Designing for Semi-Autonomous Vehicles

In-Vehicle Digital Communication During Low-Level Automation In Congested Traffic Environments

Master's thesis in Interaction Design & Technologies

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Cover: Illustration of an HMI concept made during the project.

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Abstract

The automotive industry is moving towards autonomous driving, and as more driving task responsibilities are transferred to the motor vehicle, the driver can engage in more non-driving tasks. In this project, we have investigated driver behaviour with so called *secondary tasks* (STs) in semi-autonomous motor vehicles, and how an *human-machine interface* (HMI) for digital communication, and other STs, can be designed for this level of autonomy. We have sent out a survey, created concepts, implemented low- and high-fidelity prototypes, and conducted user tests, in order to find a solution which is both comfortable, efficient, and safe to use while driving. Our solution consisted of a system with an *head-up display* (HUD) by the windshield, and two touch sensitive trackpads mounted at either side of the steering wheel. The trackpads control the content shown in the HUD, by using common touch gestures, such as pressing, swiping, and typing with our own interpretation of a T9 input method, which we call *Circular T9*. In the end, we had insufficient data to conclude whether our solution was safe enough in a real driving setting. The feedback from the user tests have been generally positive towards the concept, but critical towards the high-fidelity prototypes, specifically that there is insufficient feedback from the input interface. Our hope is that this project will inspire other projects in designing HMIs for future motor vehicles.

Keywords: Automotive, semi-autonomous driving, secondary tasks, human-machine interface, digital communication, interaction design, concept design, Circular T9, trackpads, head-up display.

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Contents

Abbreviations

ACC adaptive cruise control. 5, 39

ADAS advanced driver assistance system. 25, 26, 31, 39, 41, 51, 57, 61, 62, XVI, XVIII, XXXI

AS auto-steering. 5, 35, 39

CC cruise control. 37

DIM driver information module. 5, 7, 9, 10, 24

FCWS forward collision warning system. 5

HDD head-down display. 9

HMI human-machine interface. v, 1, 2, 3, 15, 16, 17, 23, 24, 64, 67, 68

HTA hierarchical task analysis. 24, I

HUD head-up display. v, 9, 23, 29, 30, 34, 39, 40, 41, 42, 43, 45, 47, 56, 62, 64, XXXVIII, XLIV, XLV, XLVII, XLVIII, XLIX

LDWS lane departure warning system. 5

LOC locus of control. 6, 23

MA mode awareness. 2

MOL mental overload. 7, 23

MUL mental underload. 7, 23

MWL mental workload. 7, 23

NDS naturalistic driving study. 5

NHTSA National Highway Traffic Security Administration. 3, 5, 6, 7, 8, 10, 30, 67

OEM original equipment manufacturer. 8

PA pilot assist. 24, 44

SA situation awareness. 7, 23

SEER Seamless, Efficient and Enjoyable user-vehicle inteRaction. 1, 15

ST secondary task. v, 1, 2, 5, 7, 8, 9, 23, 25, 51, 61, 62, 67

SUS system usability scale. 11, 12, 17, 18, 48, 50, 54, 57, 58, 59, 62, 67

Definitions

ACC Vehicles with ACC can adapt their speed to keep a safe distance to the vehicle in front of it. 5

AdaptIVe EU sponsered project for the development of autonomous vehicles. 1

ADAS A driving assistance system including advanced features, such as AS and ACC. 25

auto-steering A technology which keeps vehicles within the lane markings of the road. 5

DIM Commonly referred to as the "dashboard", where driving relevant indicators and gauges are placed. 5

emoji Ideograms and smileys commonly used in electronic messaging. 10

external LOC A person's belief of their life being controlled by external factors, which they cannot influence. *See:* locus of control, 1, 6

FCWS A warning system which warns the driver when the vehicle is in near-collision in the front. 5

