by navigating to a contact list and selecting a given contact in the list. The steps needed to perform this task are illustrated in Figure 18 on the next page.

The long interactions task consisted of finding and reading a 200 characters text message and answering with a prewritten reply. The steps needed to perform the task are illustrated in Figure 19 on the next page. All tasks were chosen so that they had similar navigation steps.

4.2.5 Test procedure

Each test was performed by the two authors of this report and one test participant. The roles were set to test leader and test operator. The tasks of the test leader were to give instructions and steer the interview, the task of the test operator was to manage the simulator, record time, and make notes during the interview sessions.

Each test was divided into an introduction session, three test parts and a finishing interview session. During the introduction, the participant was informed about the purpose of the study and the test and was introduced to both the simulator and the UI independently. The tasks were categorized as: A - Drive, B - Occlusion, C - Blur. The order was controlled between ABC, BCA and CAB to compensate for learnability issues.

The drive test was initiated with a benchmark drive to ensure that the participant was able to handle the drive task without disturbances. The task was to drive safely in the center of the right lane on an empty two-lane freeway at full speed (regulated to 90km/h). Afterwards, the participant was asked to rank their driving according to safety in a 1-5 scale. When having completed the benchmark, the participant then did two drive tasks, going through the UI tasks simultaneously. Driving performance during these tasks was assessed according to the Moderator Handbook (Bång, 2018).

For the Occlusion and Blur test, the truck was parked on the freeway lane and the view were slightly adjusted to ensure that the direction lines in the road would not interfere with the UI. The UI was then set to either occlusion or blur mode and the UI tasks was performed.

All tests were recorded using a GoPro Hero 4 directed at the TV screen, capturing both the driving and the UI interactions. The recordings were used during the analysis to rank driving safety and performance.

For test procedure and the manuals see Appendix VI.

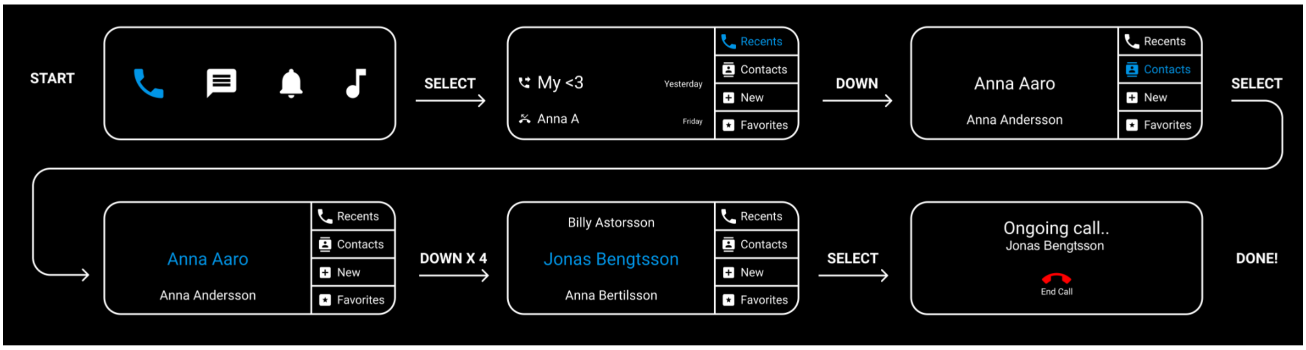

Figure 18 - Illustration of the planned interaction path - short task

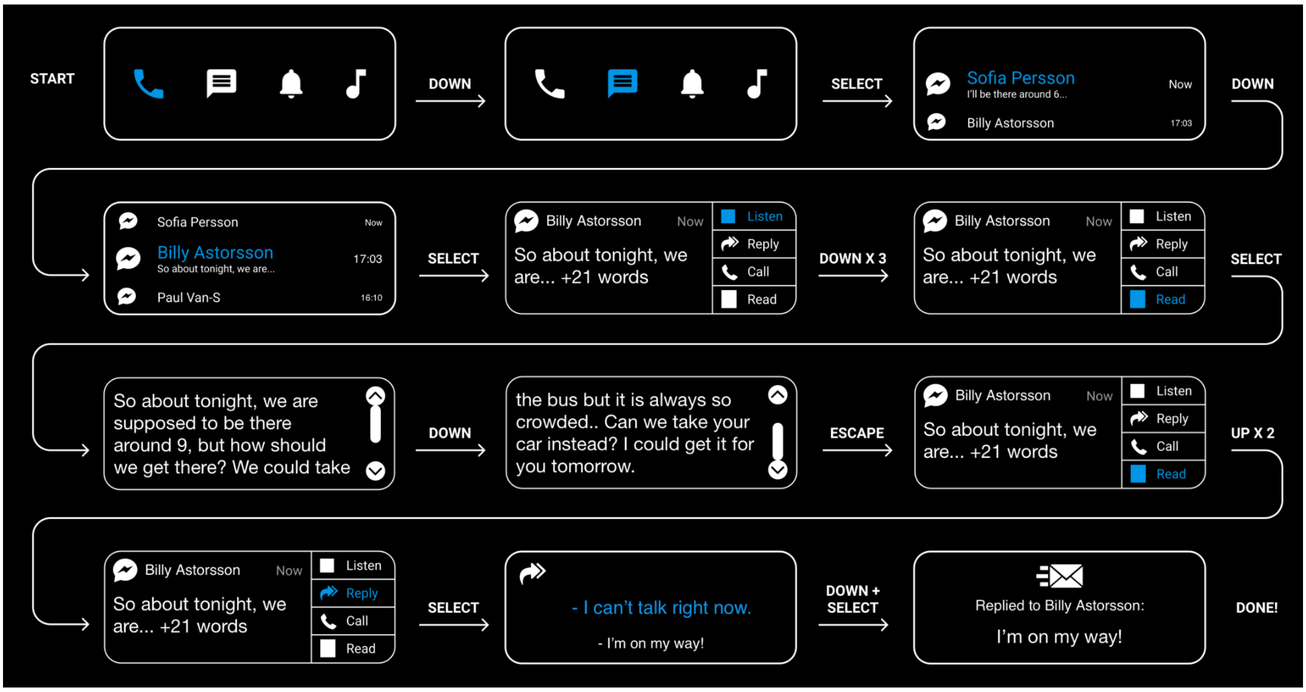

Figure 19 - Illustration of the planned interaction path - long task

4.3 Results

During the six tasks, task completion time (TCT) was measured. For the Occlusion method and Blur method, the TCT includes occluded time and blurred time respectively. This is different from NHTSA guidelines as especially the Blur method allows for interaction in the blurred state. TCTs were measured for each task and averaged across participants.

Some data points were found to be unrepresentative of regular behavior, either due to unsafe driving or making too many navigation errors in the UI and were therefore deemed unfit for comparison of the tests. Six entries were manually removed. The results are shown in Figure 20 below.

Both the Occlusion method and Blur method yield similar results to simulated driving. For the short task, simulated driving TCT (M=10.0, SD=3.8) was found to be slightly overestimated by occlusion (M=11.8, SD=2.8) and underestimated by blur (M=8.3, SD=2.9). For the long task, simulated driving TCT (M=36.3, SD=2.6) was underestimated by both occlusion (M=35.6, SD=3.8) and blur (M=32.4, SD=6.7).

The larger standard deviation on the blurred long task can be explained by some participants actively navigating the UI while blurred, while other participants waited for the unblurred state. Most participants navigated in the blurred state towards the end of the task, implying some learnability in navigating in the blurred state.

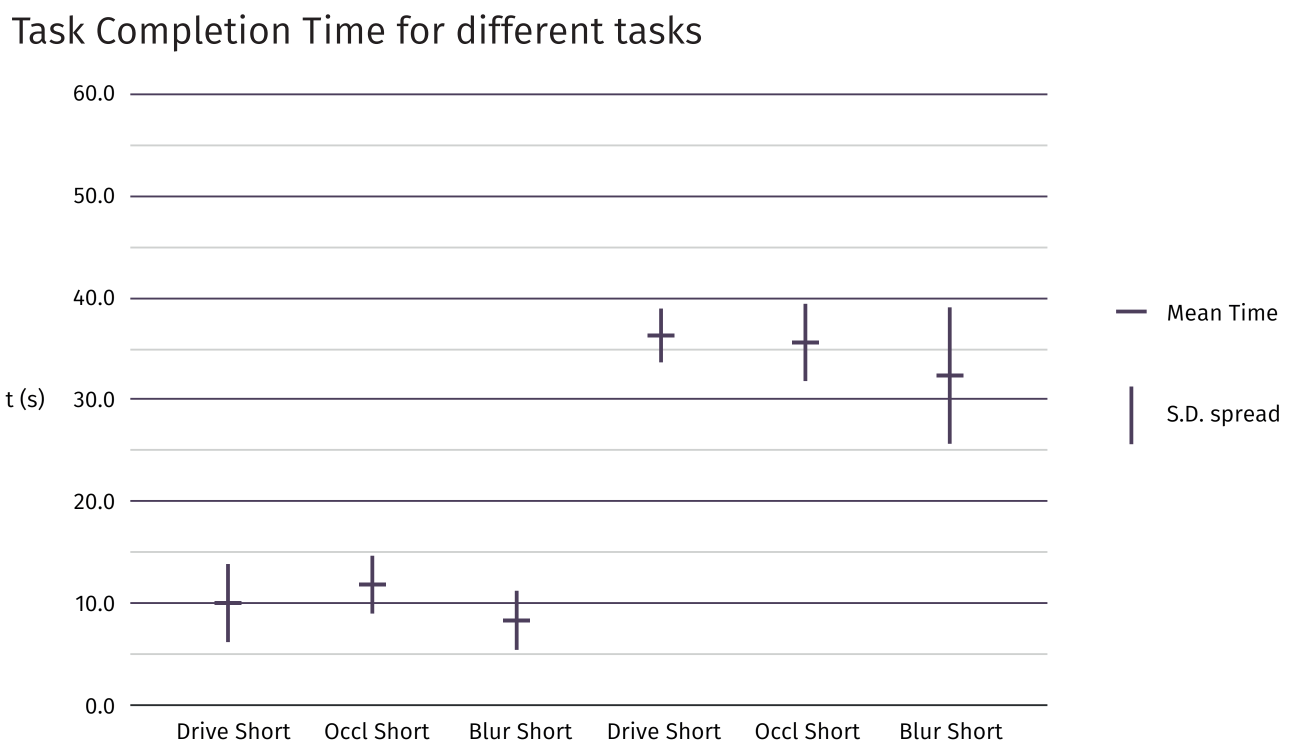

Figure 20 - Task completion times (Corrected) - Blur evaluation test

The found data would indicate that TCT for Occlusion is a better estimate of driving in this simulated environment, but comments from participants indicated differently on an experiential level and with respect to their expected learnability. Participants were asked about their preferred testing method, and comparability to simulated driving. 8 participants preferred the Blur method, 2 preferred the Occlusion method, and 2 had no preference. Regarding similarity to simulated driving, 5 participants thought the Blur method was the most similar, 1 participant said occlusion and 6 participants made no distinction. 10 of the 12 participants noted that they would see the HUD in their peripheral vision in simulated driving.

Several participants indicated that they preferred the Blur method for HUD testing because they would not lose the position of the UI and elements therein when not focusing on the HUD. Additionally, it was said that if the participants would get more time with the interface, they would be able to navigate better both peripherally and in blurred state. The Blur method was said to be realistic in simulating switching focus between 'real world' and UI. One comment stated that the blur could be confusing as it is in the middle of being able to interact and not being able to. Occlusion was stated to need more focus and active attention.

User navigation errors was measured during the tests. After the first set of tests a larger amount of errors was found in the earlier tasks irrespective of task order. As previously described, some of the data was discarded, and successive participants were given more time to get acquainted with the UI, eliminating this initial error. TCTs were measured to decrease slightly along the tasks but are controlled for due to randomized task order.

4.4 Literature

Kujala (2009) suggested the Occlusion method can be questioned regarding representability of a simulated driving environment, especially on information-filled displays such as the messaging tasks in the experiment described in this chapter. Kujala measured a significant decrease in TCT during occlusion compared to simulated driving, which was found to a lesser extent in the test described in this chapter. This may be explained by the difference in setup, as Kujala tested reading a larger portion of text and no short interactions in a UI – of which the former was suggested to be more susceptible to interruptibility. Similar results were found regarding deterioration of driving safety, but not to the extent of completely unsafe driving. Participants noted similar results of the occlusion interrupting spatial awareness within the UI, which participants argued to be expected less so in the case of HUDs.

4.5 Conclusion

The results indicate that the Blur method and the Occlusion method produces TCTs similar to simulated driving, making them both valid substitutes for UI tests in this simulated driving environment. The Blur method was preferred by participants for HUD testing since it preserves the user's spatial awareness of it and its elements. Therefore, it requires a lower mental workload as well as better simulating the UI in peripheral view. The possibility to navigate within the blurred state was also described as a more realistic feature, especially after being more familiar with the UI.

The study supports the initial suggestion that the Blur method is more suitable than the Occlusion method for testing interaction in HUD interfaces on an experiential level and should be especially suitable as a tool for comparison tests.

Further research is needed to prove it as a method for determining safe levels of visual demand and distraction. The results indicate that the blur has a tendency to underestimate the TCTs compared to simulated driving, and a possible development of the method could be to research blur levels, blurred and unblurred interval times and state transitions.

4.6 Recommendations

After testing, the Blur method was proposed as a guideline in the HUD's UI design phase. The Blur method would aid in designing UIs that enables efficient interactions during the blurred state. These characteristics are likely to be beneficial in a real driving situation and would enable UI navigation in peripheral view.

5 Look-down Angle Evaluation

IT WAS CONJECTURED that the angle of a HUD with respect to the driver's line of sight could have a significant effect on the driver's performance when using an interactive HUD. A drive simulator test was set up to evaluate this look-down angle.

5.1 Literature

In order to find how the positioning of the HUD affects performance, a short literature review was performed.

From the Alliance of Automobile Manufacturers, the following can be stated.

> *"Visual displays that carry information relevant to the driving task and visually-intensive information should be positioned as close as practicable to the driver's forward line of sight." (Alliance of Automobile Manufacturers, 2006)*

They further state that besides from brief glances at mirrors or instrumentation, the driver's gaze should be directed towards the roadway, reducing eyes-off-the-road time and maximizing the possibility for a driver to use peripheral vision to monitor the roadway for major developments while looking at a display.

In Display of HUD Warnings to Drivers: Determining an Optimal Location (Yoo et al., 1999), a test was made to determine the optimal position for HUD warnings regarding ease of detection for warning messages. Their results show that the best position for detection is to be found within 5 degrees of the forward line of sight, preferably 5 degrees down and to the right. These results are also referred to in the NHTSA guidelines as seen below.

> *"Critical displays for continuous vehicle control or critical warnings related to vehicle forward path are located within ±15 degrees of the central line of sight but as close to the central line of sight as practicable. Messages that require immediate detection should be located within 5 degrees of the forward view when possible and 5 degrees to the right and 5 degrees down for messages on a HUD." (Campbell et al., 2016)*

In Display of HUD Warnings to Drivers: Determining an Optimal Location (Yoo et al., 1999), there is also a tabular review of the up till then existing literature. The review summarizes 25 studies relevant to automotive HUDs. The literature typically compares HUD with HDD or investigates technical features. There are recommendations and guidelines on factors such as display luminance and contrast, UI colors, sizes on text and symbols, perceived UI distance and different positions and angles, but the scopes are typically limited to detection or glance. The studies that did include the look-down angle in their research indicated that an ideal angle would be found within 0-10 degrees below the forward line of sight.

Few studies were found on how position and angle affect HUD and driving performance for interactive or visually intense tasks and the ones found typically only compared HUDs with HDDs, providing no information on to what extent different positions within the ±15 degrees HUD area affects it.

5.1.1 Conclusion from Literature Review

Most literature seem to support the statement that visually intense information should be placed close to the driver's forward line of sight but regarding the exact position the results vary depending on the scope of the study. There is a trade-off between having the HUD as close to the forward line of sight as possible and not obstructing the view, but no studies could be found that investigates how different positions/angles affects performance within the ±15 degrees HUD area. Since there is a difference between the ability to detect a HUD message and actively interacting with a HUD interface, the recommendations from NHTSA cannot be fully applied to the scope of this thesis.

5.2 Aim

There is an expected trade-off between having the HUD as close to the forward line of sight as possible and not obstructing the view. To be able to create the best possible experience and performance for interactive HUDs, the correct position is crucial, making it highly interesting to know to what extent the position affects both UI- and driving performance individually. To find how the position affects, a simulator study was conducted investigating how different look-down angles affects both driving and UI performance. Four look-down angles were tested; 2.5°, 5°, 7.5° and 10°, based on similar ranges in the literature review. It is thought that performance will decrease along with a lower (i.e. towards 10°) angle. For this test no side angles were tested, and the HUD was placed in center. According to the Alliance of Automobile Manufacturers (2006), visually intensive tasks should be placed as close to the driver's forward line of sight as practicable, implying that the center position should be optimal for HUD performance.

The goal was to find how different look-down angles affects the following factors when doing interactive and highly visually demanding secondary tasks:

— Driving performance - measured in mean deviation from an optimal path.
— Secondary task performance - measured in task completion time
— Experienced drive performance - measured with subjective rating scales
— Experienced secondary task difficulty - measured with subjective rating scales

The participants were also asked to select their preferred position through the following questions.

— From which position was it easiest to perform the messaging task?
— From which position was it easiest to drive?
— From which position do you think you've had the safest drive?

5.3 Method and Design

The Lane Change Test has been applied during the evaluation. This chapter discusses that setup, including the drive simulator and testing procedures.

5.3.1 Method

The Lane Change Test (LCT), as described in ISO 26022:2010 (ISO, 2010) is a dynamic dual-task method for measuring human performance degradation on a primary driving-like task while a secondary task is being performed. The primary task is performed in a driving simulator with a dedicated software developed due to the ISO 20622 standard. The method is applicable to all types of interactions with in-vehicle information, making it highly relevant for this study.

In performing the LCT the participant is instructed to drive on a straight three-lane road with oncoming signs with symbols giving directions to another lane, see Figure 21. The participant is instructed to follow the signs and switch to the given lane as soon as they detect the message. Task performance is measured within the software as mean deviation from a predefined optimal path (in meters).

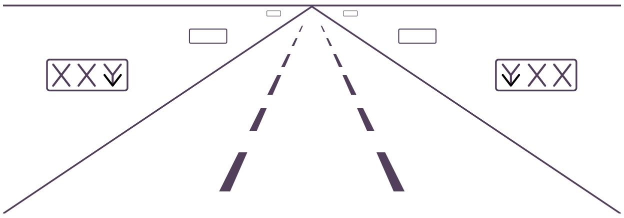

Figure 21 - Illustration of the LCT simulator setting, adapted from ISO 26022:2010 (ISO, 2010)

5.3.2 Sample

The sample was a convenience sample with the requirement of having a valid driver's license for cars and normal or corrected vision. One pilot test was performed. In total 12 people participated, 3 female and 9 male, ages 25-63. One participant's results were taken out due to a risk of partiality.

5.3.3 Setup

Driving Task

For the driving task, the Lane Change Test (LCT) according to ISO 26022 was used (ISO, 2010). The test followed the defined standards both for performing simulator testing and analyzing the results. The software used were designed and set up according to the ISO 26022 standards.

Secondary Task

For the secondary task, a similar UI as in the Blur method evaluation (Chapter 4) was used, see Figure 22. It was created and run through Framer Classic and controlled by the same joystick controller. For this test, the possibility to use side way navigation with the joystick was added.

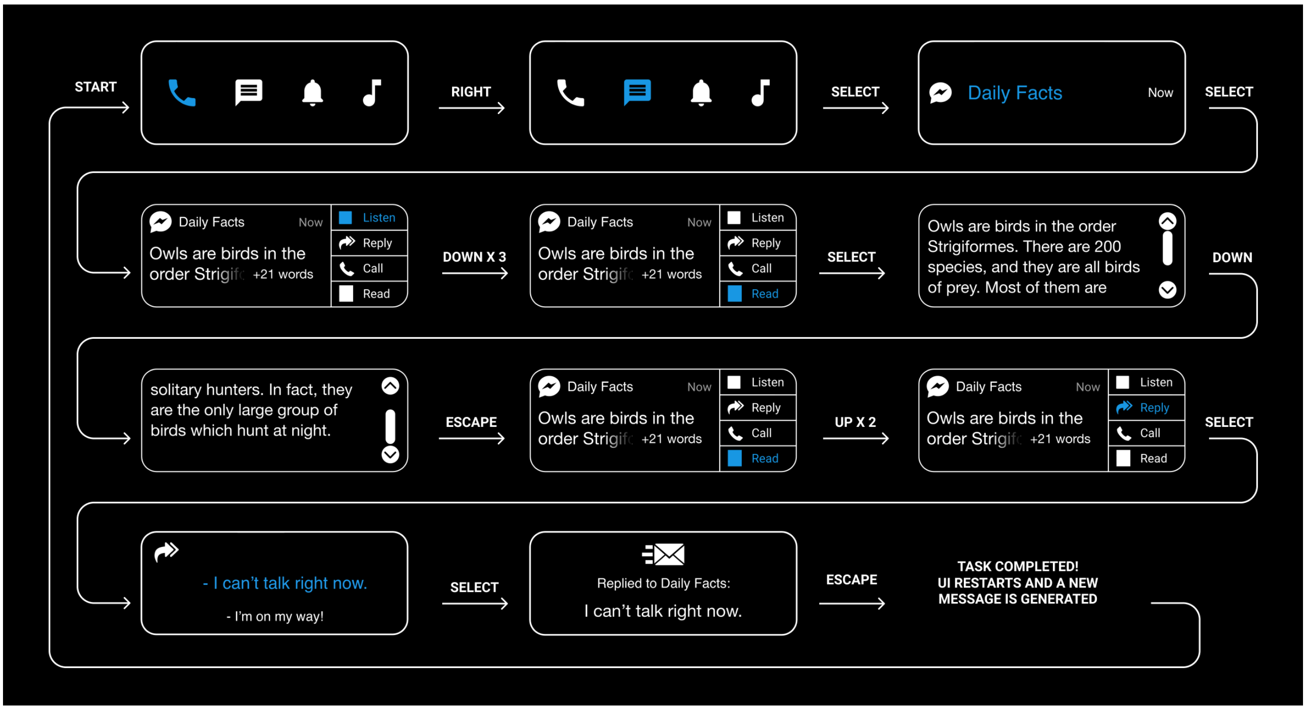

Figure 22 - Illustration of the optimal interaction path for the secondary task

Since the goal of this test was to measure both driving and secondary task performance it was important to have a secondary task that could be performed repeatedly throughout the whole test. It was also of interest to see how the tested UI would work due to both navigation and focused reading.

Each task started at the main menu. The participants were informed that in this scenario they had subscribed to a text messaging service that continuously provided them with short messages containing facts on various topics. The participants were instructed to navigate to the perceived message, to open, read and understand the whole message and then go back and send a predefined reply to the message. The reply was used to mark the end of each task, so when the reply was sent, the participant was sent back to the main menu with a new message waiting for them.

The messages were designed to be of similar length, style and language difficulty. They consisted of approximately 40 words and 200 characters and were presented in 2 pages, displaying 4 rows each.

> *"Ducks are birds in the family Anatidae. Ducks are closely related to swans and geese. Other swimming and diving birds, like grebes and loons, are not ducks. Ducks eat aquatic plants and tiny animals."*

Through the test, the participants were instructed to open and read as many messages as possible while performing the driving task safely. The look-down angle was then changed between the different parts.

Simulator Setup

This setup was scaled up with a larger road screen and increased distances compared to the Blur method evaluation, see Figure 23. The scaled-up setup allows for a less sensitive test envirvonment, making it easier to receive and keep precise angle measurements throughout the test. The setup was inspired by the setup used in Display of HUD Warnings to Drivers: Determining an Optimal Location (Yoo et al., 1999). The exact measures are presented in Figure 24.

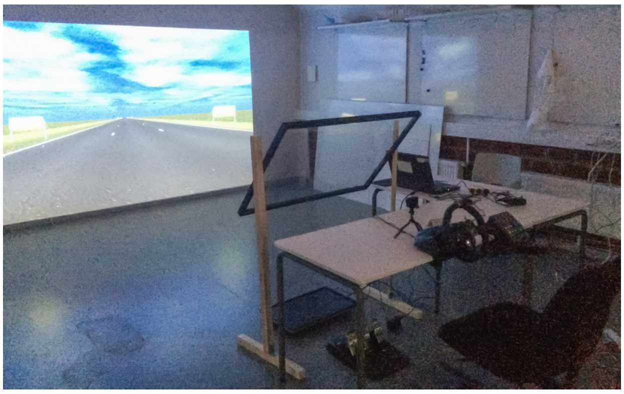

Figure 23 - Picture of the simulator setup used in the look down angle evaluation task

The setup consisted of the following:

- A projector for the simulator software
- Driving simulator software according to ISO 26022
- A racing game controller consisting of a steering wheel and pedals (Logitech G920)
- A separate controller with a joystick controlling the HUD
- A thin plastic screen mounted on a wooden frame, reflecting the HUD interface.
- A monitor placed below the plastic screen, displaying the HUD interface.
- A laptop running the HUD software
- A laptop running the simulator
- An office table and a chair
- Equipment for video, audio and time recording.

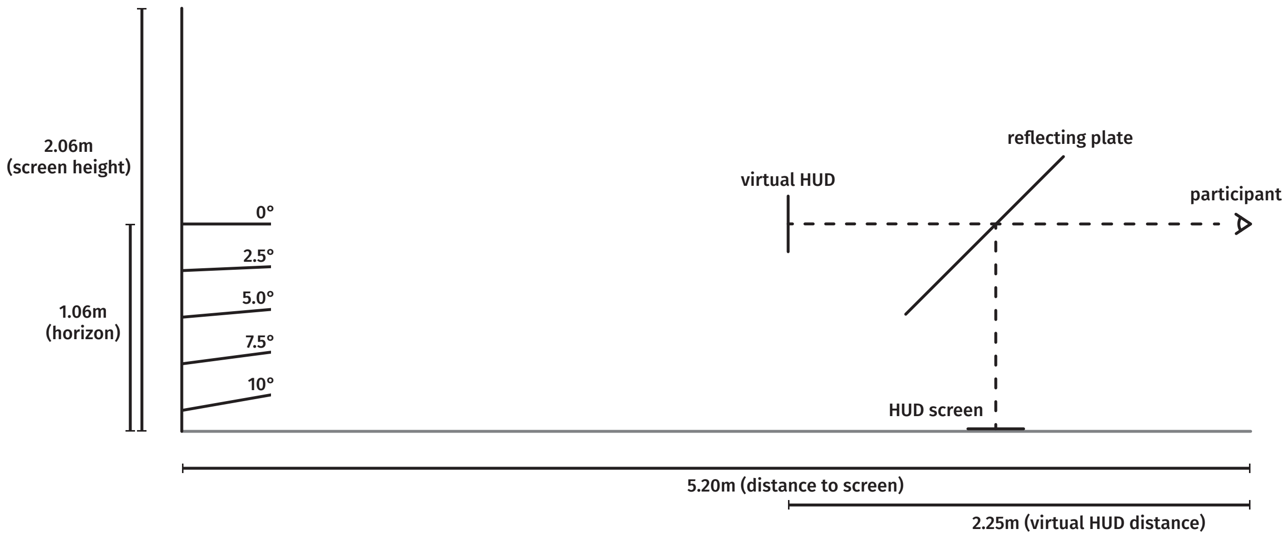

Figure 24 - Illustration of the simulator setups measurements, look down angle evaluation test

Key measures

— Screen size:	2.06 x 3.34 m
— Distance to screen	5.20 m
— Virtual HUD distance	2.25 m
— Height of the horizon	1.06 m

For measuring and adjusting the look-down angle, an angle measurement chart was created, see Figure 25. The UI was aligned with the chart before each test run, making sure that each participant had the correct angle set based on their size and seating position.

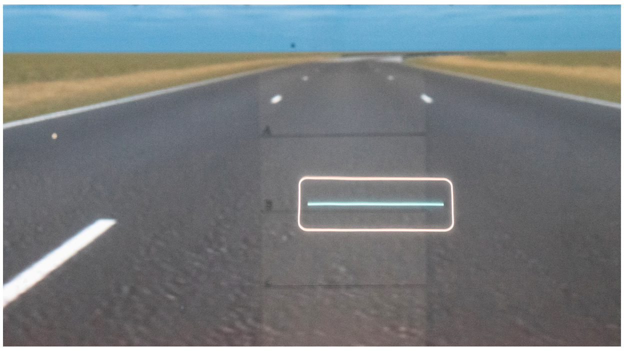

Figure 25 - Pictures showing the angle measurement chart and an example of UI alignment to angle B

5.3.4 Test Procedure

Each test was performed by the authors of this report and one test participant. The roles were set to test leader and test operator. The tasks of the test leader were to give instructions and steer the interview, the task of the test operator was to control the simulator, record time, and make notes during the interview sessions.

Each test was divided into an introduction and training session, a benchmark drive, four test drives and a finishing interview session. During the introduction the participant was informed about the purpose of the study and the test and was introduced to both the simulator and the UI independently. During the training session, the participant was allowed to perform the driving and secondary task a number of times to get used to doing them simultaneously. As soon as they felt comfortable with performing the tasks, the actual testing started.

The benchmark drive was done without the secondary task, the four test drives with the UI set at different look-down angles. The tasks were performed in a controlled randomized order to rule out learnability. All tests were recorded using a GoPro Hero 4. For the test procedure and manual, see Appendix VII.

5.3.5 Analysis

The participants' driving performance was measured through the LCT software. This output the mean deviation (MDev) of the ideal driving line for each drive. A small MDev means better driving. To account for different driving skill levels, the baseline MDev was subtracted from test entries, where this ΔMDev indicates the deviation due to the additional task.

Task Completion Times (TCT) were measured for the messaging task. Shorter TCTs indicate a better opportunity to complete the task quickly.

5.4 Results

The test recorded driving performance, task performance, and asked participants to rate their driving safety as well as the difficulty of performing the reading task.

5.4.1 Driving Performance

The results indicate that 2.5° and 5° affect driving behavior similarly, with 2.5° performing slightly better. 7.5° and 10° affect driving behavior similarly as well, with 10° performing slightly better. Mean ΔMDev with standard deviations on the upper and lower points are plotted in Figure 26 below.

The large standard deviation at 7.5° can be explained by several missed lanes due to the secondary task, whereas the other angles only had a single occurrence of missed lanes.

5.4.2 Secondary Task Performance

Here the 5° angle performs the best with an average TCT of 22.7s. The 2.5° angle scores similarly with 23.5s, followed by 7.5° and 10° with 27.7s and 28.8s respectively. The results are plotted in blue with the mean and standard deviations in red in Figure 27. These results indicate that optimum angle lies between 7.5° and 2.5°. It is thought that the 2.5° angle can create too much visual conflict with the road, whereas the 7.5° angle is too low to optimally utilize the peripheral vision.

5.4.3 Subjective Measurements

Participants rated their feeling of driving safety for each of the drives. The participants were very consistent in scoring both driving safety and task difficulty, as can be seen in Figure 28 and Figure 29 respectively.

Participants rate their driving safety as progressively decreasing with a lowering angle. The baseline drive was rated as a 4.3 on a scale from 1-5.

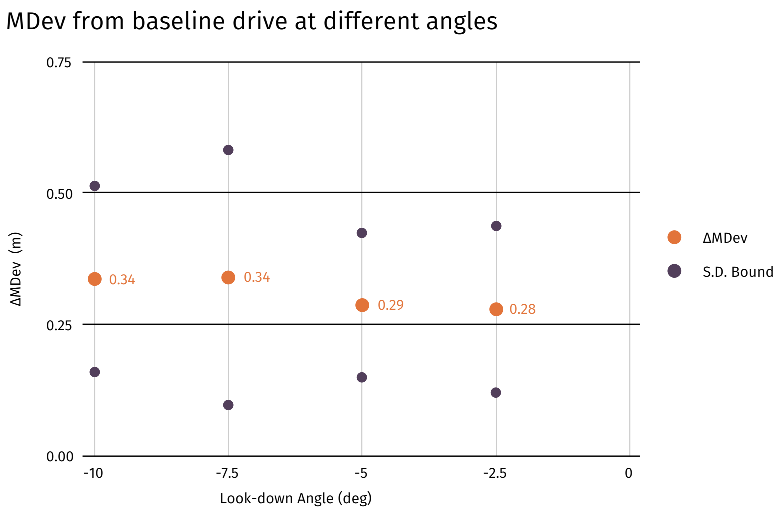

Figure 26 - Delta mean deviation from the baseline drive for different look down angles

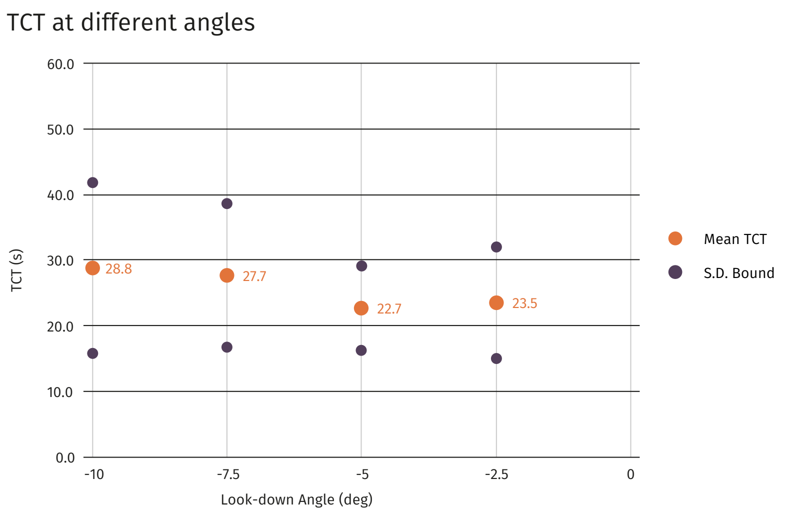

FIGURE 27 - MEAN TASK COMPLETION TIMES FOR DIFFERENT LOOK-DOWN ANGLES

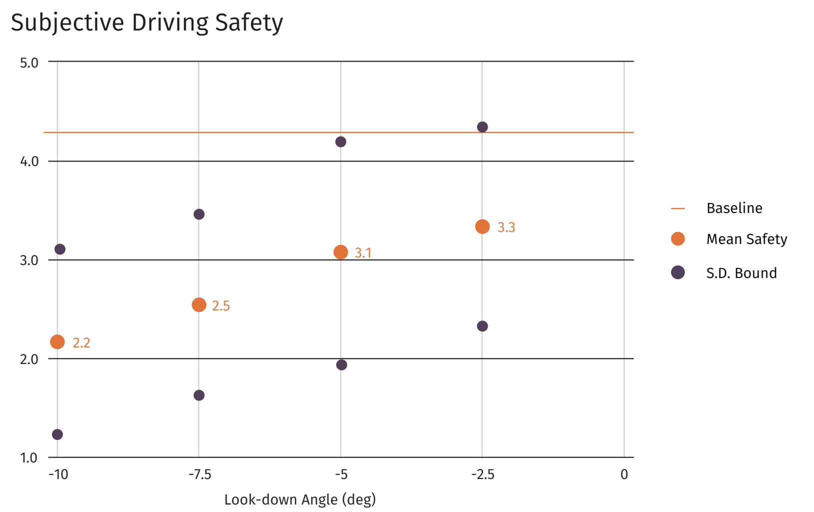

FIGURE 28 - THE PARTICIPANTS RATINGS OF THEIR PERCEIVED DRIVING SAFETY

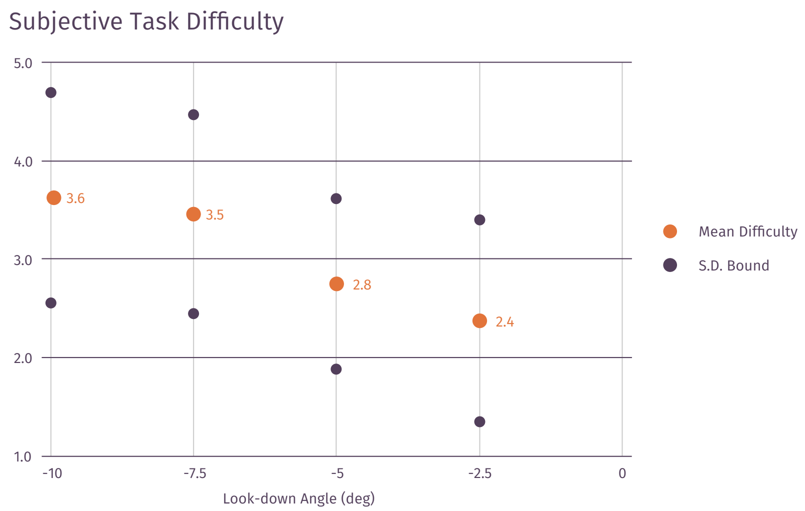

FIGURE 29 - THE PARTICIPANTS RATINGS OF THEIR PERCEIVED SECONDARY TASK DIFFICULTY

Participants also consistently rated their secondary task performance to become increasingly difficult with a lowering angle. This matches the answers from the evaluation interviews, where eight participants preferred the 2.5° angle, four participants preferred 5°, and one participant liked both 2.5° and 5° equally.

During the evaluation interview the participants were also asked about the ease of driving with different HUD positions and the preferred location for the safest drive. 8 participants said the 5° angle was the easiest to drive with, and 4 preferred 2.5°. Several participants mentioned that for 5° no visual conflict occurred between the driving line of sight and the HUD location, whereas the 7.5° and 10° angles created too much space so that the peripheral vision could not be used, or the head had to be physically moved. 10 participants found the 5° angle to be the safest to drive with, the other 3 preferred 2.5°. Similar reasons were given for the lower angles in this case. There is some discrepancy in participants giving a higher safety rating to the 2.5° angle but find 5° to be safer after all drives.

Participants in general were very positive about the use of a HUD, provided that the placement was in a good position. One participant explicitly mentioned being able to use the different colors in the UI to be able to navigate solely in peripheral vision, but only after having learned the UI.

5.5 Conclusion

The results of this study indicate that there is a strong connection between the look-down angle and both UI performance and driving performance when doing interactive and visually demanding secondary tasks. This connection must be considered when designing HUD interfaces.

The look-down angle affects both the measurable performance but also how users will interact with the interface. Different angles have a strong influence on the user's ability to perceive both the road and the HUD, which forces the user to assume one of two approaches, namely:

The first behavioral approach appears mostly in the 2.5°-5° angles. In these positions, users are able to see

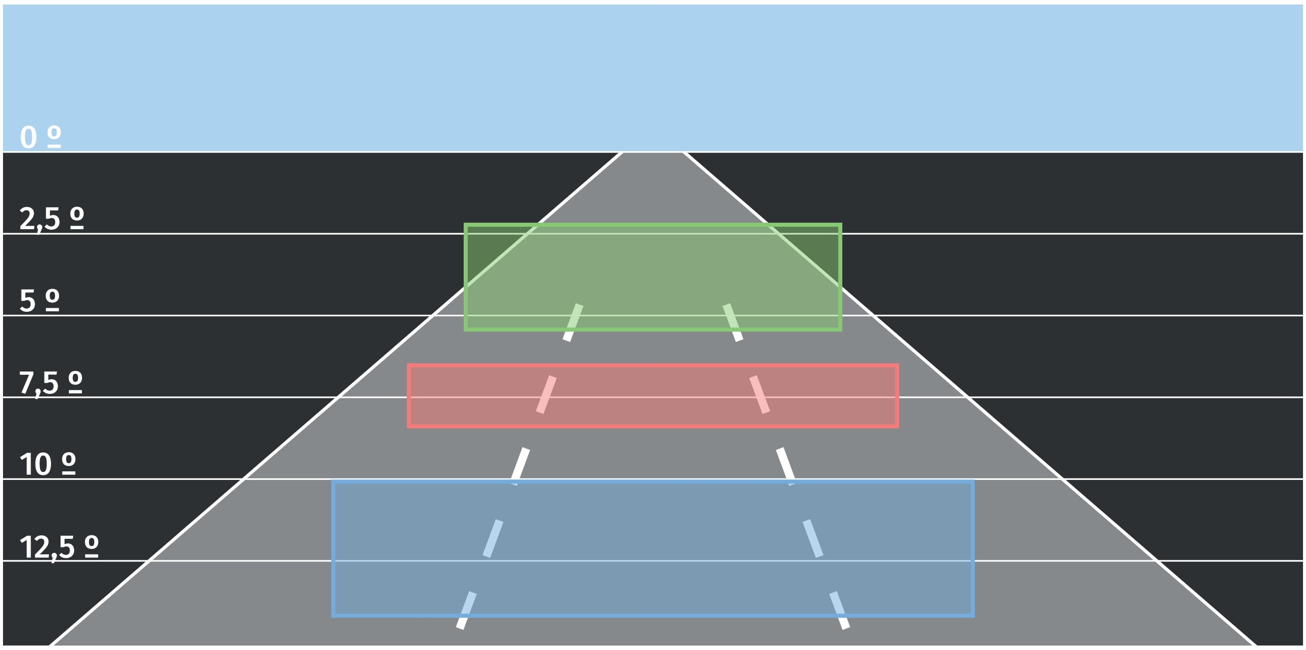

Figure 30 - Illustration of the three identified HUD positioning areas

both the HUD and the road. Users were found to mainly focus on the HUD while navigating the vehicle within the lanes through peripheral vision. When approaching a sign, the users waited until they noticed the directions in their peripheral view before switching focus and performing the lane change. Being able to combine these tasks led to improved performance in both.

The second behavioral approach appears mostly in the 7.5° - 10° angles, were users are no longer able to combine tasks in their field of view. This makes the user choose between looking at the road or the HUD. This leads to longer TCTs when looking at the road, and higher lane deviations when looking at the HUD. In some cases, looking at the HUD made participants miss a lane change. This situation generally leads to a decreased performance in both lane deviation and TCT.

The different approaches that participants assume show the possible advantages of using a HUD compared to an HDD. The first approach indicates the possibility of sharing road perception and HUD perception within the same field of view. The second approach is more similar to that of a HDD, forcing the user to choose what to focus on. In this approach users spend more time actively focusing on the road but also more time not watching the road at all. This could be dangerous for visually intensive tasks since the risk of missing information from the surroundings increases. In the first approach there is less time actively focusing on the road, but rarely any eyes-off-the-road time.

This yields a question for HUD designers, namely whether to facilitate the use of visually intensive tasks through HUDs placed in high angles, or not allow this type of interactions at all. Within the scope of this project, and the expectation of users picking up their phones, the former is recommended.

5.5.1 Recommendations for HUD positions

The look-down angle affects people's behavioral approach when interacting with the HUD and should therefore be set according to the wanted interaction type. Figure 30 describes three identified HUD areas with different implications for the type of interaction.

Look-down angle between 2.5º and 5º

With the HUD placed within this area, it is possible to mainly focus on the HUD while navigating the vehicle within the lanes through peripheral vision. The first behavioral approach is therefore likely to be used. For visually intensive tasks this is the preferred area.

Performances on all measured factors scored better for drives with the HUD placed within this area and it was also the most preferred area by the participants.

Look-down angle around 7.5º

With the HUD placed within this area, it is almost possible to focus on the HUD while navigating the vehicle within the lanes through peripheral vision. Which behavioral approach that is likely to be used is not clear for this position and users might switch between the first and second approach.

This is not suitable for intensive tasks and the switch between different approaches might lead to dangerous mistakes. How the switch between different interactions affects other tasks needs further investigation.

Look-down angle below 10º

With the HUD placed within this area, it is not possible to focus on the UI while still being able to navigate within the lane and detect upcoming signs. The second strategy is therefore likely to be used.

This area is not suitable for visually intensive tasks but might be for tasks that only requires quick glances such as the speedometer.

5.6 Limitations

This test consisted of 12 participants out of a convenience sample. NHTSA requires a minimum of 20 test participants within certain age ranges and sexes (National Highway Traffic Safety Administration, 2014), and the results may be less applicable in a regulatory sense, and results could be skewed.

The LCT software as defined in ISO 26022 (ISO, 2010) does not include other traffic. Results are therefore likely to favor empty roads and more visual conflict between HUD and surroundings is expected in regular traffic. The LCT should therefore not be interpreted as a accurate simulation of real driving, but as a comparative tool.

Despite giving the participants time to familiarize themselves with the test setup and tasks, some preferences likely due to accustomization have been found. Participants that had either 2.5° and 5° or 7.5° and 10° for their first two tasks were more likely to pick the second. Although this effect is present, it is mitigated due to the controlled-randomized order.

This study only compares different look-down angles and forces the participants to perform visually intensive tasks in them. It therefore does not indicate whether participants are likely to interact with the display in all cases. The study also does not conclude whether visually intensive should be allowed at all, and only compares safety between different angles as opposed to evaluate safety in general.

The HUD Research section produced valuable insights on the characteristics of heads-up display usage. It filled gaps in the existing research and supported the following work by defining prerequisites for optimised HUD performance.

During the method evaluation it was shown that the Blur method provided with a more accurate simulation of HUD usage than the Occlusion method. The Blur method was also shown to benefit interfaces with a clear navigation within the driver's peripheral view, an important performance factor for interactive HUDs.

An optimal position for interactive HUDs was found between a 2,5 - 5 degrees look down angle. It was found that it is only within that area the driver can fully utilize the potential benefits provided by the HUD.

UI Development

An essential part of the heads-up is the user interface that displays all information. This section describes the activities regarding the development of this user interface. These lead to a conceptual interface that has been evaluated by experts in the field.

As a preparation for the final HMI concept, the interface has been prototyped in Framer Classic, according to the User Task Flow that is descrbied in this section.

6 Situational Restrictions

Different situations require different amounts of cognitive workload. Since the HUD interface is meant to replace phone use in case of lowered cognitive workloads, the HUD interface should be adaptable to different situations. The graph below has been created to illustrate expected cognitive load as a result of type of road and traffic intensity, see Figure 31.

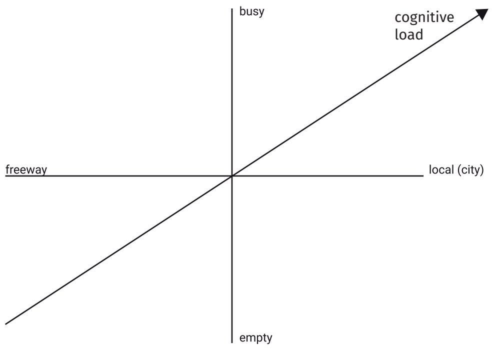

Figure 31 - Illustration of the expected cognitive load in different drive situations

Different positions on this chart indicate a different driving situation and could require a different allowed interaction with the HUD. Here an estimation should be made of the situation's cognitive load so that combined with HUD interaction it does not exceed the user's cognitive capacity.

These situations can then be combined with the expected level of automation that is currently applicable to that situation, see Figure 32. Then as a result of the automation level (L0 to L1 to L2), HUD interaction restrictions can be made.

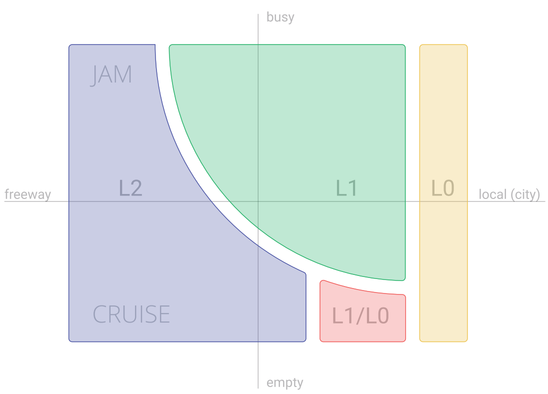

Figure 32 - Illustration of the usage of different automation levels in relation to the traffic situation

Restrictions are envisioned to happen in three different levels, namely:

Limitations: These are specific functions or services not being available within a specific situation. As an example, social media notifications may be inaccessible in L0 drive, or text messages can only be heard instead of read during a city drive.

Suppressions: These are a temporary unavailability of the interactive HUD interface. These will most likely be due to external events, such as suddenly entering a busy intersection, where the driver should pay extra attention to their surroundings. In all suppressions, the current automation level will stay active, but can be overwritten due to driver input.

Warnings: A warning will occur in urgent situations where driver attention is immediately needed. The clearest example here is when the car systems decide L2 should be disengaged and the driver should take control in L0.

According to the above, different restrictions should be set. Below follows an example of suggested restrictions, see Figure 33 on the next page. Some of these restrictions were implemented and tested in the later HMI evaluation test (Chapter 11).

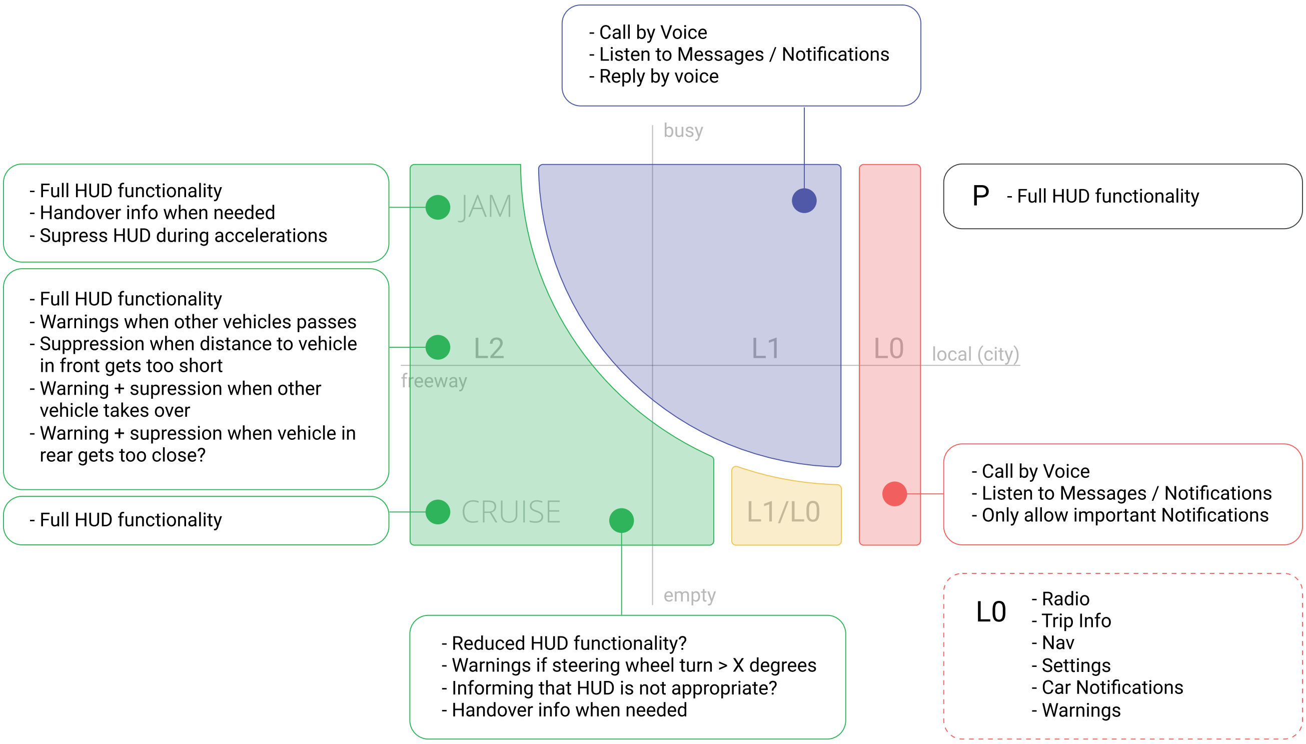

Figure 33 - Illustration showing the suggested situational restrictions

7 UI Ideation

Described in this chapter is the ideation for the final concept's user interface. The aim, and method and design are discussed.