HMI The interface between a human and a machine (for instance a car), which enables the interaction between them. v, 1

infotainment system A system in an automobile responsible for supplying the driver with necessary trip information and entertainment, such as navigation and music. 1

internal LOC A person's belief of having control over their life. *See:* locus of control, 1, 6

LDWS A warning system which warns the driver when the vehicle is drifting outside the lane. 5

locus of control The psychological degree of a person's perception of control in a given context. 6

mode awareness The degree of awareness a person has over the mode or the activated features within a motor vehicle. 2

naturalistic driving study Driving studies performed in a driver's natural environment, without controlled experiments and interference. 5

NHTSA U.S. government agency for traffic and transportation safety. 3

pilot assist A system in semi-autonomous Volvo cars, which includes the AS and ACC driving assistance systems. 24

SAE International International automotive standards organisation. 5

SAE Level 2 SAE International standard, partial automation by both ACC and AS [49]. *See:* ACC, auto-steering & SAE International, 2, 3, 5, 64

SAE Level 1 SAE International standard, driver assistance by either ACC or AS [49]. *See:* ACC, auto-steering & SAE International, 5

SAE Level 0 SAE International standard, no automation [49]. *See:* SAE International, 5

secondary task A non-driving related task. v, 1

situation awareness The degree of awareness a person has over the current situation. 7

system usability scale A standardised, subjective scoring method of the effectiveness, efficiency and satisfaction with a system. 11

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1
Introduction

The environment in today's motor vehicles are no longer just about operating the vehicle, but to supply the driver and the potential passengers with additional information and entertainment. Automobiles are thus often equipped with an *infotainment system*, which supply the driver various *secondary tasks* (STs) for the trip, such as navigational guidance and music players. The challenge in the design of these infotainment systems is to make them as clear and safe to use as possible, since it is likely the driver will be using the system while driving, to some extent. Using the system often requires the driver to divert their eyes from the road, which can distract them from the main driving tasks and the traffic environment [16]. In order to prevent dangerous traffic situations related to driver distraction, different interfaces between drivers and vehicles (automobiles or trucks) need to be evaluated.

1.1 Background

This project is part of the *Seamless, Efficient and Enjoyable user-vehicle inteRaction* (SEER) project, which is a collaboration between the stakeholders Volvo Technology, Volvo Cars, RISE Victoria, and Semcon [47, 53]. The SEER project focuses on how to improve the experience with STs for semi-autonomous cars and trucks. The project also aims to find out more about the behaviours of drivers when using certain automation systems, and how this knowledge can be used to improve current designs, by developing design concepts for different ST interactions. The general findings and knowledge gained from the project are meant to be available to the public domain, in order to increase innovation within the automotive industry, although some parts may be kept secret within the companies.

Vinnova, Sweden's department of innovations, is the main external financier of the project. The other stakeholders are responsible for the research and the development of the concepts. One of Volvo's visions is traffic safety first, and they are currently investing time in researching how to make autonomous motor vehicles safer, being part of the EU sponsored project *AdaptIVe* [55, 56]. RISE Victoria's goal is to help the automotive industry grow in a sustainable way, providing research projects in collaboration with industry partners [46]. Semcon works in several industries providing expertise in fields like design and development, amongst other, and their goal is to make better user experiences for different technologies [50, 51].

1.2 Purpose

With the the automobile and truck industry shifting more and more towards autonomous vehicles, car manufacturers are showing an increasing interest in different driver assistance and automation technologies. As more of the driving tasks are transferred to automation systems, it is important that the vehicle's *human-machine interface* (HMI) is designed in such a way, so that it prevents or hinders the driver from making unsafe assessments regarding the surrounding traffic. People with *external LOC* tend to be less attentive when driver automation is active, compared to people with *internal LOC* [18]. Therefore, there will inevitably be cases where a lack of attention can potentially lead to dangerous traffic situations. This creates a need to find specialised in-vehicle solutions for STs that are safe to use. This is especially true for highly congested traffic situations, such as in traffic jams and city-driving, where there are several things for the driver to be aware of and attentive for.

1.3 Aim

In this project, the aim is to improve communication-related driver engagement in STs during low levels of automation (specifically *SAE Level 2* and below). One of the goals is to investigate best practices for STs regarding different digital communication interactions, such as phone calling, text messaging (SMS and social media instant messaging), and email. Another goal is to develop a concept, which describes an interface (HMI) for receiving and sending this type of digital information. The HMI should be usable, efficient, and safe enough to not compromise the usability of the service, or the safety of the driver and other road users. A simple prototype will be developed, in order to test and evaluate the concept.

1.3.1 Scope

While we will try to consider many different technologies for the concept, there are two specific ones we will not consider, namely eye-tracking and voice recognition. The project stakeholders haved deemed them too early in the development to be adopted into a stable and reliable interface. However, at the time of writing this report, advances with voice recognition have been made, so we might still consider it for a secondary mode of interaction. Additionally, we will not consider any aspects of *mode awareness* (MA) of the automation state, as we will only focus on the communication aspects of an HMI concept. The core emphasis lies on creating a concept for such an HMI, while thinking outside the box regarding the interaction and user experience. This means that research will not be restricted to the automotive industry, but other industries where communication is used in critical situations as well. The HMI concept will be designed to be used in congested traffic situations, where there is a high requirement for attention, such as during traffic jams and city driving.

1.3.2 Ethical considerations

The project will be about sending and receiving digital information while driving, which could impose some ethical issues, as it is illegal[1] (in Sweden) to drive while holding communication equipment. This means that the concept must be safer than traditional cell phones. For the project itself, since user tests will be conducted, extra care must be taken with the participants in order to make sure that the tests are carried out professionally.

1.4 Research questions

Given the context of a motor vehicle with an automation level of SAE Level 2 and lower, this paper will focus on the following research questions:

(1) What safe interactions exist for using in-vehicle interfaces for digital communication, while driving in congested traffic environments?

(2) How can current HMIs for digital communication (infotainment systems) be improved, such that:

   i) it does not divert the driver's attention in congested traffic environments, and

   ii) it lends itself as an efficient tool for the driver, without sacrificing comfort and safety?

In the first research question, we will define "safe" as how well these interactions comply with common guidelines for in-vehicle equipment. Specifically, the *National Highway Traffic Security Administration* (NHTSA) guidelines, which are part of a comprehensive document explaining best practices, will be used as a reference.

[1]According to 4 ch. 10 e § in *Trafikförordningen* (SFS 2017:1284).

2

Theory

In this chapter, we will bring up relevant studies and theoretical concepts regarding driver behaviour and autonomous driving. Most of the theory discussed here will be about research relevant to driver distractions. The guidelines from NHTSA regarding in-vehicle electronic equipment will be brought up as well. We will also introduce some technologies currently used in cars regarding digital communication and entertainment, as well as give some suggestions of other interfaces which may be suitable for a semi-autonomous driving context. Lastly, some theory surrounding system evaluation methods and other statistical methods will be presented as well.

2.1 Levels of automation

The standards organisation *SAE International* have defined six levels of automation in motor vehicles, which are presented in Figure 2.1. The levels, referred to as SAE Level 0 thru 5, describe which technologies a motor vehicle must have in order to be classified at the corresponding level, under some specific condition. *SAE Level 0* describes the level which no automation at all is present and the human driver is in full control of all driving-related tasks. However, it does not exclude warning and intervention systems such as *forward collision warning system* (FCWS) and *lane departure warning system* (LDWS). *SAE Level 1* requires that either *adaptive cruise control* (ACC) or *auto-steering* (AS) is present, while SAE Level 2 requires both. All SAE levels 0 thru 2 depend on the human driver to monitor the environment, meaning that they must stay focused on the road and be able to take back control whenever the automation systems become deactivated. The higher levels of automation, SAE Level 3 thru 5, depend on the system to monitor the environment.