7.1 Aim

An ideation session was held to explore several possibilities for the UI and its behavior, as to be implemented for the final test of this thesis.

7.2 Method and Design

The method and procedure used for the UI ideation in the section below.

7.2.1 How To's

How To's is a method that produces problem statements written in the form of "How to..." (Tassoul & Houdijk, 2005). The problem statements then become open questions meant to stimulate the ideator's creativity. They describe a (sub)problem from different perspectives and provides with a comprehensive overview to the selected problem.

7.2.2 Setup

Different aspects were split up into subproblems, which were then presented in the form of 'How To' questions. Through answering these How To's, different solutions can be generated quickly (Tassoul & Houdijk, 2005). Nine questions were posed and answered in rounds of three minutes through brainwriting and sketching such as in Figure 34.

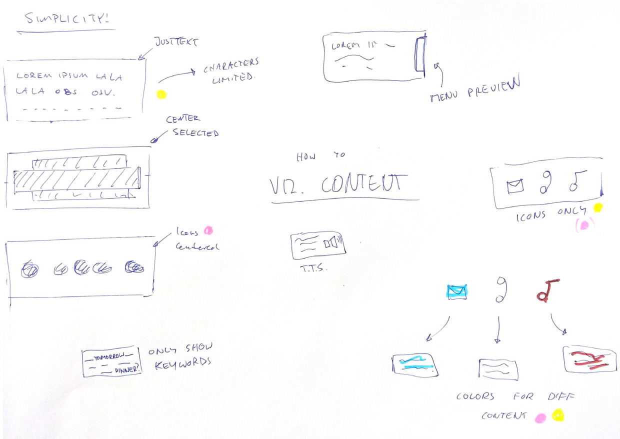

Figure 34 - Picture of one of the produced sketches, including dot voting marks

The posed questions:

- How to show suppression?
- How to show warnings?
- How to show notifications?
- How to visualize content?
- How to navigate the UI in the peripheral vision?
- How to structure navigation?
- How to show hierarchy?
- How to design for unidirectional navigation?
- What to suppress?

Ideas on all subproblems were then dot-voted and discussed to find interesting solutions to explore. From this, a list of possible solutions was generated, which served as a basis for the UI element testing. The to-be-tested solutions follows below.

Scrolling Indication

Different affordances were created to show the possibility of scrolling sideways in the main menu (Figures 35–37).

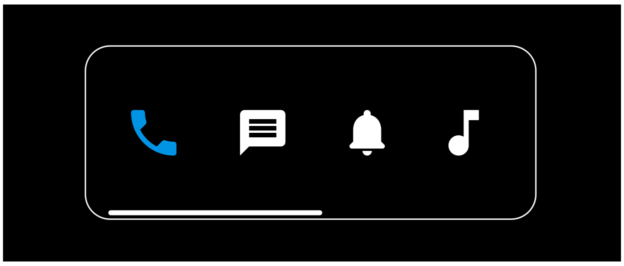

Figure 35 - Scroll bar

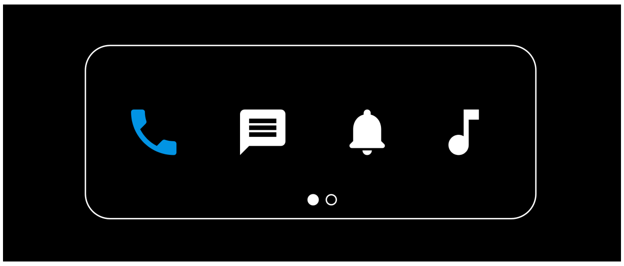

Figure 36- Page indicators

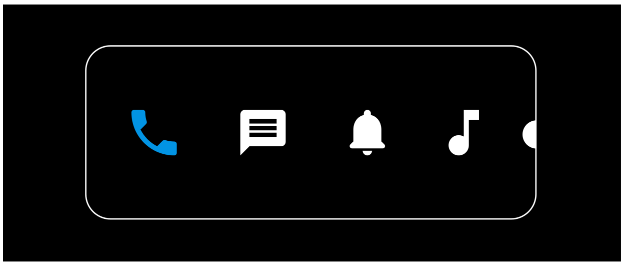

Figure 37- Cut-off dot

Micro interactions

Animating and scaling up the selected icon was tested against selection by color (Figures 38–39).

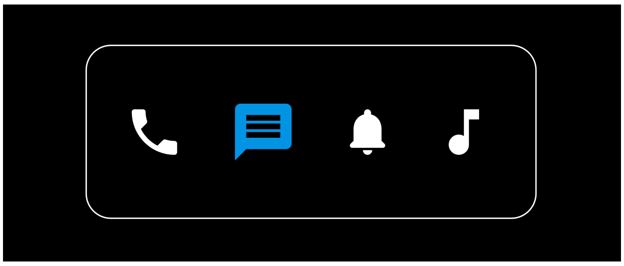

Figure 38 - Animated scaling

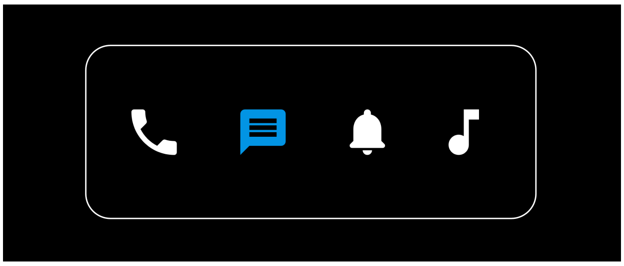

Figure 39 - No scaling, only color

Color Change

A color shift among different menu items and their subsequent structure may be applied (Figures 40–42).

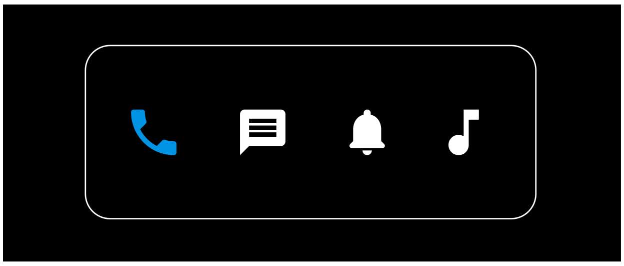

FIGURE 40 - 1ST COLOR

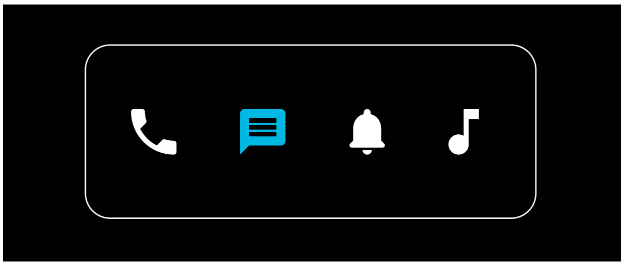

FIGURE 41 - 2ND COLOR

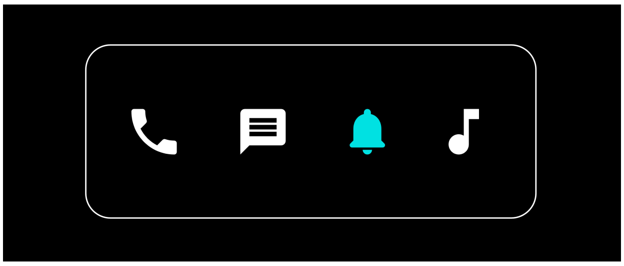

FIGURE 42 - 3RD COLOR

Notification Grouping

Notification icons may be collected per service, or all of them may be grouped into the same icon (Figure 43–44).

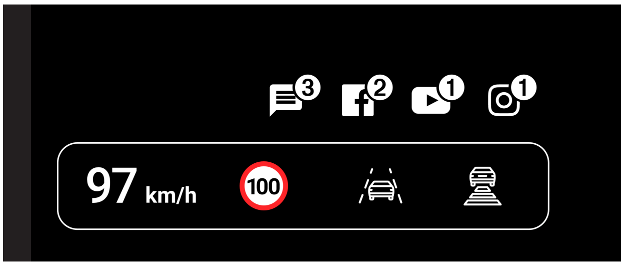

FIGURE 43 - UNGROUPED NOTIFICATIONS

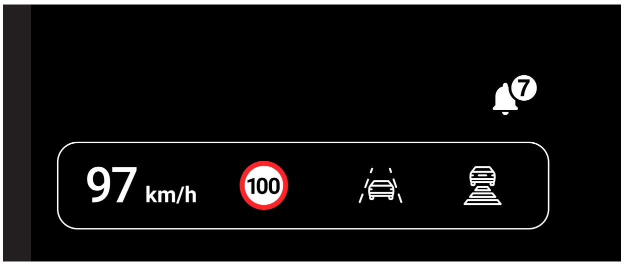

FIGURE 44 - GROUPED NOTIFICATIONS

Contact List Cap

The capital first letter may be displayed to make finding the right person easier as a trade off with a cleaner interface, see Figures 45–46.

Figure 45 - Capital letter displayed

Figure 46 - No capital letter displayed

Suppression Behavior

A suppression could be shown directly with the suppression message, or it could dim the HUD immediatel. In the latter case the message can be shown when interacting with the HUD (Figures 47–48).

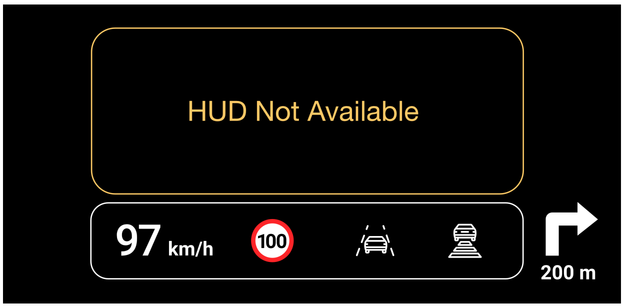

Figure 47 - Suppression message

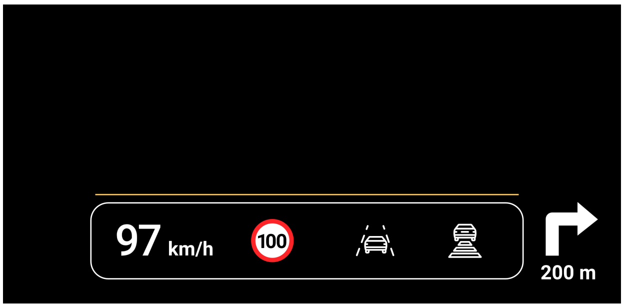

Figure 48 - Direct suppression

Drive Information Panel

It would not be necessary for the driver to be presented with drive-related information such as speed, so there is a possibility to hide that information when using the interactive HUD, see Figures 49 and 50.

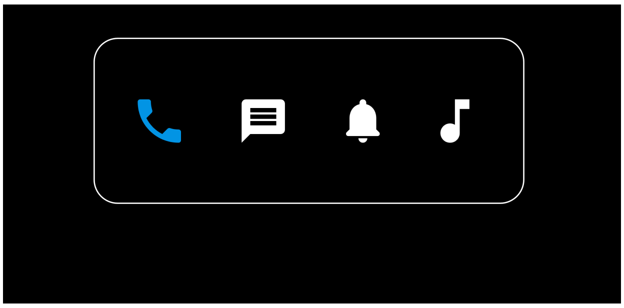

FIGURE 49 - WITHOUT DRIVE INFORMATION PANEL

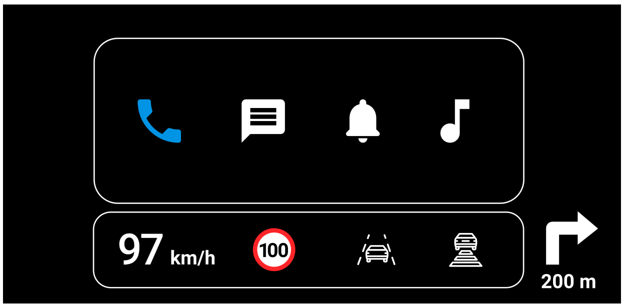

FIGURE 50 - WITH DRIVE INFORMATION PANEL

8 UI Element Testing

DESIGN ELEMENTS FROM the ideation in the previous chapter are put to the test in the UI element test. This chapter describes the aim, method and design and results and suggestions as a result of this test.

8.1 Aim

To decide on the different UI elements, an AB-test was conducted where the different versions of the ideas were tested against each other. The was performed using the previously described Blur method, which is thought to be specifically applicable to comparing UI elements and providing with an efficient alternative to simulated driving.

8.2 Method and Design

This section describes the sample and the setup of the UI element test.

8.2.1 Sample

The sample consisted of four practicing UX designers with experience in working within the automotive industry, making them experts in the field. There were three females and one male, ages 25-35.

8.2.2 Setup

The setup was put up in a small office room, see Figure 51. A TV-screen was used to provide with a background road view. The HUD could be controlled with either buttons on the steering wheel or with a joystick controller. One laptop was used to present the road view and one laptop was running the HUD software according to the Blur test through Framer Classic.

FIGURE 51 - PICTURE OF THE SETUP USED FOR THE UI ELEMENTS TEST

The setup consisted of the following

- A racing game controller consisting of a steering wheel and pedals (Logitech G920)
- A separate controller with a joystick controlling the HUD
- A thin plastic screen mounted on a wooden frame, reflecting the HUD interface.
- A monitor placed below the plastic screen, displaying the HUD interface.
- A laptop running the HUD software
- A laptop viewing the background road view
- An office table and a chair

8.2.3 Test Procedure

The test consisted of comparing the different UI elements created during the ideation session (Chapter 7). Each test was performed with one test leader and one participant. The test leader informed the participant about the purpose of the study and then the test went through 8 parts, where the participants got to try the different UI-elements one by one. After each part, the participants were asked which element they liked/disliked the most and also which principle they thought would be the most suitable in an automotive HUD. The presented UI-elements switched between a blurred and unblurred state in 1,5 second intervals according to the Blur test.

8.3 Results

The results from each test part together with short explanations and motivations are presented below. The Blur method was perceived as a working substitute for simulated driving and promoted elements with best performance within the blurred state.

Micro interactions

The animated scale up of the selected icon was preferred and thought to be the most efficient when navigating the UI in peripheral view. One participant disliked the animations due to a slightly less distinct feeling.

Scrolling indication

The page indicator was initially the most appreciated due to intuitive page representation but after some tries they all expressed that the page indicators became too unclear in blurred mode. The scrollbar won due to better blur mode performance.

Page transition behavior

The animated transitions were preferred over the static ones due to better blur mode performance.

UI colors

The color spectrum was slightly preferred, but it was also noted that different colors could cause contrast problems on varying backgrounds - giving some icons better contrast than others. Since that could be misinterpreted as a hierarchy feature, the color spectrum was not used in the HMI concept. In addition, the participants were asked to pick the color that was the clearest, and as a result a more teal blue compared to the original UI is implemented.

Notifications

The grouped notification style was highly preferred. When presenting several notification symbols at the same time they were perceived as taking too much attention, promoting infotainment too much.

Contact list cap

To present the capital letter in contact lists were highly preferred due to better blur mode performance.

Suppression behavior

The text warnings were preferred due to clarity but there were also discussed that this was likely situationally dependent, where some situations would require text info and some only a redirection of attention. In the end, both versions were implemented in the HMI concept.

Drive information panel

Participants thought it was initially hard to choose but preferred the idea of always having the drive information panel visible at all times.

9 User Task Flow

USER TASK FLOWS (UTF) are a schematic of frames in an interface, how they're related and how the user can interact within the interface. Additionally, it describes the decision the application has to make.

The interface assumes extra interaction affordances throughout the app through a 'back' button returning to the previous screen and a 'long-press back' returning to the main menu. The HUD interface may at times either show warnings, suppress the interface, or limit certain functions as a result of external factors such as unsafe driving situation or situations where a higher cognitive load is required for (assisted) driving.

A simplified version of the frames surrounding the main menu is shown below in Figure 52, including the warning/suppression and limitation feedback loop. The full version, including the frames in the call menu, the messaging menu and social media notifications, can be found in Appendix XII.

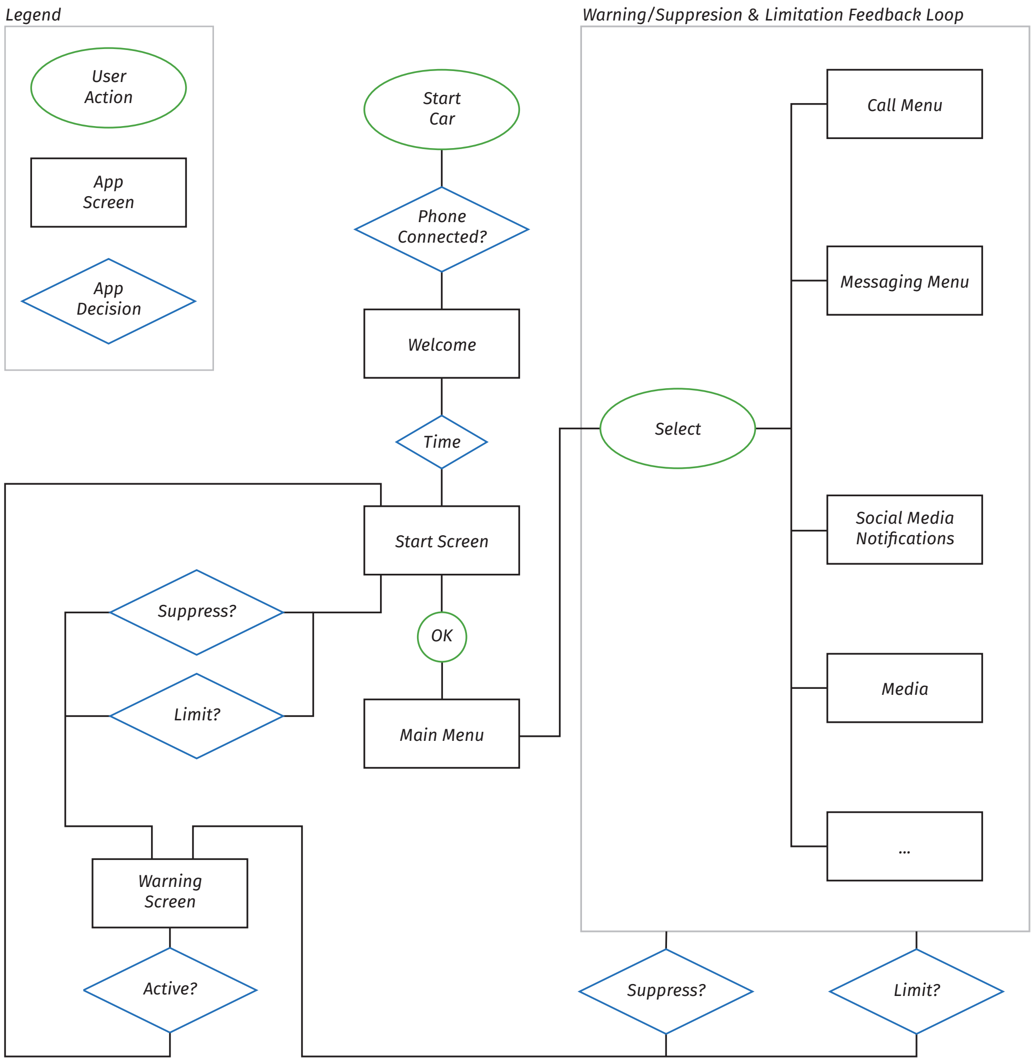

FIGURE 52 - ILLUSTRATION OF THE USER TASK FLOW

During the UI Development section, insights gained from the previous studies were applied and tested through the Blur method.

Visual clarity and clear navigation were proven to be crucial factors for interactive HUD performance. The HUD interaction where shown to benefit from enhancing visual elements through animations and microinteractions.

The final HMI concept developed in this section was a combination of the best performing UI elements and navigation structure.

Final Concept

In this section, the final concept is described. This HMI concept is meant as an embodiment of all the knowledge gained so far. It implements the guidelines that have been stated thus far, adds to them, and generates new guidelines.

Through an extensive user test in a driving simulator with a level 2 Wizard-of-Oz setup, these guidelines and the acquired knowledge is put to the test.

10 HMI Concept

DESIGN OF THE UI is largely based on the previous iterations, applying a similar graphic style to the design. Results from the UI element test from Chapter 8 were applied. Additional frames were created according to testing needs and followed a similar structure to the User Task Flow from Chapter 9. Icon menus were used where it was assumed it would be easier to understand, and lists were text based as before.

10.1 Structure

The layout of the UI is based on two different panels, as can be seen in Figure 53 below. The bottom panel is the drive information panel, which indicates the most important information such as speed, speed limit, and ADAS functions. This panel is very similar to information presented in current HUDs. The ADAS icons reflect the current state of assistance, but the bottom panel is passive and cannot be interacted with. Unless the HUD is turned off, this panel will always be visible while driving.

The top panel is the interactive part of the HUD. This is the panel essential to the scope of this thesis. Functions such as phone calls, text messaging, social media notifications and others may be displayed here. This panel may not always be visible, in contrast to the bottom panel.

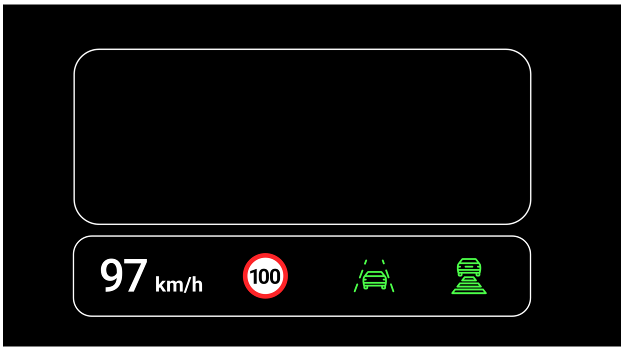

FIGURE 53 - THE TWO UI PANELS

The interactive panel can display a menu, show information such as a current phone call or text message, or an activity such as listening for voice input.

Menus exist in two different flavors, based on their content. The preferred type is for short, understandable menus. These can be displayed solely through icons and adhere to the unidirectional navigation by being navigable horizontally as shown in Figure 54. The second menu type is for longer menus or ones that cannot be (easily) represented by icons, see Figure 55.

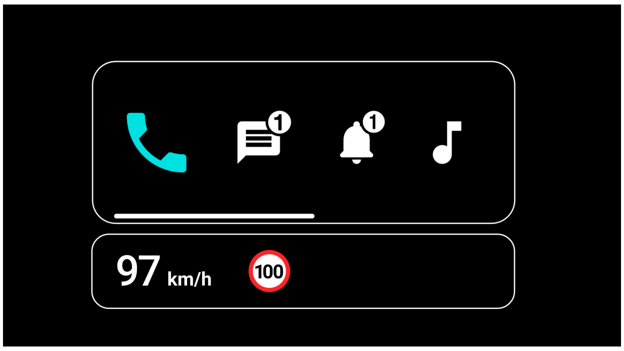

FIGURE 54 - ICON-BASED HORIZONTAL MENU

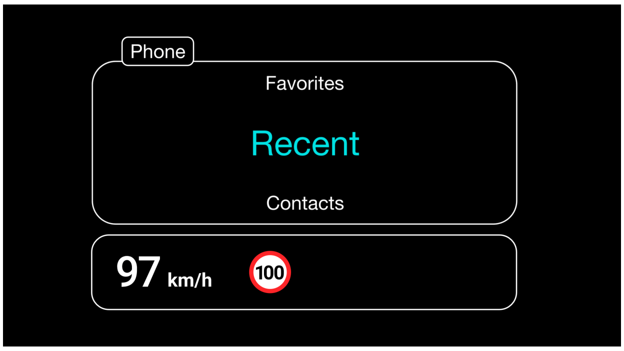

FIGURE 55 - TEXT-BASED VERTICAL MENU

In previous iterations, it was not always clear for the user where in the interface they were. Especially with the introduction of suppressions and warnings this could become an issue once the user is given back control. In order to assist the user in navigational awareness, a box stating the current menu is added on top of the interactive panel, as can be seen in the frames above.

10.2 Content

The main implemented functions are the calling feature, messaging, and some social media notifications. Calling can be done through one of the contact lists. If the shown list is alphabetic, an additional capital letter is shown to help navigation, see Figure 56. By selecting a name, a call will be placed as shown in Figure 57. An accompanying sound is played indicating a call is made.

Figure 56 - List of contacts

Figure 57 - Calling screen

Several messages are implemented in the prototype. As can be seen in Figure 58, short, conversation-style messages are represented in a similar way to phone interfaces, giving the user a familiar feeling. In contrast to phones, no colors are used, as they should be reserved for important functions (as found before). Longer messages are also available, see Figure 59, and for testing purposes can be replied through with voice command as shown in Figure 60 and 61. After a reply has been given, the conversation is updated to reflect the reply.