2.2 Related studies

There are several different concepts that are related to driver behaviour, which will be brought up in this section. Previous studies have shown that distracted drivers are more likely to end up in risky traffic situations. *Naturalistic driving studies* (NDSs) have shown that STs unrelated to the actual driving of the vehicle (for instance making phone calls or using an in-vehicle navigation system), are one cause for diverting the driver's attention from the road [16]. Other causes for driver

SAE level	Name	Narrative Definition	Execution of Steering and Acceleration/ Deceleration	*Monitoring* of Driving Environment	Fallback Performance of *Dynamic Driving Task*	System Capability *(Driving Modes)*
***Human driver* monitors the driving environment**						
0	**No Automation**	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	**Driver Assistance**	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes
2	**Partial Automation**	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/ deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes
***Automated driving system* ("system") monitors the driving environment**						
3	**Conditional Automation**	the *driving mode*-specific performance by an *automated driving system* of all aspects of the dynamic driving task with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes
4	**High Automation**	the *driving mode*-specific performance by an automated driving system of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes
5	**Full Automation**	the full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**

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Figure 2.1: The six SAE levels of automation. Image: [48].

inattention include drowsiness caused by long drives and managing driving related equipment and interfaces, such as the *driver information module* (DIM), during stressful situations. In autonomous vehicles, one study had found that the driver's attention is shifted more towards a specific in-vehicle interface of the experiment, that shows the mode or the status of the automation functions, although few long glances at the display in risky situations did rarely occur [17].

There exists several different guidelines for designing HMI's in cars today. We choose to follow the NHTSA guidelines, the reasoning for this is that the other guidelines that exist is not as comprehensive and new as the NHTSA guidelines. The other ones we looked at was the JAMA and Alliance guidelines. JAMA guidelines come from Japan and Alliance from Europe. We will describe the NHTSA guidelines more in detail later in this chapter

2.2.1 Locus of control

In psychology, *locus of control* (LOC) is the measure of a person's perception of how much control they have over a given situation. LOC is generally divided into two categories: external LOC and internal LOC. People with strong external LOC tend to think that they do not have much control over their lives, relying more on fate and luck. On the other hand, people with strong internal LOC tend to instead think that they have substantial control over their lives, where their actions can have a direct impact on their current situation. Research suggest that people with strong external LOC are more careless in traffic and more likely to end up in accidents, than people with a strong internal LOC [18]. It is also suggested that automation does not have any effect on this driver behaviour [52].

2.2.2 Situation awareness

situation awareness (SA) is a person's perception and understanding of events and information in their vicinity. It involves understanding the consequences of actions, either your own or external ones, and how these events will impact your goals, either now or in the future. People with high situation awareness are less prone to make mistakes, i.e. less accidents due to "human error", while people with low situation awareness more often will make these kind of mistakes, often in stressful situations where the information flow is high. This can be proven dangerous as accidents in cars or other vehicles can have fatal consequences, for the driver and potential passengers or other road users. According to Endsley's model of situation awareness, there are three levels of understanding: perception of the elements, comprehending the situation and projecting future status [8].

2.2.3 Workload

When driving a car, there are several things for the driver to consider. There could be internal or external events that need to be handled appropriately to avoid risks. The driver need to focus on the task of driving the vehicle itself, and many other factors during the course of the driving session. This can be described as the workload of the driver, which can be separated into three categories: visual workload, motor workload, and *mental workload* (MWL). This is similar to how NHTSA divides their distraction factors, explained in the next section. In short, visual workload refers to how many things the driver has to look at, while motor workload refers to the amount of work performed by their motor skills [6].