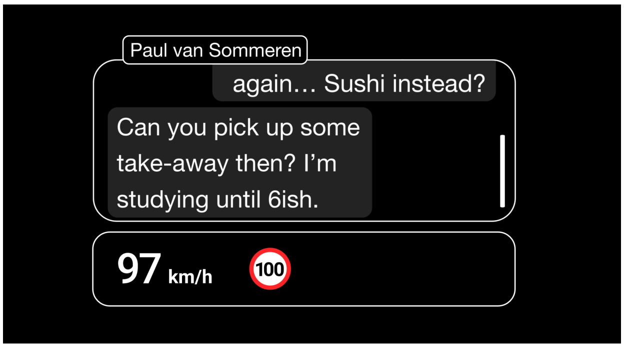

Figure 58 - Conversation structure

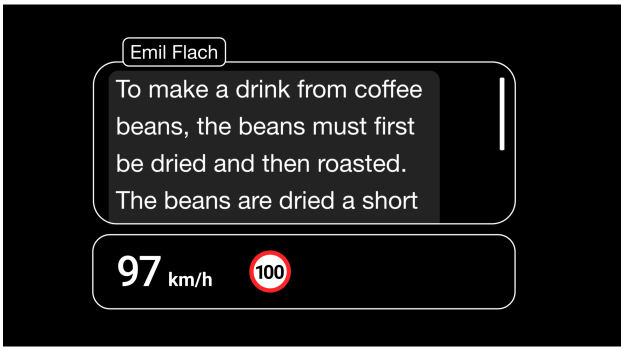

Figure 59 – Presenting a longer message

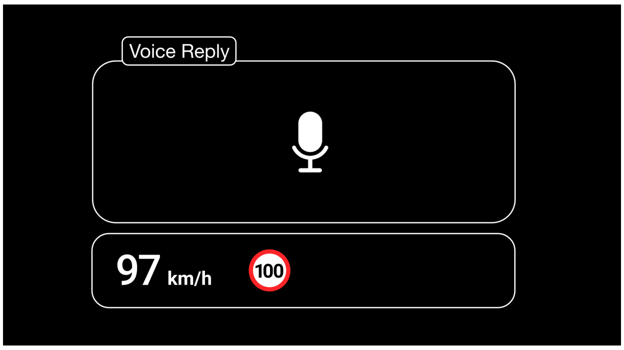

Figure 60 - Voice recording

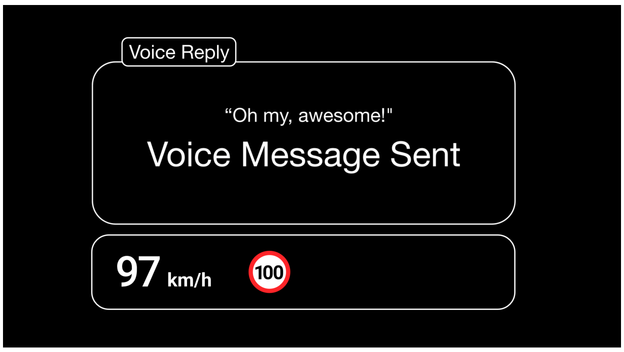

Figure 61 - Voice confirmation

Social media notifications have been implemented on a lower fidelity. In the prototype, only Instagram notifications can be opened and read (Figures 62–63).

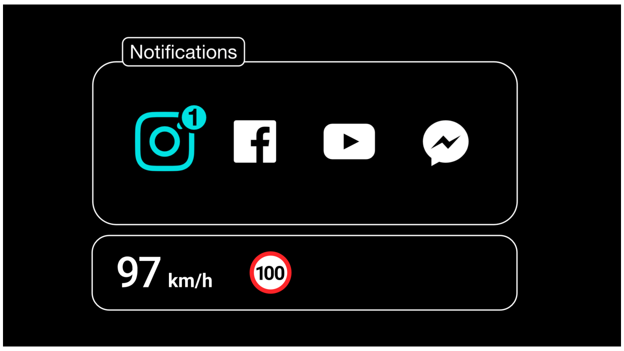

FIGURE 62 - NOTIFICATIONS

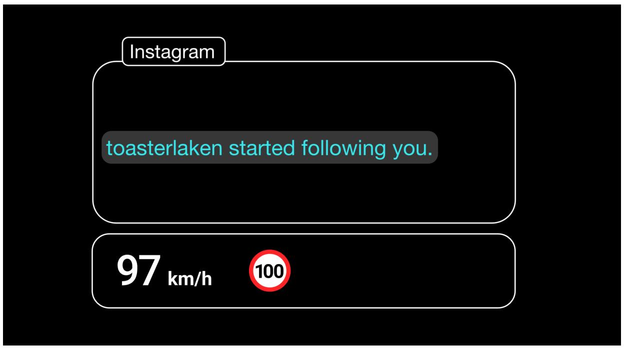

FIGURE 63 - INSTAGRAM NOTIFICATION

10.3 Behavior

As an input from the Blur method evaluation (Chapter 4), a small tick sound is implemented for navigational input (i.e. directions, select and back).

The default state for the HUD interface is only the static panel. Once the user chooses to interact with the HUD, the interactive panel shows up. If a notification is received, this notification is displayed above the static panel to indicate that the interactive panel may be opened, see Figures 64 and 65. By not giving this a border it is expected for the user to not interpret this visual as an interaction by itself. Receiving a message with any frame active plays a short notification sound and loads a new long message.

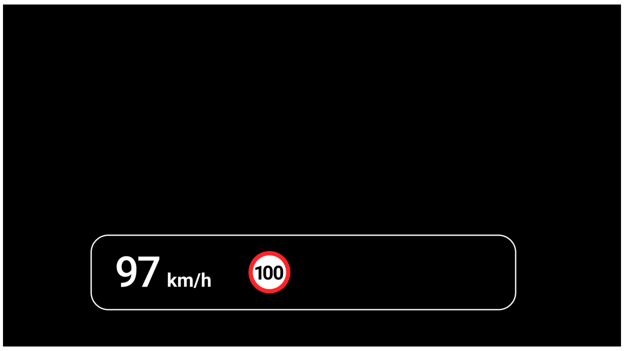

FIGURE 64 - NO NEW NOTIFICATIONS

FIGURE 65 - TWO NEW NOTIFICATIONS

As a result of the situation, the interactive HUD may be suppressed (Chapter 6). Initially the current screen will only be dimmed, and an orange line is shown, see Figure 66. This is done as to not draw the user's attention to the interface. If the user decides to interact with the HUD, a suppression message is temporarily shown as in Figure 67, explaining the reason of suppression.

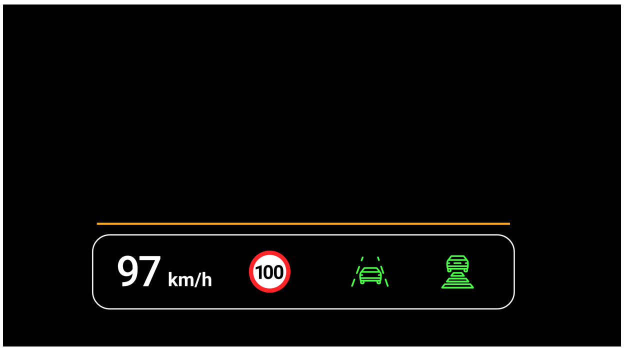

Figure 66 - Direct suppression

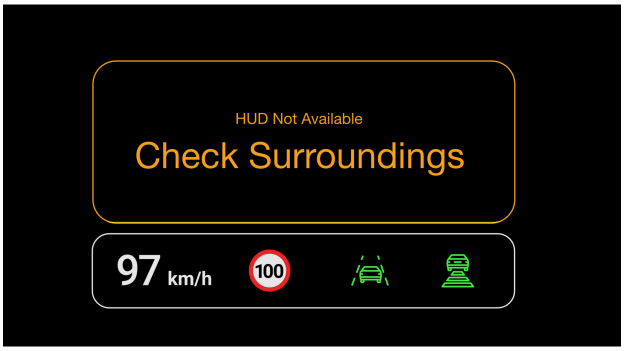

Figure 67 - Suppression message

An additional suppression that was shown was an indication for navigation, see Figure 68, as it is expected that current L2 will not make navigational decisions and as a result user input is needed. This suppression would time out automatically.

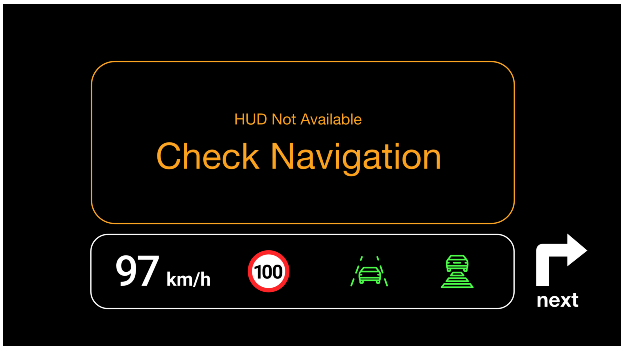

Figure 68 - Navigation message

Warnings are presented in a similar way to suppressions but give a message immediately as the user should understand the message as soon as possible, see Figures 69 and 70. In the prototype this message has a time-out but is expected to react to user input (e.g. physically taking control) in actual implementation. The warning message is accompanied by an error sound as to grab the user's attention even more.

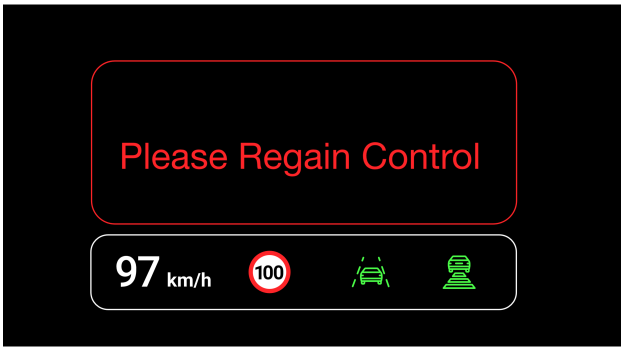

FIGURE 69 - PLEASE REGAIN CONTROL WARNING

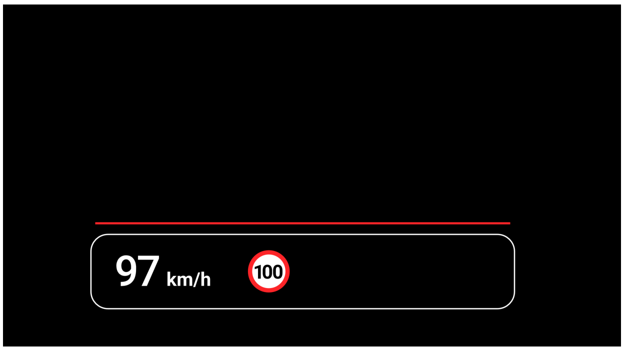

FIGURE 70 - RED WARNING SUPPRESSION

At any point during the drive the user may attempt to activate ADAS functions to go into a L2 mode. The interactive HUD may be suppressed before this is done and may be unlocked afterwards depending in the situation (Chapter 6). The active ADAS functions are, as mentioned before, shown in the drive information panel. For this prototype, both the ACC and LKAS are (de)activated simultaneously.

11 HMI Concept Evaluation

This chapter contains the setup, testing, and evaluation of the final HMI concept. The methods for evaluation are described and the conclusion, recommendations and discussion can be found here.

11.1 Aim

A drive simulator study was conducted in order to evaluate the HMI concept, see Figure 71. The study had several goals.

Test goals:

- To validate the HMI concept.
- To produce a proof of concept of an interactive HUD during optimal conditions*.
- To evaluate the interaction with the HMI concept while driving with L2 ADAS functions.
- To evaluate how drivers will perceive and react to different types of warnings and suppressions.
- To collect further insights on expected car-phone behavior.

* The optimal conditions were defined as performing known tasks on the HUD while driving in daylight with clear weather conditions on an empty freeway with L2 ADAS systems turned on.

Figure 71 - Picture taken during one of the HMI concept evaluation tests

11.2 Method and Design

This section discusses the methods used for testing, the design of the simulator setup, and the implementation of the Wizard-of-Oz setup.

11.2.1 Usability Testing

Usability testing (Van Boeijen et al., 2014) is used for validating user interaction with a selected artefact. This thesis acknowledges usability according to the ISO 9241-11 definition, i.e. "the extent to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" (ISO, 2018) .

Setting up usability tests involves creating a realistic situation or scenario with tasks for the users to perform within a certain context while being observed by researchers documenting the test. Usability tests can be used for both formative and summative research. Results can be quantitative, qualitative or combined depending on the setup and selected measures.

11.2.2 UEQ

The User Experience Questionnaire (UEQ) by Laugwitz et al. (2008) is a questionnaire meant to cover a comprehensive impression of a user's experience of a tested artifact. The questionnaire consists of 26 antonyms and comes with set instructions and tools for analysis.

11.2.3 Sample

The sample was a convenience sample with the requirement of having a valid driver's license for cars and normal or corrected vision. Two pilot tests were performed. In total 12 people participated, 4 females and 8 males, ages 25-63.

11.2.4 Test Procedure

Before the test, the participants were informed about the purpose of the test and was instructed to find a proper driver position. The HUD look-down angle was individually adjusted for each participant to 2.5 degrees to the interactive HUDs upper frame boundary, positioning the entire UI between 2.5 - 5 degrees below the driver's line of sight, according to the results of the look-down angle test (Chapter 5).

The test started with a practice session where participants were introduced to the HUD, the drive simulator, and the L2 ADAS system. The participants were given time to practice the parts until they themselves expressed that they were in control, this to rule out potential issues with learnability.

After the practice session, the participants were instructed to drive through three preselected routes. During the drives, participants were instructed to use the ADAS functions and perform given tasks through an interactive HUD running the previously described HMI concept. The participants were informed that the ADAS system, when turned on, would try to keep a safe distance to vehicles and objects in front, as well as keeping the vehicle centered within the lane at all times. They were also informed that the system would not switch lanes automatically and that the participants could do that themselves without turning off ADAS. The initiation of the ADAS was done by the participants through a dedicated ADAS on/off button. To provide with a realistic experience, a press on the button produced a suiting sound and made ADAS symbols appear/disappear on the HUD.

The test roles were defined as wizard and test leader The wizard was simulating the L2 system and controlled HUD warnings and suppressions, and the test leader gave instructions, sent notifications and interviewed the participants after each drive.

Driving tasks

The test consisted of three routes with different traffic conditions and tasks.

The first route represented the optimal conditions and consisted of a freeway drive without any traffic. During the drive the participants were instructed to make a phone call and triggered by an incoming notification to read a message with the HUD.

The second route introduced HUD-warnings and suppressions. The route started on a trafficked freeway and the participants were then guided through directions in the HUD towards a 2-lane highway. While driving on the highway the HUD produced warnings and suppressions when entering potentially difficult situations, such as intersections, and when vehicles in front came too close.

The third route introduced the please regain control warning. The route consisted of a highway drive, leading towards situations where two lanes merged. Since the ADAS was not thought to be able to handle this the participants got a please regain control warning shortly before the lanes merged.

UI tasks

Two specific UI tasks were tested, one user triggered, and phone/HUD triggered. The user triggered task was to call a specific person and required that the participant navigated to the phone menu and selected the correct person to call from one of the contact lists. The phone triggered task was to react to an incoming notification. The notifications were designed to be text messages and for each incoming notification, a new text message was presented. The participants were instructed to read all incoming messages and send a voice reply afterwards. Other presented UI parts such as social media notifications, music and settings were clickable but without implemented actions. During each drive the participants were subjected to a combination of the tasks. During warnings and suppressions, the interactive part of the HUD was temporarily collapsed with all interactions put on hold.

11.2.5 Validation methods

The users experience of the HMI concept was validated using both the short and the long version of the User Experience Questionnaire (UEQ)(Laugwitz et al., 2008), together with specific ranking scales and a set of predefined interview questions.

The short version UEQ was used for validating the interactive HUD concept during optimal conditions. The UEQ were filled in by the participants directly after the first drive.

The long version UEQ was used to validate the HMI concept as a whole and was performed by the participants after having completed all three drives. The UEQ used was altered with some questions excluded due to irrelevance. The excluded questions targeted novelty and were not thought to provide much value within this test. For the list of questions used see Appendix XIV.

Ranking scales were used to measure the perceived sense of safety and control after each drive - providing with a quick indicator of the participants experience of increased traffic and HUD suppressions and warnings.

The interview questions were used to gain further insights on the participants experience, allowing the participants to reflect over their experiences and other related aspects, such as expected phone behavior. For the full list of questions used, see Appendix XV.

11.2.6 Simulator Setup

The test was conducted in an office supply room, see Figures 72 – 76 on the next page. The main setup was similar to the one used during the angle evaluation test, but for this setup, two racing game controllers were used. The L2 functions were simulated through a Wizard-of-Oz setup with one of the test leaders performing the actual driving using the secondary set of controls behind a screen. The race game controllers were both connected to the same simulator software through modifications in the configuration files. Custom parts for connecting the wheels were modelled in CATIA V5 and 3D printed, see Figure 74. In order to simulate a realistic steering wheel feedback, the steering wheels were connected to each other through a string-based system, see Figure 76.

The setup consisted of the following:

- A projector for the simulator software
- Driving simulator software (Euro Truck Simulator 2 + Scandinavia expansion).
- Two complete racing game controllers (Logitech G920, Logitech G27)
- Connecting parts for the game controllers
- A joystick controlling the HUD software
- A thin plastic screen mounted on a wooden frame, reflecting the HUD interface
- A monitor placed below the plastic screen, displaying the HUD interface
- A laptop running the HUD software
- Two keyboards controlling the HUD software
- A laptop running the simulator
- Office tables and chairs
- Equipment for recording video and audio

Key measures

— Screen size	2×3 m
— Distance to screen	4.20 m
— Virtual HUD distance	2.25 m
— Height of the horizon	1.0 m
— HUD look-down angle	2.5 degrees

Figure 72 - Picture of both setups

Figure 73 - Picture of the setup from the participant's view

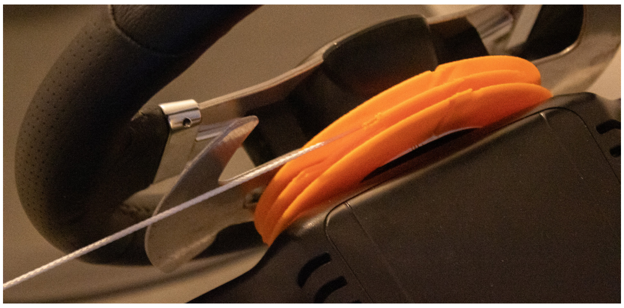

Figure 74 - Close-up of the 3D-printed parts for connecting the steering wheels

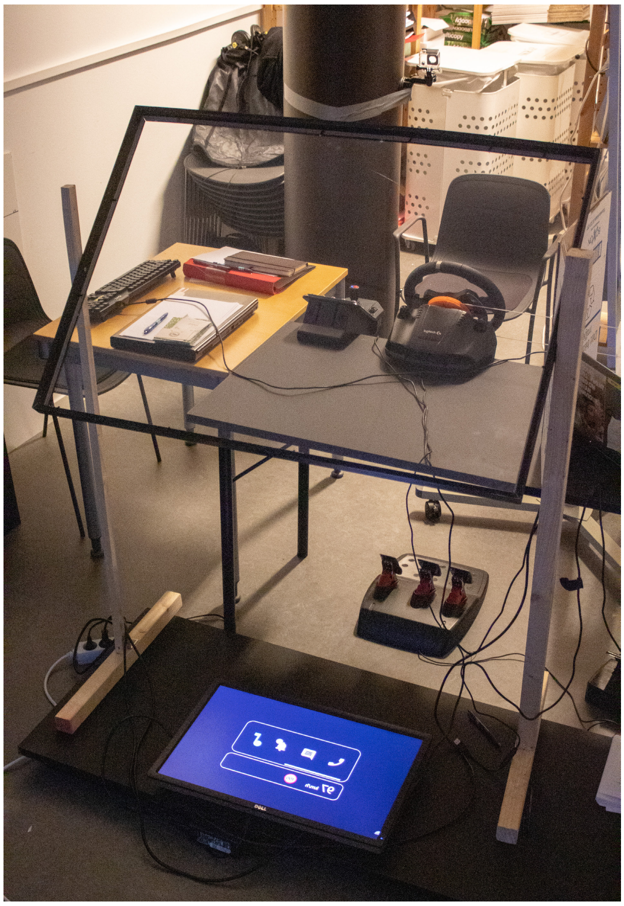

Figure 75 - Picture of the HUD and reflection screen

Figure 76 - Picture showing the connected steering wheels from above

11.3 Results

As discussed in this chapter results were evaluated through formative comments, safety and control ratings, and the User Experience Questionnaire. The section discussed the results from these different evaluations.

11.3.1 Formative Comments

From the interview sessions the following results and insights could be drawn.

Optimal Conditions

During optimal conditions the HMI concept was very well received with the participants giving it almost exclusively positive comments. Some of the received comments were “Nice!”, “HUD was fine”, “Easy to understand”, and “Simple”. Among the negative comments some were directed at the joystick controls and some were directed at the appearance of individual icons. Some participants noted that the navigation structure required many steps in some situations, for instance when locating a person in a long contact list.

All participants appreciated the presented functionality with many suggesting that it had everything you would need in a driving context. Some participants suggested added functionalities such as Twitter, radio, a digital clock and text input. Some participants requested the possibility to remove unwanted apps and functions to be able to customize their HUD interface.

Navigation Warning

The navigation warning was well received by all participants. It was an appreciated feature, believed to be useful for not missing an exit.

Suppression

The suppression warnings got a mix of positive and negative comments. Most participants liked the idea and appreciated that the system tried direct their attention where needed. The main critique came from participants stating that they did not understand the reason for the suppressions and therefore did not know how to react to them. Some found them annoying and unnecessary and some found them to be too subtle - requesting brighter colors and flashes.

Most participants expressed that the suppressions made them feel safer. One participant wanted more information in order to feel safe and one participant expressed a feeling of decreased safety due to not knowing how to react. The mentioned participant also expressed a will to only get suppressions or warnings when the system requests an action from the driver.

When it came to the sense of control most participants expressed that the suppressions increased their feeling of control with some mentioning that it increased their awareness and made them focus more on the surroundings. Some stated that it made them feel less in control in a positive way since it reduced the risk of trusting the system too much. Some said that it made them feel less in control due to confusion and the fact that the system acted without being told to.

For a short conclusion, most participants appreciated the idea of the system trying to redirect their attention where needed but, in this scenario, it wasn't always obvious why it tried to do so, which lead to confusion.

Control Warning

The Please Regain Control warning was very well received. All participants tried to take control of the vehicle when being given the warning and it was described as “clear”, “obvious” and “easy to understand”. One participant failed to take control but that was caused by a setup failure, presenting the warning too late giving the participant insufficient overtaking time. The results from that drive were taken out of the analysis.

The HMI Concept

After going through all drives the participants were asked questions connected to their perceived value of the concept as a whole.
All participants but one expressed that they would like to use the presented concept in their own car if it was available. The person that would not want to use it thought that the concept did felt safe and controlled in its existing form but was worried that the safety could be jeopardized over time when an increasing amount of developers tries to push their apps to the system.

All participants thought that the concept would be a sufficient substitute for their phones while driving. Some added performance demands, for example "If easy to connect" or "If voice recognition works well enough". All participants also expressed that they had not felt the need to use their own physical phone during the test.

HUD-Phone connection

When it comes to expected phone behavior all participants expressed that the HUD should handle all incoming notifications, sounds and media when connected, and that the phone should be either muted, put to sleep mode or be temporarily turned off. Many also expressed that they would be annoyed by getting notifications from several sources and that the phone being passivized could be an acceptable safety feature.

They all expected the phone to be connected through Bluetooth or similar wireless connection. Many pointed out that the connection should be done automatically when they were alone in the car and ask if there were passengers, this to avoid connecting to the wrong phone, which would be annoying, or to risk disclosing unwanted information to the passengers.

All participants thought that they would accept not being able to use their phone while connected. Some participants added performance demands such as "As long as the system is 100% working" and some that it had to be easy to disconnect. It was believed that the phone it could be faster to make an emergency call with the phone rather than the HUD. One participant accepted not being able to use it but questioned why, pointing out that the HUD should be so good that the phone did not felt needed.

11.3.2 Safety and Control

Participants were asked to evaluate their sense of control and their sense of safety on a scale from 1-7 after each drive. These answers were used to get an indication of the effectiveness of suppression and warnings and overall test fidelity. Some entries were taken out as a result of to accidents occurring due to participant inexperience with the simulator or Woz fault.

Participants felt both safe (5.2) and in control (5.4) in general. The first drive was perceived the most safe and controllable. The second drive was perceived the worst for both, and the third in the middle. The values can be seen in Figure 77 below.

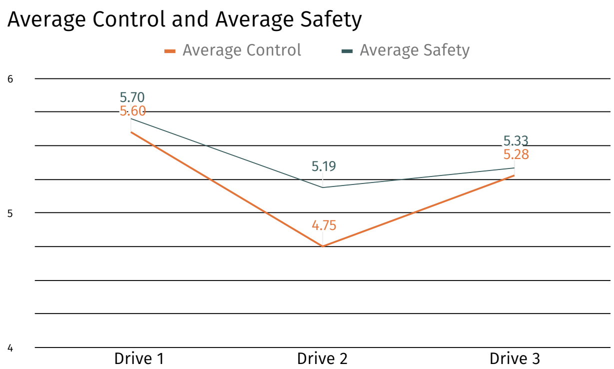

Figure 77 - Participants ratings of their perceived safety and control

The first drive scores the best as expected, as there was no traffic and no suppression or warning occurred. This situation illustrates the ideal use of a HUD and is perceived well. After the introduction of suppression in certain situation the sense of safety and sense of control dips but regains some value after the third test.

This is explicable because the participants did not get acquainted with either suppression or warning signals and may have been surprised as a result. For the third drive they knew what they could expect and how to deal with the situation accordingly. It is expected that this value is the most applicable of the three drives.

From the formative comments it can be concluded that participants appreciated the warnings, especially when they would get used to the messages and it when they would appear. They also mentioned that they would feel both safer and more in control as a result of the warnings. This makes it more likely that the lowered ratings are an effect of the traffic and new situations.

11.3.3 User Experience Questionnaire

The UEQ is a method to evaluate User Experience. It is a quick and reliable version to measure UX of interactive products (Hinderks, Schrepp, & Thomaschewski, n.d.). Two versions of the UEQ were held during the test. The short version was filled in by participants after the initial drive, and the full version was filled in after the whole test. The full version had some items omitted because the axis of Novelty was of lesser interest. Both versions of the questionnaire can be found in Appendix XIV. The UEQ comes with a benchmark, which compares the results with over 14,000 people from 280 studies regarding different types of products.

After the first drive, after which the participants have experienced driving unobstructed in L2, the HUD and L2 experience was rated 'above average' (at least 0.5 percentile) in both pragmatic and hedonic quality according to the UEQ benchmark. The results on these axes are shown in Figure 78.

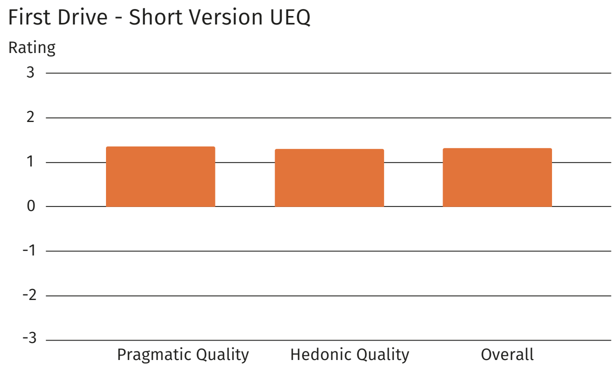

Figure 78 - Results from the short version UEQ, targeting the optimal conditions

According to the benchmark, values above 0.8 should be considered positive. Pragmatism scores as 1.35 and hedonism as a 1.29, for an overall score of 1.32.

The full questionnaire was filled in after suppressions and warnings had been experienced. As discussed in Safety and Control, participants went through a slight adjustment curve through these and were asked to evaluate their full experience over all three drives. The results per axis can be seen in Figure 79 below. The pragmatic axis consists of perspicuity, efficiency and dependability, the hedonic axis consists of stimulation and novelty. Attractiveness is a separate scale.

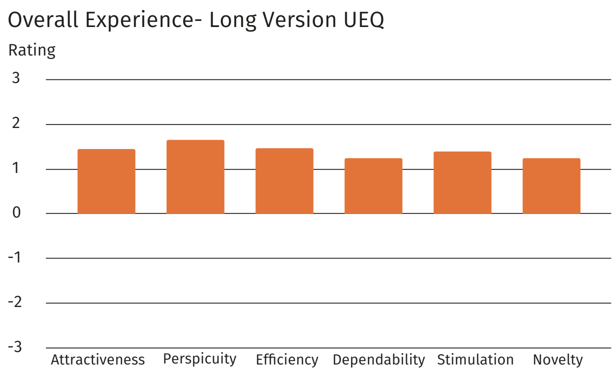

Figure 79 - Results from the long version UEQ, targeting the overall experience

Results are similar to the short version, with all axes scoring above 1.2. All values can be considered positive as they score above 0.8. According to the benchmark, perspicuity, efficiency, stimulation and novelty score as 'good' (at least 0.75 percentile) and attractiveness and dependability score as 'above average' (at least 0.5 percentile). Despite the small sample size, the concept's results are significantly positive ($p<0.05$) on the attractiveness, perspicuity, efficiency, and simulation scales. No outliers were found in the data, indicating an understandable questionnaire and serious responses (Schrepp, 2019).

11.4 Conclusion

The HMI concept overall got a highly positive receival from the participants. The interactive HUD as an HMI concept worked well during L2 driving and was experienced as both safer and more efficient than using a handheld phone.

The UI performed well and was perceived as simple and intuitive but for some tasks it required a high number of navigation steps. A working voice assistant should though be able to solve most of these issues, providing with a one-command shortcut to many wanted actions.

The suppressions were appreciated as a concept but has to be made clearer, either through more informative suppressions or more predictable behavior. As presented in the test they produced too much uncertainties to be seen as a successful design.

The warnings for navigation and please regain control both performed well and got a positive receival. Though it should be noted that additional feedback, such as vibrations in the steering wheel or short brake indications to further alert the driver could be applicable.

According to the UEQ the overall HUD experience can be considered a success, as it was considered 'positive' on all axes due to their score above 0.8. All axes scored at least a 0.5 percentile compared to the UEQ benchmark, with 4 scoring at least a 0.75 percentile.

The rating scales showed a predictable pattern and indicated that the feeling of safety and control are likely to increase with gained experience of the system and situation. That the last drive was getting a high score would despite testing the most critical situation further indicates that the please regain control warning performed particularly well.

11.5 Discussion

L2 Simulation

The L2 simulation was a critical factor for this test. Since the experience of the HMI concept very much depends on the participants experience of L2 driving, the simulation had to produce a realistic and trustworthy L2 experience to give valid results. In order to achieve that, the test implemented the most important key elements and eliminated the less important one. Automated steering with steering wheel feedback was implemented through the string system and worked very well in providing a proper steering experience. To keep a certain speed and hold an exact distance to surrounding vehicles were too hard to implement properly and was therefore eliminated by informing the participants that the system would only try to keep a safe distance and speed at all times and that it was nothing to worry about. Due to that, the simulators speedometer was taken away since it would otherwise risk creating suspicion about the L2 behavior. Finally, letting the participants be in control of the L2 on/off button and experiencing a realistic sound and visual feedback also added to the experience.

All participants expressed that the L2 system felt realistic and some participants were actually tricked to believe that it was a programmed mechanical system controlling the vehicle when L2 was turned on.

At some points the wizard failed to keep a safe distance, leading to the vehicle coming dangerously close and occasionally bump into vehicles ahead. This did affect the trust in the system and also the outcome of those particular tests. Some entries were taken out of the results due to that.

Safety and Control

A question that will arise in most simulator setups is how applicable the simulator is with respect to reality. It is described above that in general the L2 was convincing, but it is still possible that there is a simulator effect. It is unsure how big the extra sense of safety is in the simulator, and how this affected participant behavior. It is possible that participants paid more attention to the HUD than they would in an actual situation, and as a result had less situational awareness.

Because the participants were asked to rank both their sense of safety and sense of control in this situation, the above effect applies to these rating scales as well. This makes it likely that the scales are overestimated compared to actual driving, but the learning pattern might still occur between different situations.

During the test, the participants were instructed to perform certain tasks, such as calling a specific person or reading a text message that they had received. This makes the test more evaluative of the UI, and less of the participant's behavior in a real situation. A cognitive underload was likely not experienced, as the participants were performing tasks the majority of the time. The authors recommend follow-up studies on how the interaction with the HUD would change if these interactions were self-initiated due to boredom.

Lack of Side View

In this setup it was not possible for the participants to look to the sides. This affected the simulation, especially by making it much harder to enter highways and crossings. In an optimal situation there would have been screens on the sides as well, but that brings a higher risk of simulator sickness, and puts a higher demand on the simulator fidelity. It might have produced a more realistic feeling for some participants but since the crucial parts of the HUD experience were tested on freeways and highways, the lack of side view was not likely to have an effect on that. It might though have had an effect on the general perception of safety and control and could therefore be part of the reasons to the drop on those factors in the second drive.

The UI Element test (Chapter 8) was done with a setup were the participants could control the UI through buttons on the steering wheel. This test was done with a joystick controller due to hardware limitations. The HUD interface has not been tested for dependency on the physical input type, which has a potential effect on the use. A reason could be the movement of the steering wheel during L2 drive, or better or worse button placements in different configurations.

During earlier tests it was mentioned by several participants that they would likely use voice commands in similar interfaces. These voice commands would eliminate the majority of navigational input and, if the voice command is good enough, make it easier for users to perform certain tasks.

UI Content

The major text-based tasks performed during the test were text messages, and to a lesser extent social media notifications. These two information sources were initially stated as the scope but have not been explored separately except for the UI design. It would be worth it to investigate if they're different on a cognitive-load level, how they're interacted with and how they should be handled individually to craft the best possible experience.

Coloring of Logos

Most brand guidelines states that their logos must only be presented in the specified brand colors or possibly with added black or white versions. The HMI concept's current navigation style, showing its position through coloring the logo would then be a violation to most brand guidelines. It could be argued that HUD colors should be an exception due to their functional rather than aesthetic purpose, but it must still be noted that implementing brand logos could be seen as violating the brand guidelines for some companies.

UEQ

The UEQ had positive results on all qualities. This may be interpreted as very positive, but it can also be argued that not all values should score high. The interactive HUD's task is to replace interaction that would happen on the phone. In that regard it should only slightly be more stimulating to use than the phone. The experience of novelty might attract more use than a phone would, and despite it being safer to use, pose a higher risk due to increase usage time.

Another possible limitation is the balance between the pragmatic and hedonic values. As one of major aspects is safety, it would be okay to trade hedonic values for pragmatic ones. This can be tested in comparison or through iterations but should be kept in mind.

The UEQ's application stimulates spontaneous answers, without thinking too much about the specific meaning of the antonyms. In these spontaneous moments, it is possible that different participants make distinctions between just the UI, the simulator experience, or their expected experience while filling in the questionnaire. Despite the results being significantly positive, this effect could be minimized through an increased sample size.

The HMI concept presented in this section was tested in a level 2 Wizard-of-Oz setup. The evaluation was made through the User Experience Questionnaire, UEQ, and interviews with the participants.

The test was a success with high scores on the UEQ, proving that it was well functioning, efficient, had clear logics and provided with a good user experience. The test confirmed the findings from the UI development section.

During the interviews it was shown that the concept was perceived to enhance the experience of the car rather than being a limitation to the phone. The HMI concept was thought to be a proper substitute to a phone while driving and the participants also expressed that they would accept their phones to be blocked from physical usage while connected to the HUD.

Guidelines

As the main goal and the culmination of this thesis, all generated guidelines are presented in this section. These guidelines are created to be a foundation for future interactive heads-up displays, and is directed at both researchers and designers in the field.

12 The Interactive HUD Guidelines

THESE GUIDELINES ARE created with the purpose of providing guidance for designers and researchers within the automotive field when designing for interactive HUDs. They are based on the research presented in this thesis, complemented with best-available research where needed.

The guidelines add to existing guidelines such as guidelines provided by NHTSA (Campbell et al., 2016) and the Alliance of Automobile Manufacturers (2006). They are focused on the human-machine interaction with the aim to increase performance, user experience and safety for drivers using an interactive HUD. The guidelines aim to support the driver's cognitive underload through activities on an interactive HUD as an alternative to use their phone. These support the stated goal of making the use of nomadic devices in cars obsolete. Existing standards and research do not consider the effect of L2, specifically the lower cognitive load, and need to be updated regarding the driver's expected behavior. As a result of the above, the implementation of some of these guidelines might lead to violations of principles in existing standards, especially regarding acceptable usage, content and interaction times for in-vehicle devices.

As guidelines are dependent on multiple situations, some guidelines may become redundant when implemented along others. In these cases, it is up to the designer's or researcher's discretion to consider both and make a balanced decision.

These guidelines make a distinction between two applications of the HUD; passive and interactive. A passive HUD is meant to support driving functions, such as speed indication and ADAS indicators. An interactive HUD is meant for secondary tasks, such as entertainment and messaging, and can be interacted with while driving.

The key words "must", "must not", "should", "should not", "recommended", and "may" in this document are to be interpreted as described in RFC 2119 (Bradner, 1997), which can be found in Appendix XVI. Whenever 'navigating' is used, this means navigation within the UI, unless GPS navigation is specified.

The guidelines presented in four categories: content, interface, physical and phone. The individual guidelines are ordered within their category to reflect importance, but the overall categories are not. Guidelines are color coded based on their respective study according to the following legend:

- Cultural Probes
- Context Mapping
- Peer Ideation Session
- Blur Method Evaluation Test
- Look-down Angle Evaluation Test
- UI Elements Test
- HMI Concept Evaluation
- Referenced Studies

HUD Content

This set of guidelines provides guidance on the content of the HUD, i.e. what information should be available, what functions should be accessible, and what should not be shown.

The information and interaction available on an interactive HUD should be situationally dependent

It is crucial that the available information and interactions are dependent on the cognitive load and situational risk, with content being limited to the risk of making mistakes or the severity of consequences. The amount of available interactions should be dependent on the expected risk, based on the situation and the estimated driver's cognitive load. Examples of potential low-risk situations are low-traffic highway drives with L2 or queueing in traffic jams.

HUD content should change or disappear based on situational needs

HUD content should adapt to upcoming events to direct the driver's attention where it is needed. For example, HUD content may disappear when a vehicle in front brakes or gets closer than a set distance.

Content restrictions may be done through function limitation, suppression or active warnings.

Based on the situation, content should be restricted to create safer driving circumstances. Proposed in this thesis are:

— Function limitation (not allowing certain functions such as long texts)
— Suppression (temporarily disabling the complete interactive HUD)
— Active warning (overriding the HUD with a warning message)

HUD content availability should be dependent on active automation functions.

The active automation functions can be an important indicator of the driver's cognitive load and predict the amount of attention the driver can direct to the HUD. These functions should be part of deciding what content is available.

Incoming notifications may selectively be displayed

Incoming notifications should be ranked in levels of priority (Bång & Hillding, 2018b). Notifications should then be displayed or suppressed depending on their priority level in different situations. For example, notifications of the lowest priority may only be displayed in low-risk situations such as queuing in a traffic jam.

Notifications may be delayed depending on the situation

If certain driving situations require extra cognitive load, notifications should be suppressed temporarily as to not overload the driver. When the required cognitive load has lowered, notifications may be presented as new.

Drive information should be displayed in addition to the interactive HUD

Drive information as presented in the passive HUD gives the driver a better sense of control, as well as affirm the responsibilities as a driver. It increases the driver's feeling of security and familiarity since drivers are used to having speed and relevant drive information visible at all times.

The driver should be able to choose from which apps to allow content or interaction within the HUD

The HUD should only present information of personal importance. The driver should therefore be able to choose which apps can be interacted with through the HUD. Important note: the selection should only affect the available content, but situational dependency should decide what interaction is allowed.

Traffic situations may be used to predict or assist use

Traffic information gathered from car data or online data may be used to alter the HUD interface to assist the driver. For example, alternative routes may be presented when nearing a traffic jam, or a message may be displayed when the user needs to take an exit ramp.

HUD Interface

This set of guidelines tells how the user interface can be designed for, how the content can best be presented, and additional visual guides.

HUD interfaces should enable navigation within the driver's peripheral view

Navigation within the peripheral view is desirable since it minimizes the driver's eyes-off-the-road time. As a consequence, HUD interfaces should be designed to facilitate this as much as possible.

HUD interfaces should only present the most relevant information

To create an efficient interaction and minimize eyes-off-the-road time, stripped interfaces with only the most relevant information are preferred (Figures 80 - 82).

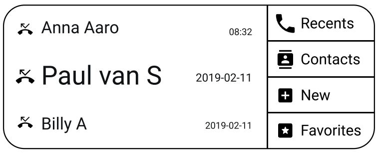

Figure 80 - Too much information

Figure 81 - Less information

Figure 82 - Preferred

Colors should be used solely to show hierarchy in the UI

Since performance is a major factor in HUD use, colors should solely be used for functional reasons. Suggested colors are white for general interface, turquoise for selection. Functional car warnings and errors should be shown in orange and red respectively (Figures 83 – 85).

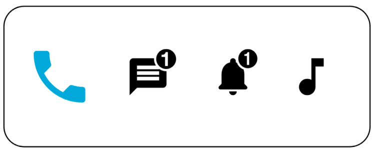

Figure 83 - Proper use: selection

Figure 84 - Proper use: warning

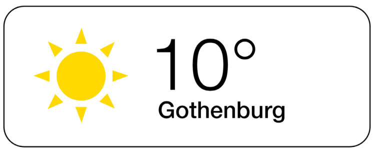

Figure 85 - Improper use: aesthetic

- ### *Icons should be used where possible*

Icons are easier and quicker to interpret than text (Tubik Studio, 2016). In order to help the driver process information better, icons should be used where possible (Figures 86 – 87).

FIGURE 86 - TEXT-BASED WARNING

FIGURE 87 - PREFERRED: ICON-BASED WARNING

- ### *UI navigation should be unidirectional*

Navigation should be unidirectional (Bång & Hillding, 2018b). Multidirectional navigation is more demanding and as a result affect performance. Horizontal and vertical navigation should not be used within the same screen. See examples in Figures 88 – 82 below.

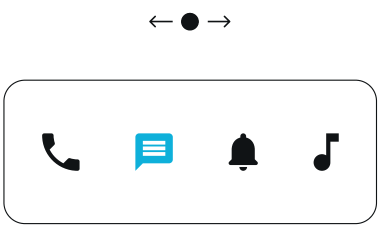

FIGURE 88 - HORIZONTAL NAVIGATION

FIGURE 89 - VERTICAL NAVIGATION

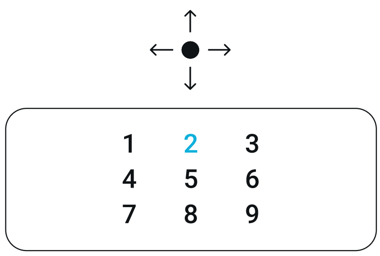

FIGURE 90 - IMPROPER USE: MULTIDIRECTIONAL

- ### *Haptic input modes should match navigation through the UI*

HUD interfaces perform better when the haptic input modes match navigation through the UI. The interpretation of mismatched haptic inputs is more difficult in situations with a higher cognitive load, such as using the HUD while driving.

- ### *Animations and micro interactions should be used to enhance understandability*

Both animations and microinteractions can be used to indicate hierarchy and reflect user input. These will help the user understand the interface more easily.

Additional audible or haptic feedback should be used for HUD interaction

HUD interfaces perform better when audible or haptic feedback is used in addition to visual feedback. The additional feedback clarifies interaction and enhances navigation within the driver's peripheral view.

The current location in the UI may be indicated in the UI

To help the user understand the current UI frame, the current menu's name may be shown in a dedicated place, see an example in Figure 91. This is especially helpful after a suppression, when the driver could regain control of the UI.

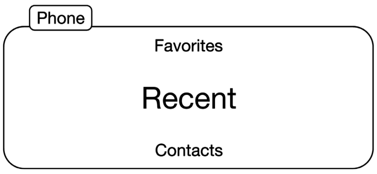

FIGURE 91 - UI WITH LOCATION PRESENTED

Items such as notifications may be grouped to avoid clutter

A clean, understandable UI is essential. In order to avoid clutter, notifications from different sources may be grouped under a single item. See a comparison in Figure 92 and 93.

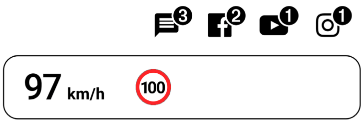

FIGURE 92 - UNGROUPED NOTIFICATIONS

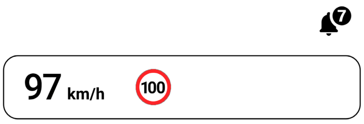

FIGURE 93 - GROUPED NOTIFICATIONS

Interactive HUDs should match expected phone behavior where applicable

Predictable structure and logic will help the driver understand the HUD better. In accordance with Jordan's Compatibility principle (Jordan, 1998), the HUD can be designed for matching phone behavior. This may not be applicable to all situations, as input methods are different and certain functions may or may not be available.

An enlarged capital letter may be placed in alphabetic lists to aid quick navigation

Long lists can become hard to navigate quickly. An enlarged capital can help the driver to navigate quickly while observing the HUD in the peripheral vision. Additional methods may be implemented to navigate quickly through different letters.

Voice control should be considered for short commands

Voice control can increase efficiency and should therefore be considered as a complement to physical controls.

Voice should be available as an input method for messaging

To avoid having to write messages, voice should be available for speech-to-text or sending voice messages.

HUD Physical

This set of guidelines indicates how HUDs should be physically placed to allow for the best interaction.

● ***Interactive HUDs should be placed 2.5 - 5 degrees below the driver's line of sight***

The area between 2.5 - 5 degrees below the driver's line of sight, as illustrated in Figure 94, is optimal for both driving and secondary task performance. This area offers the best possibility to either navigate the HUD interface or monitoring the road in peripheral vision while focusing on the other. In positions below 5 degrees of the driver's line of sight it is no longer possible to perform driving and HUD interaction simultaneously, which forces the driver to switch between the tasks repeatedly. This behavior is more similar to HDD use and should only be considered if presenting passive information such as speed. The area between 2.5 - 5 degrees below the driver's line of sight is optimal for both driving and secondary task performance. This area offers the best possibility to either navigate the HUD interface or monitoring the road in peripheral vision while focusing on the other. In positions below 5 degrees of the driver's line of sight it is no longer possible to perform driving and HUD interaction simultaneously, which forces the driver to switch between the tasks repeatedly. This behavior is more similar to HDD use and should only be considered if presenting passive information such as the speedometer.

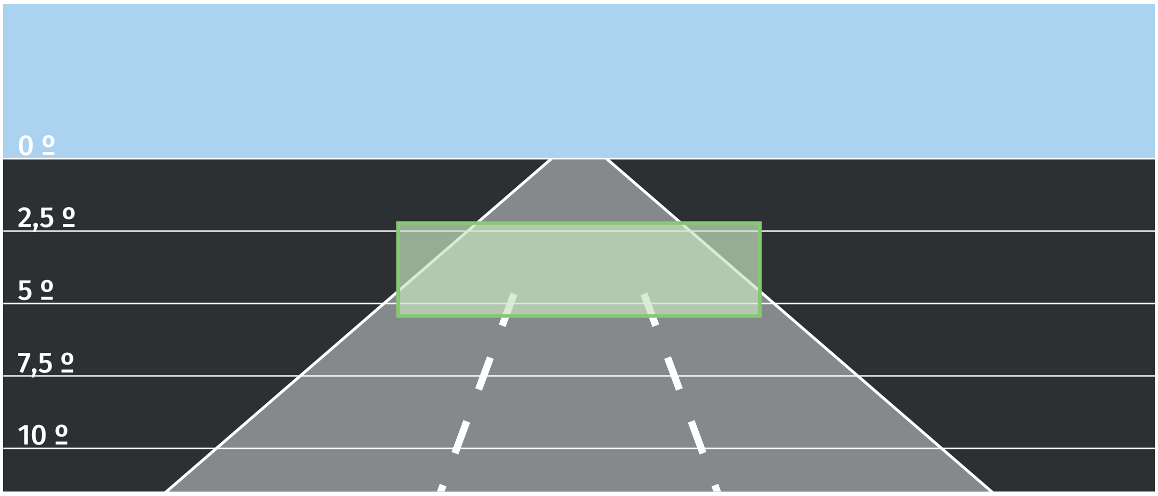

Figure 94 - Illustration showing the optimal HUD position area

●●● ***HUD interfaces should be positioned to not visually interfere with road events***

HUDs that interfere visually with road events, such as traffic signs or other cars, could lead to delayed or missed detection of these events (Yoo et al., 1999) and should be avoided. This may be situationally dependent, as for example a traffic jam could allow for minor interference without significant performance loss.

Phone

This set of guidelines indicates behavior directly related to the phone, and its relation to the HUD.

The HUD should be seen as a temporary extension of the phone

The interactive element of the HUD should function as an extension of the phone, not a separate system. The HUD should facilitate functions that are handled from the phone, as to give the driver the feeling that the HUD temporarily facilitates the driver's phone needs. Additionally, phone data should not be stored in the car system to emphasize this temporary aspect.

The HUD should be the only input and output when connected to the phone

A properly designed HUD should be safer to use than a phone while driving. Therefore, the HUD should be considered as being the only way to interact with, for both incoming and outgoing services.

Notifications on the phone itself should be disabled when connected to the HUD

Notifications on the phone are a major trigger for phone use. When connected to the car, notifications on the phone itself should be suppressed as to not incentivize the driver to pick up their phone.

The phone may be blocked from usage when connected to the HUD and the driver is alone

To help the user in making the right modality choice, the phone may be blocked from usage. A prerequisite is that the functions a driver would use are also available on the HUD. In any case the driver should be able to disconnect from the HUD in blocked state, at their own responsibility.

The driver should be able to choose whether the phone is paired with the system

The driver should have the choice to connect or not connect to the car system for any reason. A message such as 'Connect to phone?' on the HUD may be implemented to allow the driver to choose.

The phone should be able to connect automatically

Handoff from the phone to the car should be as smooth as possible. In a similar way to current systems, the driver should not have to use to phone settings to connect (given that for example Bluetooth is on).

The car may send unhandled notifications to the phone after driving

Notifications that have been suppressed, delayed or unopened during the drive may be send to the driver's phone so that they do not get the feeling that they potentially missed something.

Ending

Conclusion

LEVEL TWO AUTOMATION has been shown to lower the cognitive demands on the driver to operate vehicles. As a result, drivers may experience a cognitive underload during driving. This may incentivize the driver to pick up and use their phone as a result. A proposed solution in this thesis is the development and implementation of an interactive heads-up display that replaces the functions of the phone.

It was found that heads-up displays have been well researched, but the research for interactive heads-up displays is virtually nonexistent. This thesis was adapted accordingly to explore different aspects from a user experience perspective, a user interface design perspective, and test method development.

Different user studies confirmed the user's felt need to use the cell phones while driving, and the dangerous situations this might create. Users were involved in documenting and analyzing their own behavior and helped in identifying solutions through co-creation.

The Blur method has been prototyped, put into testing, and evaluated. It was found to be an effective way of qualitatively evaluating UIs for (interactive) HUDs, as it sufficiently simulates alternating focus between the road and the HUD. Quantitatively it was found similar in task completion time to both the industry-standard Occlusion method and simulated driving, although more research is needed to finetune blurring intervals and blur level for best representation. The Blur method has been put into practice to evaluate different UI elements, where it has proven added value in designing for HUD UIs.

The look-down angle from the driver's line of sight was shown to be an important factor in the performance of tasks in the HUD. Three possible placement angles have been found, namely: an optimal HUD angle between 2.5° and 5° down from the driver's line of sight; an unrecommended angle between 5° and 7.5° where the driver has a false sense of security in HUD use and performance deteriorates, and; angles below 7.5° where the HUD has no real benefits and shows similar behavior to a traditional HDD.

All knowledge has been brought together in an HMI concept with a HUD in an L2 Wizard-of-Oz setup. Qualitative data from the test has been used to add to the guidelines and give recommendations on improving the HMI. The User Experience Questionnaire showed significantly positive results ($p<0.05$) on the attractiveness, perspicuity, efficiency, and simulation scales, as well as scoring 1.46 on pragmatism and 1.32 on hedonism.