MWL is used to describe how many things the driver has to consider at the same time, by their neurophysical, perceptional and cognitive abilities [6]. The point when the MWL reaches a critical level, i.e. the driver is feeling overwhelmed by all the internal and external events and actions to consider, is called *mental overload* (MOL). Contrary, if the driver feels that they have too little things to consider and as a result becomes less attentive, it is called *mental underload* (MUL). Both conditions should be avoided, as they are deemed equally serious, but for different reasons. Monotonous driving environments, such as highway driving, could potentially be a risk for MUL, while MOL is more often associated with stressful driving, e.g. congested traffic situations in cities [52, 57].

2.2.4 NHTSA guidelines

A report of guidelines and recommendations have been compiled by NHTSA regarding in-vehicle electronics, which outlines how ST devices distracts the driver and what to consider when designing vehicle interfaces, in order to prevent accidents [39]. The report defines three types of distractions: *visual*, *manual*, and *cognitive*. Anything that makes the driver divert the eyes from the road, is considered a visual distraction. For instance, the DIM has many indicators which forces the driver to look down. Manual distractions refer to the type of distraction where the driver takes their hands of the steering wheel, in order to operate another non-driving related device, such as a cell phone. Lastly, cognitive distractions include events and activities which divert the driver's attention from their main driving tasks.

In the report, NHTSA have taken results from several driver distraction studies, and determined the risk odds ratios from various secondary tasks in both cars and heavy trucks [16, 39, 40]. A risk odds ratio of 1 means it is as safe as the baseline measures. Ratios above 1 indicate STs with an increase in driving risk, while ratios below 1 work as protective ST, which make it safer to drive doing these STs rather than doing no ST at all. Examples of risk odds close to 1 are talking or listening to a hand-held phone in both trucks and cars, and adjusting the instrument panel in a truck. The protective STs that are mentioned are auditory-visual tasks, and include talking in hands-free phone in a truck, or interacting with a passenger in both. The risk odds increase when performing STs such as reading, reaching for moving objects, or text messaging on a mobile phone, all visual-manual tasks. All the tasks requiring the driver to operate a hand-held phone are not recommended, according to NHTSAs guidelines. Text messaging on a phone (in a truck) had the highest risk odds ratio out of all STs.

The NHTSA guidelines are divided into three phases, with the first phase (which only considers visual-manual in-vehicle equipment) being the only one proposed so far [39]. The guidelines are meant to guide *original equipment manufacturers* (OEMs) to design in-vehicle equipment that discourage drivers from high risk STs, and are aimed only towards light vehicles, such as passenger cars and lighter trucks and buses. The guidelines specifies STs which are inherently distracting to the driver, including viewing non-driving related images and videos, reading auto-scrolling texts, using more than 6 button or key presses for text input, and reading more than 30 alpha-numeric characters of text. NHTSA recommends OEMs to design their in-vehicle equipment, so that it prevents the driver from performing unsafe STs while driving.

The guidelines also state two test methods, which can be used to determine whether a specific ST should be performed while driving or not. The first test method is to measure the glance time away from the road, having a threshold of at most 2 seconds of glance time away at any one time, and at most 12 seconds of cumulative glance time away, during the performance of the task. The second test method uses a visual occlusion technique to ensure that a task can be performed while driving using 1.5 second glances and a cumulative glance time away from the road of no more than 9 seconds.

Lastly, the guidelines state that ST device functions should be designed so that it requires at most one hand to operate (including input devices mounted on the steering wheel), and that the active display of the device should be located as close as possible to the driver's forward line of sight, with a maximum of 30° of downwards viewing angle.

2.3 Current interfaces for digital communication

There were several types of interfaces for digital communication we thought of before the design process of the project, that seemed interesting to try out. The aim of the project was to see which one fits best for our goals (safety, comfort, efficiency). Communication in cars these days are most often done via a mobile phone, either by talking (hands-free or hands-on) or text messaging. Many modern cars have infotainment systems with touch screens, which can be connected to a mobile phone. These infotainment systems often come with complementary tangible input interfaces, such as buttons and knobs, used to navigate menus and input text.