The thesis comes together in 32 guidelines in four categories, based on the research performed. The guidelines serve as a basis for designing a HUD that combines a safe, efficient interaction with an enjoyable user experience. The guidelines can assist in solving part of the problem that is the result of the cognitive underload that can be experienced in L2 automated drive.

The authors recommend that designers and researchers will take a holistic approach to interactive HUDs and understand the intricacies and complexities that the many variables involved bring to such a system. The guidelines presented can be considered a basis for the process of bringing together different aspects. Interactive HUDs have thus far not been sufficiently researched, and it is expected that more knowledge will be contributed to this field, as the guidelines presented in this thesis have.

Discussion

THIS THESIS HAS provided new knowledge and has produced guidelines for designers and researchers when designing for interactive automotive HUDs. It has evaluated a new method for comparing UIs for interactive HUDs and evaluated HUD position and look-down angle. It has also identified phone related needs and evaluated an HMI concept in various simulated L2 driving scenarios.

Many questions have been subject to discussion that will be of value for future development of interactive HUDs, as well as help the reader understand possible limitations of the study.

Forward Focus

One of the insights from this study is that the use of an interactive HUDs draws the driver's attention to the front of the vehicle. This pattern will occur regardless if the driver is mainly focusing on the road view and peripherally navigating the HUD or–the opposite–if the driver is mainly focusing on the HUD, using the peripheral view to keep track of main events on the road view.

Even though this behavior is likely safer than focusing on a handheld nomadic device, it comes with implications that should be considered for creating safe driving behavior.

The main drawback with putting too much attention on the front area of the car is that the driver's awareness of the surroundings decreases. This could lead to the driver failing to detect objects approaching from other directions. The risk increases for objects that are harder to detect, such as approaching motorcycles and bicycles. The risk also increases in demanding traffic situations such as crossings, near schools and playgrounds, and roads with a high occurrence of wildlife.

This poses higher demands on the vehicle's safety systems. For vehicles that feature interactive HUDs, the systems may have to be adjusted to involve a larger detection area and more actively direct the driver's attention where needed.

The Look Down Angle Evaluation

It is shown that the area of 2,5 – 5 degrees from the driver's line of sight is the optimal position for interactive HUD, both due to HUD UI performance and drive performance, but there might be situations where other positions still would be preferred. One example is when standing in a traffic jam with a short distance to cars in front, the HUD could then benefit from a lower angle due to less visual interference.

An important note regarding the look-down angle evaluation is that it is partially simulator dependent. The validity of the angles depends on the setup, where the screen size and eye-to-screen distance decides the testable angle range. For the test setup described in this report, no angles below 10 degrees would be valid since that would mean that the driver would be looking below the screen. For look-down angles below 10 degrees, another type of setup might be required to give a proper simulation of the driver's closest road view, the area between 0-5 meters in front of the driver's position.

Safety Potential

The interactive HUD can be used to affect driving behavior in many ways. The possibility to control when to present HUD content can preferably be used as a means to increase the distance between vehicles during highway drive. By suppressing the HUD if a vehicle in front gets closer than a specific distance, the driver would have to keep a certain distance be able to use the HUD. Hereby the need for staying connected could be used to promote a safer behavior.

Warnings for regaining control could also be made more efficient if placed in the HUD. Not only is it easier for the driver to redirect attention to the road due to faster eye focus adjustments, it is also easier for the vehicles safety systems to get the drivers attention when knowing where the driver's focus likely will be.

Tasks lengths/interactions

The NHTSA visual manual guidelines include set times for how secondary tasks should be designed to be acceptable. The guides are based on the interaction behavior that occurs when a driver repeatedly glances at an interface on the instrument panel during L0 driving:

> *"The NHTSA Guidelines recommend that devices be designed so that tasks can be completed by the driver while driving with glances away from the roadway of 2 seconds or less and a cumulative time spent glancing away from the roadway of 12 seconds or less." (National Highway Traffic Safety Administration, 2014)*

These guidelines are very much applicable for L0 driving. The problem is that the use of an interactive HUD does not follow the previously described glance behavior. On a correctly positioned HUD, the driver is able to switch focus faster between the UI and the road view. The driver is also able to partly navigate the HUD or keep track of major events on the road through the peripheral view. This leads to another type of interaction behavior where the driver is able to focus on the HUD interface for longer time periods while still being able to track the road.

These differences in interaction behavior show that the NHTSA guidelines are not adapted for interactive HUDs and need to be updated. Since NHTSA also does not consider the difference between L0 and L2 driving, the guidelines need updates in that area as well.

The findings from the work presented here suggests that interactive HUDs might require longer task times to be able to create a proper interaction experience. Being able to read longer texts, scrolling through conversations and lists of contacts is likely necessary for making an interactive HUD a sufficient substitute to a phone while driving.

Longer tasks on an interactive HUDs are not likely to be acceptable during L0 driving and possibly not in all L2 driving situations either. In many situations during L2 driving, especially when supported by HUD integrated safety systems, the interactive HUD has potential to both be safer and provide an improved driver experience.

Especially in understimulating situations, such as driving on low-traffic highways for a longer time periods with L2 automation, the HUD can help the driver to stay alert and reduce the risk of boredom that could lead to the driver picking up their phones.

There are several issues with handheld nomadic devices. They take away attention from driving, decreasing the driver's chances to detect rapid changes in the road view and increasing the time needed for regaining control. In an accident, the car's movements or the release of an airbag easily turns the nomadic device into a dangerous projectile, potentially aggravating the consequences of the accident.

Research Setting

The study features desktop drive simulators as a main test method. This brings limitations that should be considered. The HMI concept has not been tested or tried out in a moving scenario. This could bring unknown effects to some people such as driving sickness. Vibrations could also be perceived as disturbing when reading longer texts.

This also means that it has not been evaluated when the driver experiences the needed concentration connected to complicated drive situations. This increased complexity could affect both the experience and the perceived value of the interactive HUD.

Interactive HUDs in Trucks

The study has taken a general approach to interactive automotive HUDs, implying that the findings should be applicable for cars and trucks. The user studies included car and truck drivers, and both car and truck driving simulators have been used. Even though the general approach is desirable it should be noted that the simulators had more similarities to a car than a truck, especially regarding the driver's moving patterns.

Compared to cars, trucks typically feature increased cabin movements resulting from the trucks larger mass and differing suspension techniques. It also features different moving patterns due to the common feature of a suspended driver's seat - making the truck driver move up and down in relation to the windscreen while driving. Another difference is that trucks often features close-to-vertical windscreens, creating other demands on the HUDs technical requirements and possible projection techniques. The guidelines and the HMI concept are equally applicable for both cars and trucks, but additional research and development is needed to make the physical HUD in a truck perform equally well.

Light and contrast

The HMI concept has only been tested in controlled environments with sufficient light and contrast between HUD and surroundings. In other scenarios the environment might lead to contrast issues and the HUD might need to be adjusted for that. Different light modes might be needed, for example decreased/increased brightness for different situations and adjusted colors for different landscapes or night driving. For instance, the white main color might be less suitable in bright roads.

Sample sizes

All drive simulator tests in this study features sample sizes between 10-12 participants. NHTSA recommends a 24 participants minimum (National Highway Traffic Safety Administration, 2014) and ISO a 10 person minimum (ISO, 2017b). The decision to for a lower sample size than NHTSA recommends, while otherwise referring to the NHTSA guides and procedures is connected to the type of study and time-frame. The tests in this study are explorative and not meant to prove a specific design, making a 24-participant sample size overly rigorous and unnecessarily time consuming. ISO suggests that a 10 person sample size is sufficient and a study by Pournami et al. (2015) have shown that a 10 person ISO sample cohort of a 24 person NHTSA sample produces consistent results. Therefore a minimum 10 participants sample size was chosen for all drive simulator tests. 12 participants connects to having a controlled randomized task order, where 12 participants is the least amount needed for 4 controlled randomized tasks.

Blur method

To benchmark and evaluate the Blur method was one of the thesis' objectives and since the Blur method evaluation (Chapter 4) showed promising results, it was also used as a tool for testing the UI elements (Chapter 8). As expected, blurring did promote UIs that performed better in blurred state. The clearest example of that was the design of the scrolling indication, where all participants initially liked the page indicator dots better but then changed their minds and picked the scrollbar due to better blurred state performance. This type of behavior shows that the Blur method made a difference and can preferably be used as a tool for designing better HUD interfaces.

In the performed tests, the code for blurring the UI was put directly into the prototype using the coding implementation of Framer Classic. Since this is not possible in most prototyping software, and since

Framer Classic is currently being phased out in favor to Framer X, a dedicated software for blurring the screen should be developed. That software should then work independently, as a screen overlay to other apps, which would make the method more approachable.

Safety

This study builds on the principle that phone functions are safer to use in a HUD than a handheld device while driving, and that the introduction of L2 automation systems will increase the usage of handheld devices due to a lowered workload and increased driving monotony.

Within those frames the HUD is likely to be safer. In a wider perspective questions remain whether the HUD is the safest available alternative and if the HUD can be made safe enough.

There are several issues with handheld nomadic devices. They take away attention from driving, decreasing the driver's chances to detect rapid changes in the road view and increasing the time needed for regaining control. In an accident, the car's movements or the release of an airbag easily turns the nomadic device into a dangerous projectile, potentially aggravating the situation.

The HUD provides a potential solution for decreasing the time needed to regain control and detect changes in the road view while performing secondary tasks.

In the comparison of HUD versus a handheld device, the HUD is safer, but compared to not using the HUD and solely focusing on the road while driving it may not be, and there might be better solutions than the HUD that this study has failed to explore. For instance, devices for blocking signals and forcing nomadic devices to be unusable while entering the car could be alternative solutions, even though it would likely be an impairment of the user's experience and bring other unwanted consequences to the driver's behavior.

Given the circumstances that people are inevitably going to use their handheld devices while driving, the HUD can be designed as a safer substitute and has the potential for additional safety features.

Blocking physical phone usage while connected

During the HMI concept evaluation test (Chapter 11), the participants were highly positive towards blocking the phone from physical usage while being connected to the HUD. It is presented as a guideline due to the clear response, but it is solely based on interview data and has not been tested in a realistic context. It should also be noted that it likely depends on how the drivers perceive the interactive HUD UI. A well-functioning HUD UI that fully meets the drivers needs and expectations is likely the distinguishing factor for accepting the phone to be blocked from physical phone use while connected

Recommendations for Future Work

Further research on the physical HUD controls needs to be conducted - especially with regarding how L2 driving affects different types and position of controls, with guides on how the controls should be designed to meet demands of both cognitive and physical ergonomics in different situations and use times.

An MVP based on the guidelines should be developed and implemented in an actual vehicle HUD. The system should then be tested under more realistic conditions, first at a controlled site and later in real traffic.

Research should be conducted with the purpose of defining acceptable types and length of interactions for interactive HUDs during L2 driving. These results should be added to the existing guidelines provided by NHTSA and ISO.

Tests and procedures, similar to the currently used Occlusion or LCT test, for proving that a task is acceptable in an interactive HUD should also be developed and made available for designers and researchers of interactive HUDs.

A standardized test procedure and a dedicated software for performing the Blur test should be developed and made available for designers and researchers of interactive HUDs.

More research should be conducted on the effects of cognitive underload to interaction behavior. Throughout this study, tasks were given to participants which made them perform goal-driven behavior. It is possible that this behavior changes if drivers interact with a HUD due to cognitive underload, as more explorative behavior could be observed.

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Appendices

Appendices

Appendix I: Probe Design

Hej!

Vi heter Billy och Paul. Vi studerar båda teknisk design på Chalmers och detta är en del i en förstudie för vårt examensarbete. Arbetet handlar om hur människor använder mobiltelefoner vid bilkörning. Vårt mål är att ta fram säkrare sätt att göra detta på.

System för bilkörning måste vara säkra men också användarvänliga. För att kunna åstadkomma detta samlar vi nu information om hur folk använder sina mobiltelefoner idag.

Det är där vi behöver din hjälp!

Vi vet att det finns ett starkt behov av att använda mobiltelefoner och att det även finns situationer där människor vill och ibland triggas att använda sin mobiltelefon under bilkörning.

Det vi försöker ta reda på är hur dessa situationer uppkommer och vad det är som triggar dem. Som en del av det har vi tagit fram den här dagboken.

Under den kommande veckan vill vi att du fyller i dagboken i samband med att du kör din bil. Fanns det situationer under körningen där du lockades att ta upp din telefon? Vad hände? Berätta.

Sekretess

Vi är mycket väl medvetna om de tabuer, lagar och regler som finns kring mobilanvändning under bilkörning men vi har också sett att det finns situationer där människor fortfarande känner ett behov av att ta upp sin mobiltelefon.

Denna dagbok och all information i den kommer att behandlas med full sekretess. Den kommer endast att användas för vår analys och dina svar är helt anonyma - de kommer inte att kunna kopplas tillbaka till dig på något sätt.

Vi hoppas att du därmed känner dig trygg med att du kan dela med dig av dina erfarenheter på ett ärligt sätt.

Om något känns oklart är det bara att fråga. Våra kontaktuppgifter finns precis här under.

/Paul & Billy

Billy Astorsson
+46 70 232 88 76
billya@student.chalmers.se

Paul van Sommeren
+46 70 91 97 538
paulv@student.chalmers.se

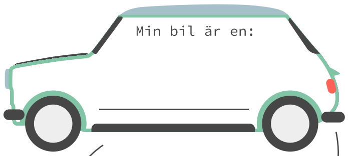
Det här är din dagbok!
Innan vi börjar skulle vi vilja veta lite mer om bilen du brukar köra och de system du brukar använda. Finns det saker du verkligen gillar eller ogillar när det gäller din bil?

Efter detta kommer ett exempel på hur vi tänker att ett dagboksinlägg skulle kunna se ut. Har du telefonen i fickan eller på en hållare i bilen? Använder du röstkommandon för att styra din telefon? Fick du ett kul sms? Om du tycker att det är intressant tycker vi det också! Låt oss få veta!

Min Bil

Min bil har
- ☐ Cruise control / Farthållare
- ☐ Adaptive Cruise control
- ☐ Stop-and-go cruise control
- ☐ Lane assist
- ☐ Hands-free steering
- ☐ Manuell växellåda
- ☐ Automatlåda
- ☐ Annat...

Jag använder också
- ☐ GPS-navigator
- ☐ Android Auto/ iOS Carplay
- ☐ Handsfree
- ☐ Kabel för ljud
- ☐ Bluetooth
- ☐ Annat...



Detta tycker jag inte om med min bil:

Detta gillar jag med min bil:

Fylls i före körning Klockslag 08:05

Datum 29/1

Innan jag satte mig i bilen idag använde jag min mobiltelefon till att..

Jag skickade ett sms till en kompis och satte på lite musik på spotify. jag parkopplade mobilen med bilstereon via BT.

Fylls i efter körning Klockslag 09:05

Fanns det situationer under körningen när du kände för att använda din mobiltelefon? Vad hände och vad gjorde du? Försök beskriva precist, så om du fick ett meddelande - skriv vilken app, om det innehöll text/bilder/video etc.

Telefonen plingade till och jag blev nyfiken på om det var min kompis som hade svarat. Jag tog upp telefonen vid ett rödljus. Hon hade skickat en bild på dagens outfit via snapchat. Det blev grönt rätt fort så jag hann tyvärr inte svara henne.. Jag har en telefonhållare på instrumentpanelen så jag satte telefonen där. Lite senare bytte jag låt på spotify. Jag gjorde det medans jag körde när telefonen satt på sin hållare.

Såhär tänker vi oss att det skulle kunna se ut när en körning blivit ifylld. Vi ser fram emot dina svar!

Hur använde du telefonen efter körningen? Beskriv den närmaste tiden efter att du lämnat bilen.

Så fort jag hade parkerat så tog jag upp telefonen och svarade min kompis. Sedan gick jag ur bilen och gick sista biten mot jobbet. Jag stoppade i mina hörlurar och bytte låt på spotify.

Info om körningen

Berätta lite om körningen. Vilken typ av körning var det? Körde du själv eller var ni flera i bilen? Vilka typer av vägar körde du på? Hur var trafiken? Vilka system använde du? Cruise Control? Lane Assist? Båda? Hände något utöver det vanliga?

Detta var min vanliga väg till jobbet och jag körde ensam. Det tar ca 35 minuter och jag kör mest på E6:an. På motorvägen var det rätt lite trafik men inne i stan brukar det bli lite köer. Jag har också fyra rödljus att ta mig igenom innan jag kommer fram. På motorvägen använder jag cruise control men inte i stan. Idag flöt det på bra, men vissa dagar kan det vara kö långt ut på motorvägen. I de lägena får jag ju ringa jobbet och säga att jag blir lite sen. Jag borde väl egentligen använda handsfree till det men jag har inte riktigt haft tid att skaffa en ännu.

Nu är det din tur!

Fyll i dagboken under dina kommande tio körningar. Försök göra det så nära inpå varje körning som möjligt.

När dagboken är ifyllld, skicka tillbaka den till oss.

Lycka till! - Billy & Paul

Fylls i före körning Klockslag

Datum

Innan jag satte mig i bilen idag använde jag min mobiltelefon till att..

Fylls i efter körning Klockslag

Fanns det situationer under körningen när du kände för att använda din mobiltelefon? Vad hände och vad gjorde du? Försök beskriva precist, så om du fick ett meddelande - skriv vilken app, om det innehöll text/bilder/video etc.

Hur använde du telefonen efter körningen? Beskriv den närmaste tiden efter att du lämnat bilen.

Info om körningen

Berätta lite om körningen. Vilken typ av körning var det? Körde du själv eller var ni flera i bilen? Vilka typer av vägar körde du på? Hur var trafiken? Vilka system använde du? Cruise Control? Lane Assist? Båda? Hände något utöver det vanliga?

Nu skulle vi vilja få veta lite mer om din mobiltelefon också. Vad brukar du använda? Vilka funktioner är viktigast för dig? Vad i mobilen kan du inte leva utan? Vi vill veta allt!

Min telefon

Jag använder mest min telefon för att:
(ringa in, fyll i)

___ringa___

Textmeddelanden

Kolla film

____

Ta foton

Ta anteckningar

Använda kalendern

____

Spela musik

Surfa

____

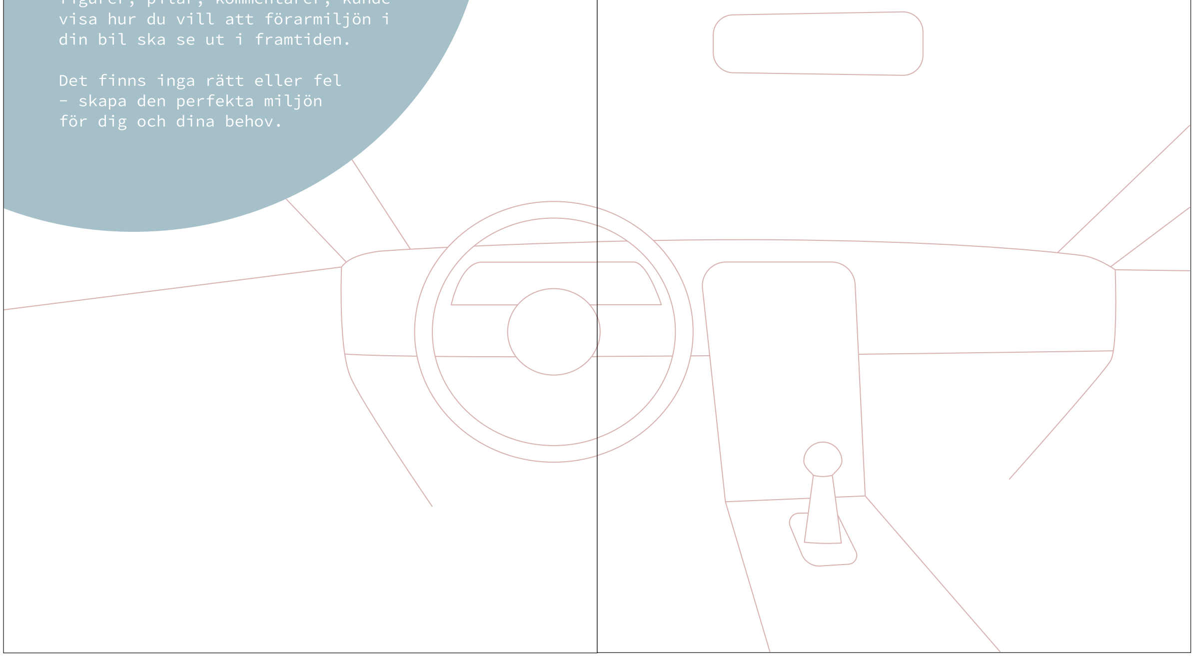
Berätta lite mer..

Vad tycker du om telefonanvändning och bilkörning i allmänhet? Berätta om dina erfarenheter.

Vi tror att den här dagboken kan ha fått dig att reflektera en del över din bils förarmiljö. Är det kanske något i den du skulle vilja förändra?

Vi tänkte att du här, med lite enkla figurer, pilar, kommentarer, kunde visa hur du vill att förarmiljön i din bil ska se ut i framtiden.

Det finns inga rätt eller fel – skapa den perfekta miljön för dig och dina behov.



Utvärdering

Hej igen!
Tack för all tid du har lagt på att fylla i denna dagbok! Innan vi avslutar skulle vill vi bara veta lite mer om hur veckan har varit för dig. Hur har det känts att logga dina resor? Är det kanske något som vi har missat att fråga?

Hur har veckan varit för dig? Har något hänt utöver det vanliga?

Hur kändes det att svara på våra frågor?

Använde du telefonen som vanligt eller var något annorlunda?

Hur kändes det att logga dina körningar på detta sättet?

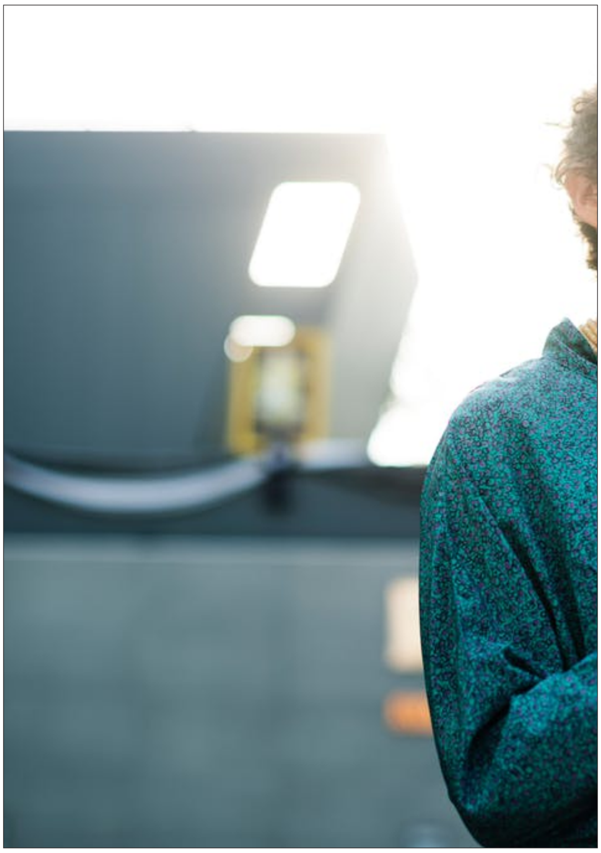
Något annat du vill tillägga?

Färdigt!

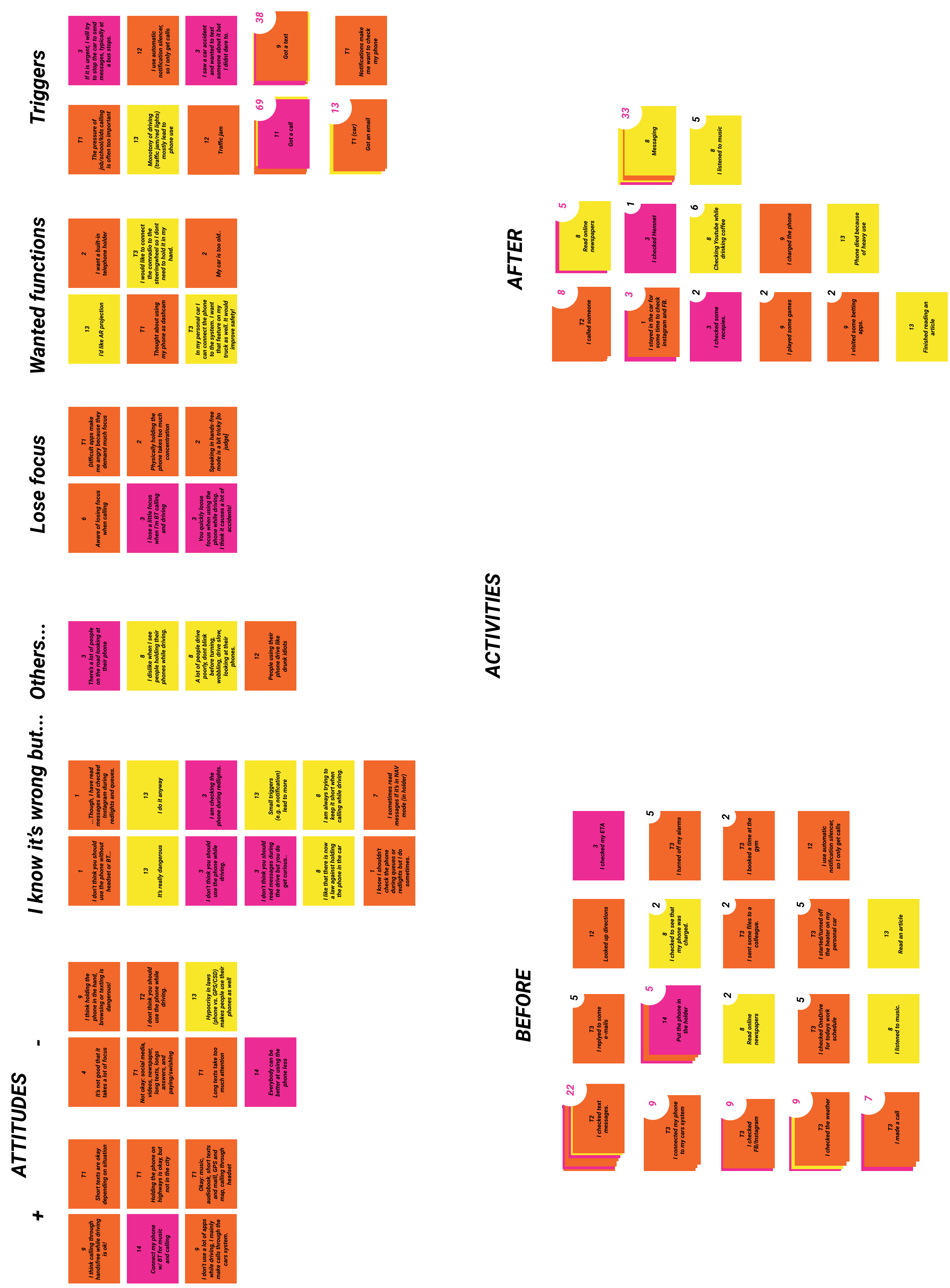
Snyggt jobbat!

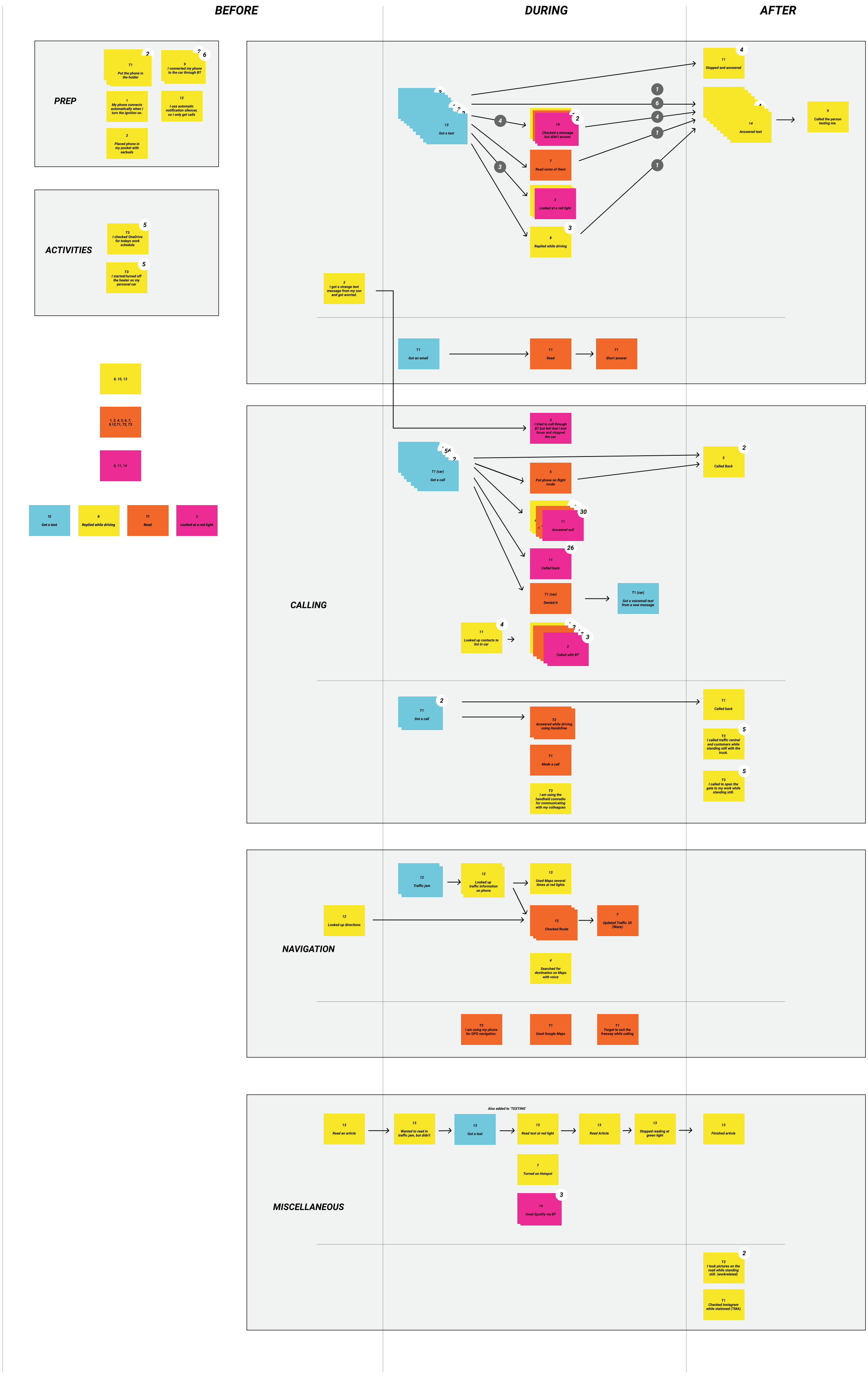
Nu är det bara att se till att vi får tillbaka dagboken. Stoppa den i det medföljande kuvertet och stoppa den i närmsta brevlåda.

Vi ser verkligen fram emot att få ta del av dina svar!



Appendix II: Probe KJ




BEFORE
DURING
AFTER
PREP
ACTIVITIES
CALLING
NAVIGATION
MISCELLANEOUS

Appendix III: Contextmapping Materials

I'm reading the news on the HUD

You just texted your friend through your HUD, and you see this person:

I missed the exit ramp because I was reading the news on the HUD

You're reading a message on your HUD when the car warns you it's turning off ACC/LA

I wanted to take a selfie with the built-in camera, but had to fix my make-up first

You're driving on the freeway, when this person overtakes you on the left:

DRIVING
SVT pop-up:
"Melodifestivalen inställd
- visa mer"

BEFORE
Sambo cut his finger while cooking and needs to go to the first aid

ENTERING THE CAR
I'm having an important call with my boss

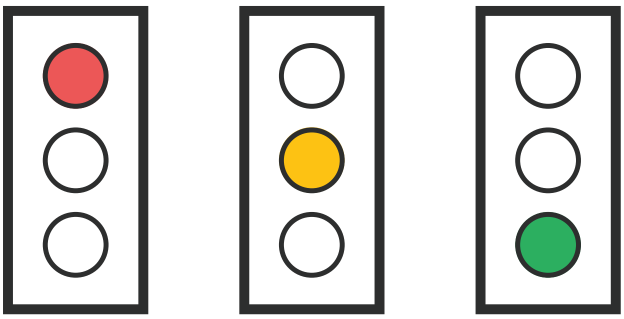
DRIVING
I receive a mail that says my morning meetings has been moved to another location

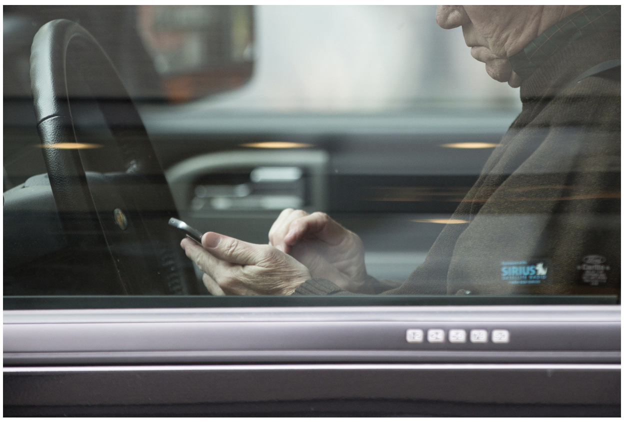
BEFORE
I'm listening to a podcast during breakfast, then I step into my car

DRIVING
Candy Crush sends a reminder that I can play again

DRIVING
My best friend is texting me and I know it's important

DRIVING
Facebook has 4 unread notifications





Appendix IV: Blur Determination

In order to determine the blur value appropriate for the Blur Method, a calculation was done to estimate the amount.

Adult eyes have a diopter strength of 60D to 70D (Nave, 2000; Palanker, 2013) for relaxed and tensioned respectively. These translate to an equivalent focal length of 16.7mm and 14.3mm respectively. The pupil size normally varies between 1.5mm and 8mm, depending on light intensity (Palanker, 2013). With these values, the F-stop of the eye can be approximated, as seen in Table 1 below.

	60D (Relaxed)	70D (Tension)
1.5mm pupil size	11.1	9.5
8mm pupil size	2.1	1.8

Table 1 – Approximated F-stop value in relation to pupil size and tension

Looking beyond 1 meter approaches the relaxed eye, i.e. 60 diopters. Since the HUD is expected to be around 2 meters virtual distance, the average of these values is used.

Average of f/11.1 and f/2.1 is, due to the logarithmic scale, f/4.8. By comparing a photo taken at these settings with the blur amount, a blur of 15px was set (for a 1920x1080px screen).

Appendix V: NHTSA Occlusion Protocol

1. Test Apparatus.
Intermittent viewing of an electronic device interface can be provided by a variety of means such as commercially-available occlusion goggles, a shutter in front of the interface, or other means.

— The occlusion apparatus used should be transparent during the viewing interval and opaque during the occlusion interval.
— The occlusion apparatus should be electronically controlled.
— During the occlusion interval, neither the electronic device interface displays, nor the device controls should be visible to a test participant.
— During the occlusion interval, operation of the device controls by a test participant should be permitted.
— The switching process between the viewing interval and the occlusion interval should occur in less than 20 milliseconds and vice versa.

2. Test Device.
The electronic device under evaluation should be operational and fitted to a vehicle, driving simulator, or vehicle mockup in a design which duplicates the intended location of the interface in the vehicle (i.e., the viewing angle and control placement relationships should be maintained).

3. Test Participants.
Twenty-four test participants should be enrolled using the previously described (Subsection VI.A) criteria.

4. Each test participant should be given training and practice as follows:

— How to perform each testable task on each device of interest without using the occlusion apparatus.
— How to drive the occlusion apparatus while not performing a testable task.
— How to perform each testable task on each device of interest while using the occlusion apparatus.

5. Each test participant should practice each testable task and use of the occlusion apparatus as many times as needed until he or she becomes comfortable in performing the task and using the occlusion apparatus.

6. Different task stimuli (e.g., addresses, phone numbers, etc.) should be used for each instance of testable task performance for a particular test participant. Task stimuli should be provided to a test participant immediately prior to the beginning of each instance of testable task performance.

7. Test Procedure.

Testing is performed in accordance with ISO International Standard 16673:2007(E), "Road vehicles—Ergonomic aspects of transport information and control systems—Occlusion method to assess visual demand due to the use of in-vehicle systems" with the following exceptions:

— Where the ISO Standard states that at least 10 participants are to be tested, the NHTSA Guidelines recommend that 24 participants be tested.
— Where the ISO Standard states that each test participant should be given at least two and up to five practice trials for each testable task, the NHTSA Guidelines recommend that each test participant receive as many practice trials as needed to become comfortable in performing the task.

8. The viewing interval (shutter open time) should be 1.5 seconds followed by a 1.5- second occlusion interval (shutter closed time). The sequence of viewing intervals followed by occlusion intervals should occur automatically without interruption until the task is completed or the trial is terminated.

9. Task stimuli (e.g., addresses, phone numbers, etc.) are provided to a test participant prior to the start of testing. When the task stimuli are given to a test participant, the device should be occluded (i.e., a test participant cannot see the device interface) and it should remain occluded until after testing has begun.

11. Testing starts when a test participant informs the experimenter that he or she is ready to begin the trial. The experimenter then triggers the alternating sequence of viewing intervals followed by occlusion intervals.

12. When a test participant has completed the task, he or she verbally instructs the experimenter that the task has been completed with the word, "done" (or other standardized word). The experimenter stops the occlusion apparatus operation.

13. There should be an automatic means of recording the number of unoccluded intervals a test participant needed to complete the task.

14. Each test participant performs each task being tested five times to determine whether that task meets the acceptance criterion.

15. As per ISO 16673:2007, invalid trials are removed. Note that unoccluded total task time is not determined as part of this test procedure. Therefore, the occluded total task time greater than four times the average unoccluded total task time trial exclusion case in ISO 16673:2007 cannot be used. Individual trials are considered invalid and removed if:

- A test participant refuses to complete a trial
- A test participant says he or she is done with a trial but is not
- The experimenter judges that the participant cannot successfully complete a trial
- The experimenter judges that the participant is not genuinely attempting to perform the protocol and related tasks as instructed, or
- A task performance error is made by the test participant. The handling of task performance errors is discussed in Subsection VI.H.

16. As per ISO 16673:2007, the mean Total Shutter Open Time (TSOT) for each test participant is calculated.

17. Acceptance Criterion.
A task should be locked out for performance by drivers while driving unless the mean TSOT calculated above is 12.0 seconds or less for at least 21 of the 24 test participants.

Appendix VI: Blur Method Evaluation Procedure

Make sure the safety evaluation form is ready to be filled in, the GoPro ready to record, and the planned order of tasks (i.e. ABC, BCA or CAB) according to schedule.

Inform the test person of the study, its purpose and give them the informed consent form. Inform that we are evaluating different test methods and the relation between them, not the participant theirself. Participants can quit at any time without giving reason. Explain that we're testing different methods of simulating interaction with the screen in the occlusion method and blur method, as compared to regular driving. We're not comparing performance

Show the simulator and let the participant get acquainted with driving in ETS2. Show the 'control panel' and let the participant get acquainted with its controls (navigating, selecting and going back). Make sure they are okay with calling and texting (UI1) and the navigation in all menus.

Benchmark safety for 45 seconds and let the participant evaluate safely 1-5.

Setup A - Manual Driving
Inform the participant that the most important task is to drive safely, since we're comparing testing methods under regular conditions. Evaluate safety 1-5 after.

Task 1 - UI 1 - Call
Make a call to 'Jonas Bengtsson'

Task 2 - UI 2 - Text
Find the text message that you've received from Sofia, read it and tell her through a quick-reply that you'll call her later.

Setup B - Occlusion Method
Task 1 - UI 1 - Call
Make a call to 'Anne Andersson'

Task 2 - UI 2 - Text
Find the text message that you've received from Billy, read it and tell him through a quick-reply that you're on your way

Setup C - Blur Method
Task 1 - UI 1 - Call
Make a call to 'Billy Astorsson'

Task 2 - UI 2 - Text
Find the text message that you've received from Paul, read it and tell him through a quick-reply that you can't talk right now.

Evaluation

Question the participant about the experience, specifically how both blur and occlusion feel like compared to driving.

Questions:

- What were your general thoughts on the driving?
- Did you feel you drove safely in the driving task?
- What are your thoughts on the UI, did it feel intuitive?
- How were the controls for navigation?
- How did you experience the difference between Occlusion and Blur?
- What differences did you notice?
- Which one did you prefer to use?
- Does either one better simulate driving, and if so, which?
- Did you notice the HUD peripherally when 'driving'?

Wrap-up

Use an alias (Participant number) for the notes/results and the recording of the test.

Thank the participant for joining the study.

Appendix VII: Look-down Angle Evalutation Procedure

Before starting the test, make sure that:

— The LCT folder is empty and that all files from the previous tests are correctly named and stored due to the LCT protocol.
— The GoPro is ready to record
— The Stopwatch is ready to record.
— That the planned order of tasks is set (ABCD, ...,)

Welcome and inform the participant of the study, its purpose and give them the informed consent form. Inform that we are evaluating the HUD system and not the participant theirself. Participants can quit at any time without giving reason. Explain that we're testing the HUD for different angles to see how it affects the performance.

— Let the participant sit down in the simulator and find a comfortable seating position.
— Adjust the simulator to the first testangle in the planned task order.
— Let the participant get acquainted with the LCT software and controls.
— Delete all generated test files.

Show the 'control panel' and let the participant get acquainted with its controls (navigating, selecting and going back). Inform them about the secondary task and let them go through at least two-three messages in the procedure.

Secondary task:
You have signed up for a daily facts service, sending you messages with short facts. You need to read through each message and then send a reply to get a new one. Your reply to all messages given should be "I'm on my way." After each reply you should get back to the starting menu and open up the newly received message.

Benchmark Drive

Make sure that the LCT folder is empty.
Inform the participant that the main goal is to drive safely and follow the signs at all times.

— Do a benchmark drive with the HUD turned off.
— Let the participant evaluate safety 1-5.
— Let the participant evaluate secondary task difficulty 1-5.

Setup A - 2,5 degree angle

Remind them to read through all messages before replying and to try get through as many messages as possible. Inform the participant that the most important task is to drive safely.

— Let the participant evaluate safety 1-5.
— Let the participant evaluate secondary task difficulty 1-5.

Setup B - 5 degree angle

Remind them to read through all messages before replying and to try get through as many messages as possible. Inform the participant that the most important task is to drive safely.

- Let the participant evaluate safety 1-5.
- Let the participant evaluate secondary task difficulty 1-5.

Setup C - 7,5 degree angle

Remind them to read through all messages before replying and to try get through as many messages as possible. Inform the participant that the most important task is to drive safely.

- Let the participant evaluate safety 1-5.
- Let the participant evaluate secondary task difficulty 1-5.

Setup D - 10 degree angle

Remind them to read through all messages before replying and to try get through as many messages as possible. Inform the participant that the most important task is to drive safely.

- Let the participant evaluate safety 1-5.
- Let the participant evaluate secondary task difficulty 1-5.

Evaluation

Questions:

- What were your general thoughts on the driving task?
- Did you feel you drove safely in the driving task?
- What are your general thoughts on the HUD when used like this?
- What are your general thoughts on the UI we used for this test?
- How were the controls for navigation?

Show a picture of the four different HUD positions (angles):

- From which position was it easiest to perform the messaging task?
- From which position was it easiest to drive?
- From which position do you think you've had the safest drive?

Ending questions/test regarding distances?

Appendix VIII: Peer Ideation Results

What should be ok to do in a car?

- Everything legal
- Work
- Making calls
- Eat and drink
- Listening to music/media
- Playing games that doesn't require visual attention
- Google stuff through voice commands
- Sending text messages/Email
- Use navigation systems
- Taking photographs of nice views along the road
- Snapchat

What should absolutely not be ok to do in a car with a HUD?

- Media or games that takes too much attention and could be hard to switch focus from.
- Sleeping
- Leaving the driver's seat
- Things that requires two-hand use
- The entertainment systems should automatically be turned off in demanding situations.

How can the car make people feel safe when using the HUD?

- Simple UI with easy interaction
- Make situation dependent information
- Provide with feedback communicating that everything is under control - "Relax, I've got this"
- Provide with raw data/system status on important systems.
- Make the HUD adaptable, so that it disappears when something happens, indicating that the driver has to put attention on the road.
- Provide with warnings - "A vehicle 200m ahead is braking"
- Provide with safety information when entering high-risk areas such as roads with a lot of wildlife, outside schools etc.
- To be informed of the risks can indicate that the car has control.
- Only present relevant info - don't overload the driver.

What information/functionality would you like to have in a vehicle HUD and when?

- Use symbols instead of text when possible
- Different modes/states, like "Work mode" presenting news etc. or "Vacation mode" presenting hotels, camping sites, tourist attractions etc.
- ETA
- Outside temperature (always)
- The name of the currently played song (on highways)
- Avoid longer texts during city drives
- In city drive or areas with 30km/h speed limits it should be limited to phone calls due to higher risk.

What type of information/functions can be shown in the following situations; highway drive, city drive, traffic jam?

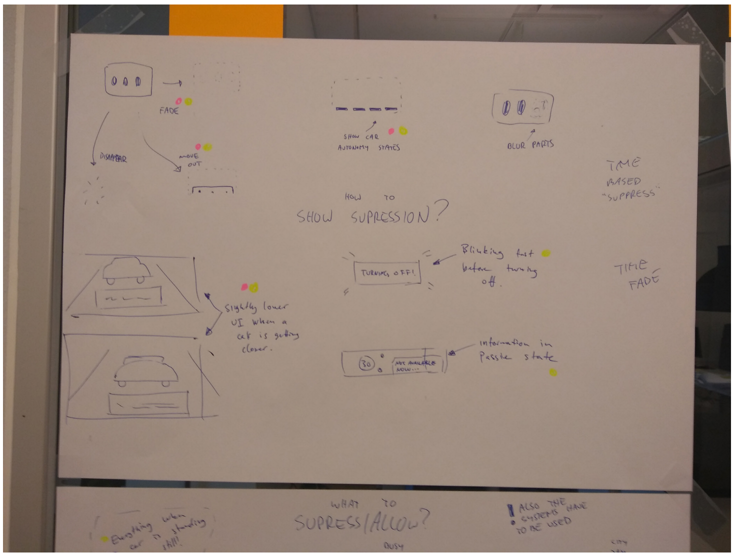
Highway drive with L2 automation
- Messenger/Text messages
- Order food
- Calls
- Music/Spotify
- Traffic information
- Calendar
- Planning tools

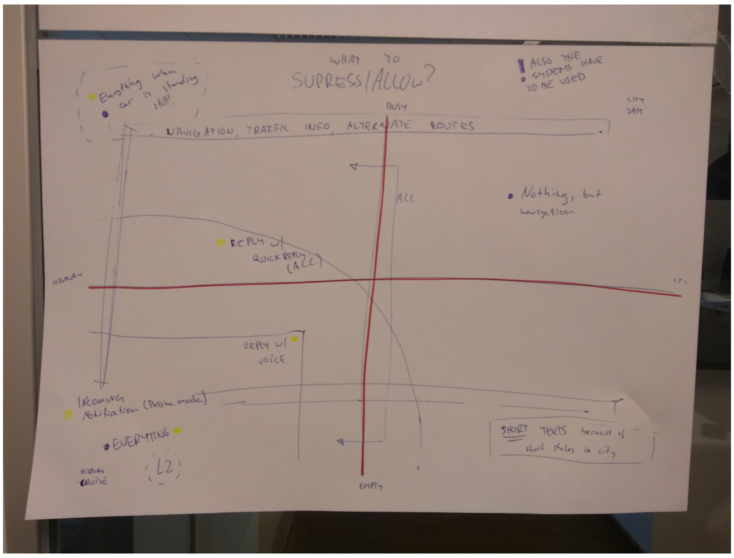
City drive
- Navigation
- Speed limits
- Calls
- Music/Spotify
- Information about surroundings, sightseeing (audio only)

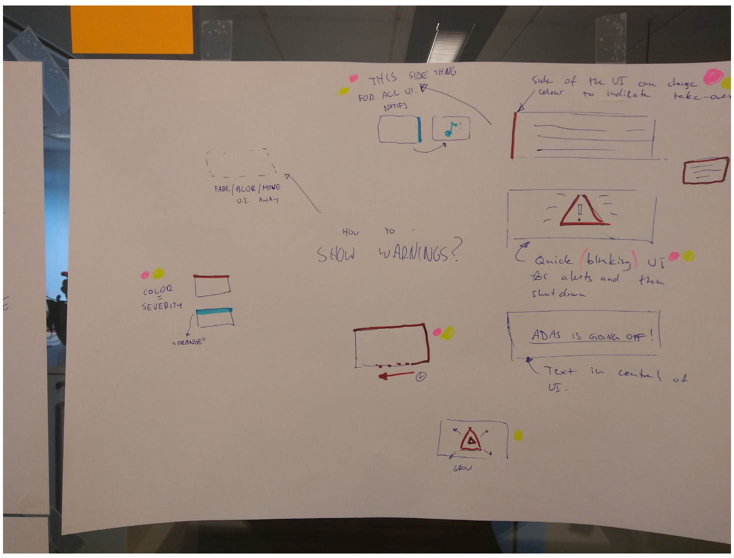
Traffic Jam
- Entertainment
- Alternative routes
- Youtube
- Movies
- Calls
- Spotify
- Games
- Instagram
- Snapchat

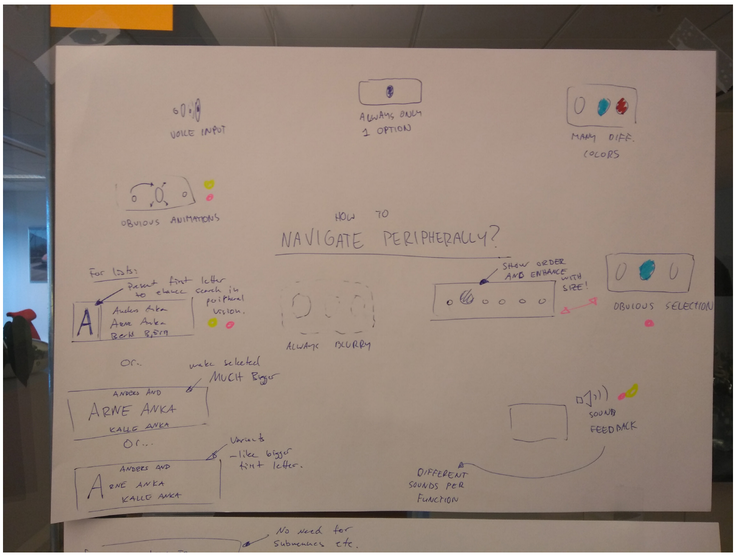
How should the phone handle information that's already been handled in the car?
- Present leftover notifications
- Should be able to choose
- Receive notification/reminder about things that haven't been interacted with
- Nothing should be stored in the car system itself
- Information that can't be interacted with should be postponed to post-drive.