The interaction between the driver and the desired digital information can be broken up into incoming and outgoing information. Interfaces for incoming information can be both visual and auditory. All cars and trucks have a DIM near the line of sight of the road, which shows text and ideograms of important driving related information, usually warnings about the engine, fuel and slippery roads, but also things such as the driving distance until the fuel tank is empty. By using displays near the driver's line of sight, such as a *head-up display* (HUD), similar solutions could be made for digital communication, whether it is to show full text messages, or just notifications. Outgoing information can be sent using different keyboard typing methods and touch gestures, preferably near where the driver has their hands on the steering wheel, in order to minimise the manual distraction.

2.3.1 Visual and auditory interfaces

Communication revolves around the exchange of information between two parties, and there are several ways of receiving information, which may or may not be obtrusive to the driver. The information has to be conveyed in an efficient, comfortable and safe way, according to the project requirements. Visualising digital communication while driving is a task that have been tried with several interfaces and techniques before. The most common way to visualise information to the driver is, as mentioned, via the DIM, which could be either by analogue (gauges and meters) or digital (displays) components. Additionally, there is often an infotainment system in the middle-front compartment of the car, often showing non-driving related information. The problem with DIMs and infotainment systems is that they are *head-down displays* (HDDs), meaning that they require the driver to take their eyes of the road. A solution to this is to bring them closer to the line of sight, in the form of a HUD, for instance by having a projected image on a small screen by the windshield. Another form to consider is speech synthesis, having incoming messages be read to the driver. This frees up the visual distraction, but may introduce new problems, such as cognitive distractions.

2.3.2 Text entry methods

Text input is one of the major methods of digital communication today, used, for instance, when writing emails, text messages, or social media status updates. There are several text entry methods which may be beneficial for an automotive environment. The numerical key pads used on older mobile phones have the advantage of eliminating the visual distraction, since one can use the physical affordance of the keys to input characters. In combination with the T9 word prediction software, the number of key presses can be reduced. Modern smart phones mostly use the XT9 prediction software together with the QWERTY keyboard layout, which predicts words the user types depending on the letters the have written so far, and thus may reduce the number of errors the user makes.

Swipe is another text input method that can be used on QWERTY keyboards. By swiping your finger across the keys you want to use in your word, Swipe can anticipate which word you wanted to write. This doesn't need to be as precise as hitting individual keys with standard QWERTY input methods, potentially making it less error prone. Another form of text input is Scribble, which is a gesture based input method. Scribble works by having the user "scribble" individual characters or a whole word as you would write it on paper, and the software would then translate this into digital text. This has the same potential as the numerical keypads for the older mobile phones, since there is no need for any of the affordances present in key pads, and thus one could potentially learn to scribble without looking.

As mentioned earlier, in order to minimise the manual distraction of an input interfaces, we could, for instance, have the input device mounted directly on the steering wheel. This may be beneficial in the sense that it allows the driver to quickly take control over the vehicle in critical situations. One idea for such an input device is a knob at the back of the steering wheel, which the driver could use to navigate through a list of options shown on a display, for instance auto-generated replies to a text message[1]. Another type of interface could be a split keyboard, much like what is used in iOS on their iPad devices, making it potentially easier to type when compared to a full keyboard on one side of the wheel. However, as the NHTSA guidelines has stated, using both hands for an interface is not recommended, so extra care must be taken when considering bimanual input interfaces.

2.3.3 Notification methods

There may be some cases where it is not appropriate to convey the full message to the driver, for instance when in highly congested areas. An alternative would be to

[1]Basson, S.H., Bravin, S.E., Huber, W.B., Kanevsky, D., Noll, A.J., and Skwersky, A., (2017). *Messaging in attention critical environments.* US9680784 B2

notify the driver of an incoming message, without being too obtrusive. The DIM works this way, by lighting up indicators that notify the driver about some aspects of the car, while warning sounds are used to immediately warn the driver about an issue requiring their immediate attention. The concept of using ideograms could perhaps be used in a HUD, for instance in the form of *emojis* to express simple emotions. Another notification device could be haptic feedback in the driver seat or in the steering wheel. Different vibration patterns could be used to convey different types of notifications.