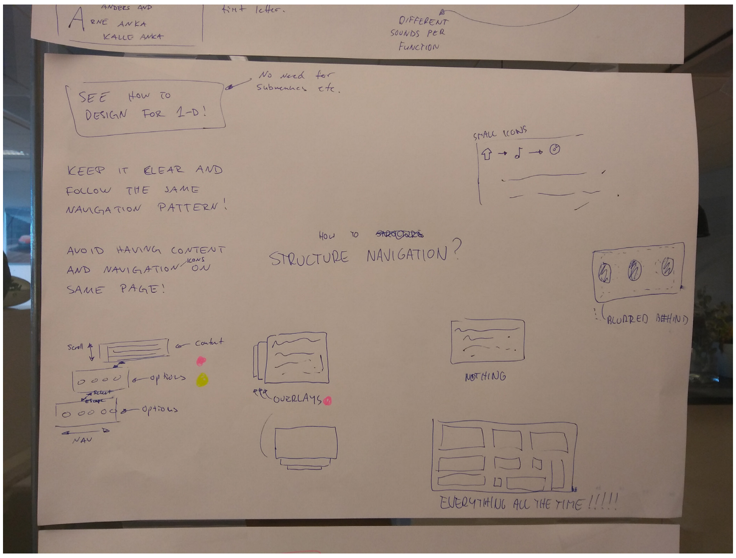
Appendix IX: UI Ideation Results

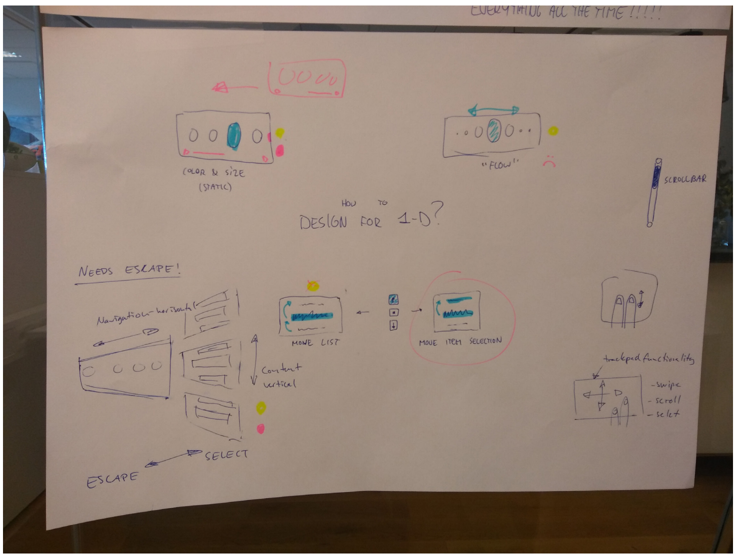


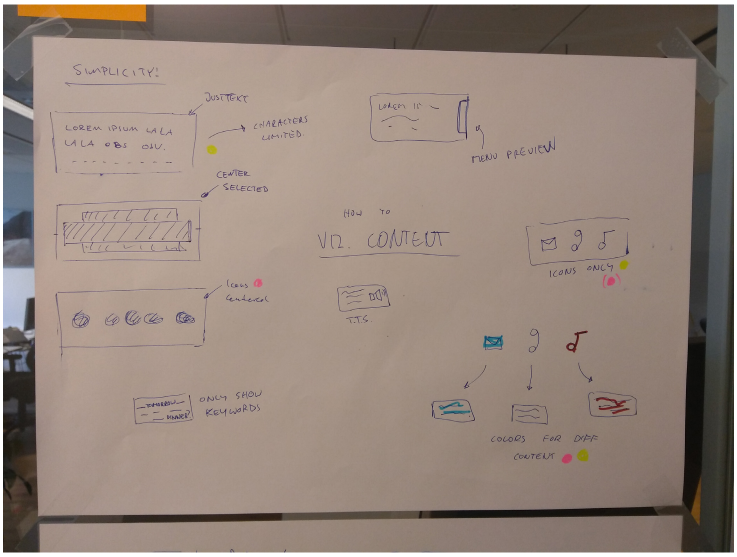


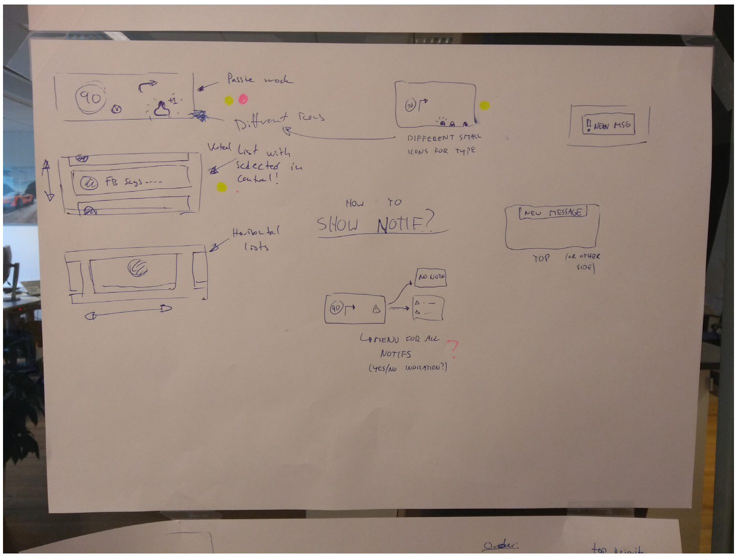


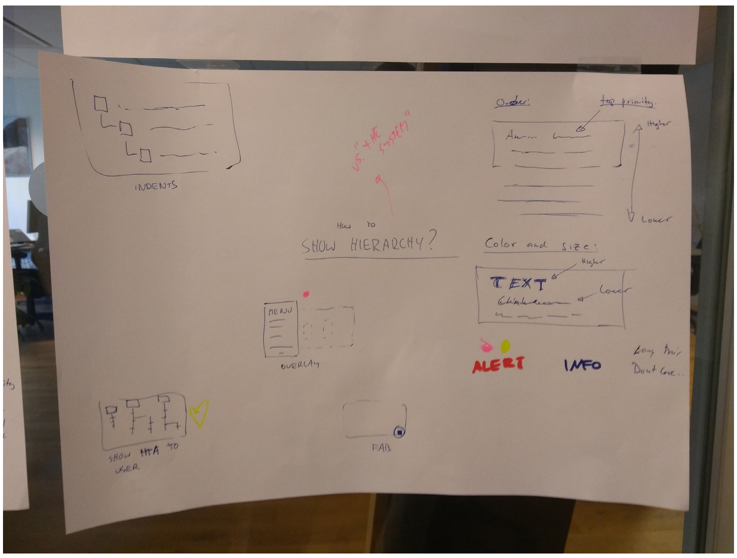

VOICE INPUT
ALWAYS ONLY 1 OPTION
MANY DIFF. COLORS
OBVIOUS ANIMATIONS
HOW TO
NAVIGATE PERIPHERALLY?
SHOW ORDER AND ENHANCE WITH SIZE!
OBVIOUS SELECTION
ALWAYS BLURRY
ARNE ANKA
MUCH Bigger
SOUND FEEDBACK
DIFFERENT SOUNDS PER FUNCTION
No need for submenus etc.


SEE HOW TO DESIGN FOR 1-D!
No need for submenus etc.
SMALL ICONS
KEEP IT CLEAR AND FOLLOW THE SAME NAVIGATION PATTERN!
AVOID HAVING CONTENT AND NAVIGATION ICONS ON SAME PAGE!
HOW TO
STRUCTURE NAVIGATION?
BLURRED BEHIND
OVERLAYS
NOTHING
EVERYTHING ALL THE TIME!!!!!


COLOR & SIZE (STATIC)
"FLOW"
SCROLLBAR
HOW TO
DESIGN FOR 1-D?
NEEDS ESCAPE!
MOVE LIST
MOVE ITEM SELECTION
trackpad functionality
- swipe
- scroll
- select
SELECT
ESCAPE


SIMPLICITY!
CHARACTERS LIMITED
CENTER SELECTED
MENU PREVIEW
HOW TO VIZ. CONTENT
ICONS ONLY
TTS
ONLY SHOW KEYWORDS
COLORS FOR DIFF CONTENT


DIFFERENT SMALL ICONS FOR TYPE
NEW MSG
HOW TO SHOW NOTIF?
NEW MESSAGE
TOP

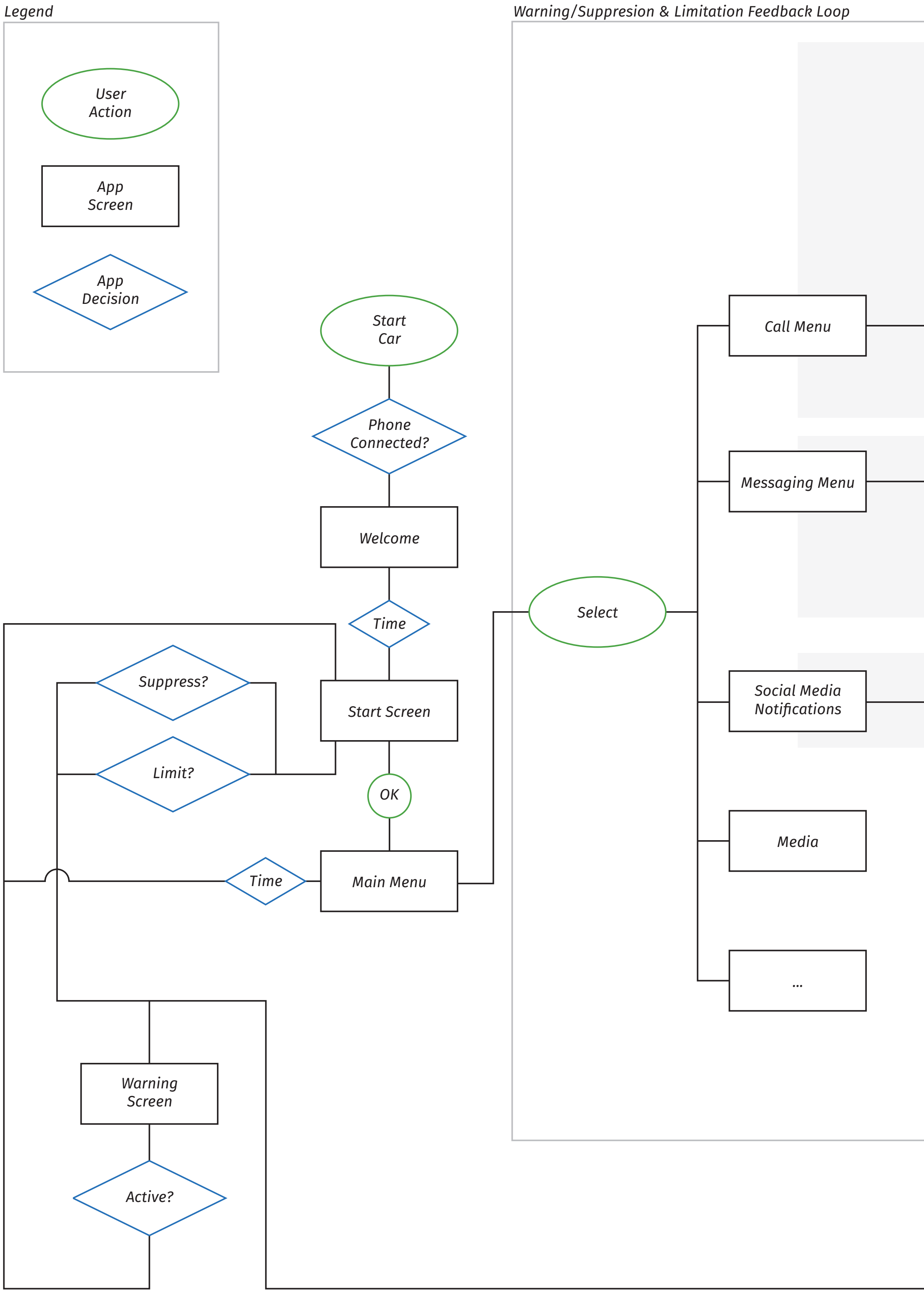

INDENTS
HOW TO SHOW HIERARCHY?
TEXT
MENU
OVERLAY
ALERT
INFO
FAB

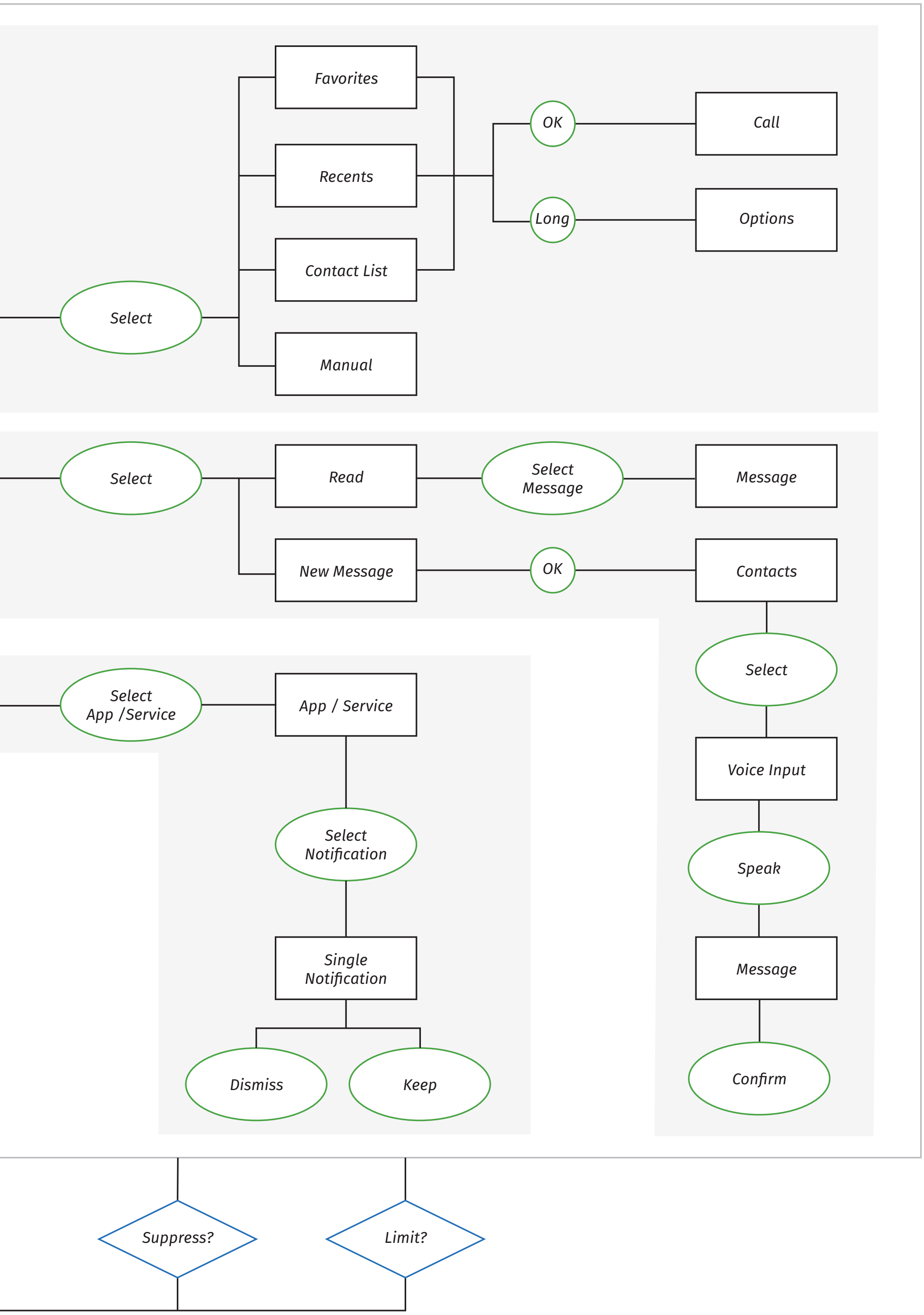
Appendix X: UI Element Test Results

	1					2		3	
	Animated	Static	ScrollBar	Single Dot	Double dot	Animations	Static	Color spectrum	All Blue
Test 1									
Test 2									
Test 3									
Test 4									
Notes:			Scrollbar is hard to get at first but is most clear after using it for a while. Double dot is most intuitive but too unclear in blurred mode.					Several colors might lead to contrast problems in different situations. Some colors might get better contrast than others.	

4		5		6		7		Preferred Color			
Ungrouped	Grouped	Cap	No Cap	Text Warning	Line Warning	Top Only	Both	1	2	3	4
Ungrouped takes too much attention and promotes infotainment too much.				Could be different behaviours. Text is less confusing but might draw unwanted attention when users reads the text instead of focusing on the road.		Hard to choose, difficult to know without driving, should be tested with more levels etc.		Set			

Appendix XI: User Task Flow




Favorites
Recents
Contact List
Manual
Select
OK
Long
Call
Options
Select
Read
New Message
Select Message
OK
Message
Contacts
Select
Voice Input
Speak
Message
Confirm
Select App /Service
App / Service
Select Notification
Single Notification
Dismiss
Keep
Suppress?
Limit?

Appendix XII: Prototype Links

Blur Method Evaluation

Part 1

https://framer.cloud/AGlVX

Part 2

https://framer.cloud/nhbLd

Look-down Angle Evaluation

https://framer.cloud/CYAEQ

UI Elements Test

Scrolling

https://framer.cloud/AdziU

Animations

https://framer.cloud/vDgpp

Color

https://framer.cloud/GsaWI

Notifications

https://framer.cloud/fgGBZ

Contacts

https://framer.cloud/mxwpL

Warning

https://framer.cloud/HBjwg

L2 Display

https://framer.cloud/oLlkp

HMI Concept

https://framer.cloud/CErwO

Appendix XIII: User Experience Questionnaire

Short version UEQ

boring	O O O O O O O	exciting
not interesting	O O O O O O O	interesting
obstructive	O O O O O O O	supportive
complicated	O O O O O O O	easy
inefficient	O O O O O O O	efficient
confusing	O O O O O O O	clear
conventional	O O O O O O O	inventive
usual	O O O O O O O	leading edge

Long version UEQ (altered)

annoying	O O O O O O O	enjoyable
not understandable	O O O O O O O	understandable
creative	O O O O O O O	dull
easy to learn	O O O O O O O	difficult to learn
valuable	O O O O O O O	inferior
boring	O O O O O O O	exciting
not interesting	O O O O O O O	interesting
unpredictable	O O O O O O O	predictable
obstructive	O O O O O O O	supportive
good	O O O O O O O	bad
complicated	O O O O O O O	easy
unlikable	O O O O O O O	pleasing
unpleasant	O O O O O O O	pleasant
secure	O O O O O O O	not secure
motivating	O O O O O O O	demotivating
meets expectations	O O O O O O O	does not meet expectations
inefficient	O O O O O O O	efficient
clear	O O O O O O O	confusing
impractical	O O O O O O O	practical
organized	O O O O O O O	cluttered
attractive	O O O O O O O	unattractive
friendly	O O O O O O O	unfriendly

Excluded Questions

fast	O O O O O O O	slow
inventive	O O O O O O O	conventional
usual	O O O O O O O	leading edge
conservative	O O O O O O O	innovative

Appendix XIV: HMI Concept Evaluation Procedure

Before starting the test, make sure that setup is ready and everything is in order.

Welcome and inform the participant of the study, its purpose and give them the informed consent form. Inform that we are evaluating the HUD system and not the participant theirself. Participants can quit at any time without giving reason.

Experience: Reaction & Emotion as a result from the interaction
w.r.t previous experiences & the context

Preparation and Training

- Let the participant sit down in the simulator and find a comfortable seating position.
- Adjust the HUD to a proper angle.

Let the participant get acquainted with ETS2
- For instance, let them start at the Göteborg service place and instruct them to find their way to E6 Malmö. (Daylight, Traffic turned OFF)
- Stop the truck when they feel that they are in control.

Let the participant get acquainted with L2 driving.
- Instruct them to start driving on the highway and activate L2 when they feel in control.
- Wizard takes over and drives the truck.
- Instruct them to try different stuff (brake, turn, accelerate etc.) To learn how the L2 will behave.
- Wizard adapts to the driver input and the road.

Let the participant get acquainted with the HUD.
- Introduce the HUD and go through the interface while the truck is standing still.
- Calling
- Messages
- Notifications
- Suppressions

Test part 1 - L2 Driving with a Heads Up Display (Warm Up)

This part focuses on the least demanding situation, L2-Highway-Low Traffic, and gives the participant an experience on how it could be to operate the HUD during optimal conditions.

- E6 Göteborg - Malmö
- Traffic OFF

Instruct the participant to get into the car and connect their phone to the cars system. Start driving and turn on L2. During the drive the participants will be given several instructions/tasks to perform with the HUD. Also inform them to interact with all incoming notifications/messages/calls.

Tasks

User Triggered

- You just remembered that you promised to call you best friend … just before leaving Göteborg.
- Call …

Phone Triggered

- Wizard sends a message from the person you just called.
- Read the message
- Give a reply

After driving

- Fill in the short version UEQ about the simulation.

Rating Scales

- How much in control did you feel during this drive? (1-7)
- How safe did you feel during this drive? (1-7)

Answer the following questions

- How did you experience the HUD system used in this scenario?
- How did you experience the interface and navigation?
- How did you experience the presented functionality?
- Is it something you would like to add?
- Is it something you would like to take away?
- How do you expect your phone to behave when connected to the cars system?
- How did you experience the L2 driving (WoZ)?

Test Part 2 - Warnings/Suppressions in Traffic & Traffic Jam

This part focuses on a more demanding situation where the traffic increases and it introduces the participants to HUD warnings. This tests how the participants experiences the HUD when traffic increases and also how safe or in control they feel when the HUD is producing a warning. Additionally it tests slowing down/speeding up warnings during a traffic jam.

- E6 Göteborg - Malmö
- Traffic on to 10
- Start on the side of the road to let traffic build up.

Instruct the participant to start driving and turn on L2. Instruct the participants to read a number of notifications or messages while driving.

Tasks

Wizard first drives at 90 to let the participant get into the task and then slows down slightly. The slowdown will then trigger surrounding traffic to do takeovers and pass into the left lane. When ever that happens, the wizard suppresses the HUD temporarily, letting the driver react to it. After a few times, the driver is instructed to stop.

Rating scales

- How much in control did you feel during this drive? (1-7)
- How safe did you feel during this drive? (1-7)

Answer the following questions

- How did you experience it when the HUD produced warnings?
- Did the HUD warnings make you feel more or less safe?
- Did the HUD warnings make you feel more or less in control?
- How did you experience the HUD behaviour when entering the traffic jam?
- What did you feel about the suppression? In what situations would they be necessary?
- How did you experience using the HUD when driving in the traffic jam?
- How did you experience having a vehicle in front as background for the HUD?
- In what situations would you expect warnings?
- What would be too much suppression?

Test Part 3 - Switching, L2-L0-L2

This parts tests the transition between L2 to L0 and back. It also tests HUD suppression since it will show only the notification symbol at L0 and giving an option to check them at L2.

- E6 Göteborg - Malmö
- Traffic set to 10

Instruct the driver to drive with L2 on, use the HUD and follow the navigation arrows when needed.

When the car turns towards the exit, handover information will be presented on the HUD and it will then disable the HUD and temporarily suppress all incoming notifications. After a short drive using L0 on a city road, the participant is instructed to get back to the highway and turn on L2. During the L0 drive, the participant will get notifications but cant read them due to HUD suppression.

When the participant is back on the highway, the received notifications will be presented. The participant can go through them and is then instructed to stop.

Rating scales

- How much in control did you feel during this drive? (1-7)
- How safe did you feel during this drive? (1-7)

Answer the following questions

- How did you experience the handover between L2 to L0?
- How did you experience the lack of HUD functionality during the L0 drive?
- How did you experience it when the system suppressed the HUD during the L0 drive?
- How did you experience it when being able to go through notifications again during L2?
- Should some information be available also during L0? If yes, what information?
- How do you think you would use this in the long run?

Final Questions

Go through the full version UEQ considering the HUD in the whole test.

Answer the following questions

- How much attention did you have to pay to driving in the different situations? (Cognitive Load)
- How do you use your phone in the car today?
- Do you think you would like to use a system like this in your own car? Why / why not?
- Did you feel the need to use your phone at some point during the test? Why / why not?
- How do you think a system like this could affect your phone use?
- Do you think it would increase or decrease your phone use in general?
- Do you think it would increase or decrease your phone use while driving?
- Do you think this HUD system is sufficient as a substitute to your phone while driving?
- Does the HUD enhances the experience of the car or limiting the experience of the phone?
- How do you expect this system to connect with your phone when entering the car?
- Would you be okay with not being able to use your phone while connected?
- Is there anything you would like to add or something you have thought about that we have missed to discuss?

Appendix XV: RFC2119

Excerpt from Bradner (1997).

“A.MUST: This word, or the terms "REQUIRED" or "SHALL", mean that the definition is an absolute requirement of the specification.

B.MUST NOT: This phrase, or the phrase "SHALL NOT", mean that the definition is an absolute prohibition of the specification.

C.SHOULD: This word, or the adjective "RECOMMENDED", mean that there may exist valid reasons in particular circumstances to ignore a particular item, but the full implications must be understood and carefully weighed before choosing a different course.

D.SHOULD NOT: This phrase, or the phrase "NOT RECOMMENDED" mean that there may exist valid reasons in particular circumstances when the particular behavior is acceptable or even useful, but the full implications should be understood and the case carefully weighed before implementing any behavior described with this label.

E.MAY: This word, or the adjective "OPTIONAL", means that an item is truly optional. One vendor may choose to include the item because a particular marketplace requires it or because the vendor feels that it enhances the product while another vendor may omit the same item. An implementation which does not include a particular option MUST be prepared to interoperate with another implementation which does include the option, though perhaps with reduced functionality. In the same vein an implementation which does include a particular option MUST be prepared to interoperate with another implementation which does not include the option (except, of course, for the feature the option provides.)

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Gothenburg, Sweden 2019
www.chalmers.se

Automation systems such as pilot assist in cars and trucks help the driver more and more in taking over monotonous driving tasks. As a result, many drivers get understimulated and pick up their phone, which may lead to dangerous situations. A possible solution is to enable phone use in a safer way by integrating phone functions in an interactive heads-up display. However, research in this area is virtually nonexistent. This thesis researches several important aspects for the best user experience of such an interactive heads-up display. Several user studies are performed, physical aspects are examined, and a UI is iteratively developed. All of these lead to a set of guidelines that create a foundation for interactive heads-up displays.

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