2.4 Statistical methods

There are some statistical methods which are useful for gaining insight about some set of data. There are two methods, the *chi-squared* test and *system usability scale* (SUS), which will be presented in this section. The chi-squared method is useful for comparing nominal and ordinal data, using hypothesis testing, and SUS is used to compare two or more systems, or system versions, with each other.

2.4.1 Chi-squared test

The chi-squared test is a statistical method, which is using hypothesis testing to see whether there are any significant difference between categories of data [20]. Hypothesis testing works by stating a *null hypothesis*, which states no difference in the data in question, and an *alternative hypothesis*, which state that there is a significant difference. The goal of this test, is to reject the null hypothesis in favour of the alternative hypothesis, in order to confirm a difference, or accept the null hypothesis, in order to confirm no difference.

The chi squared test works by first finding categories of nominal data to test on, such as, in the case of drivers, those who drive daily and those who drive occasionally, and those who are male and those who are female. Nominal data are data that have no intrinsic value, such as the daily and occasional driver categories mentioned above. Ordinal data is data that can be ranked or ordered relatively to each other, but does not have a meaningful value to compute a statistic for [21].

Chi-squared, denoted χ^2, is given by the following equation:

$$\chi^2_{i,j} = \frac{(x_{i,j} - E(X)_{i,j})^2}{E(X)_{i,j}},$$

where $x_{i,j}$ is the number of sample points in a pair of options of the respective categories, and $E(X)_{i,j}$ is the expected number of sample points. In other words, $E(X)_{i,j}$ is calculated by taking the product of the total number of sample points, C_i and D_j, for options i and j of the two respective categories (such as the male-female and daily-occasional categories mentioned previously), and dividing by the actual number of sample points $x_{i,j}$. The relation is given by:

$$E(X)_{i,j} = (C_i \times D_j)/x_{i,j}$$

By computing $\chi^2_{i,j}$ for each possible combination between the categories (in our example there are four: male - daily, male - occasional, female - daily, and female - occasional) and adding the results, you get the final χ^2 value.

Before we can use this value to see if we will reject the null hypothesis or not, we first have to specify a significance threshold (α), where $\alpha = 5\%$ is a commonly used value. Having a lower value for α will strengthen the statistical likelihood of the rejection being valid. We also need the *degrees of freedom* (ν), which is given by $\nu = (N-1) \times (M-1)$, where N and M are the number of options in each category, respectively. Using χ^2 and ν, a P-value can be obtained, which is a percentage between 0% and 100%. If the $P < \alpha$, then we can reject the null hypothesis.

2.4.2 System usability scale

The SUS is a scoring metric for system usability and efficiency, and can be calculated using the answers from 10 subjective questions regarding the system. Each question is answered with a value between 1 and 5, where 1 means *strongly disagree* and 5 means *strongly agree*, and values in between are a linear interpolation of the two extremes. The questions that are used for the SUS are:

1. I think that I would like to use this system frequently,
2. I found the system unnecessarily complex,
3. I thought the system was easy to use,
4. I think that I would need the support of a technical person to be able to use this system,
5. I found the various functions in this system were well integrated,
6. I thought there was too much inconsistency in this system,
7. I would imagine that most people would learn to use this system very quickly,
8. I found the system very cumbersome to use,
9. I felt very confident using the system, and
10. I needed to learn a lot of things before I could get going with this system.

The questions alter in the way they are phrased. Odd-numbered questions are phrased such that a 5 would increase the score, while even-numbered question are phrased such that a 1 would increase the score. The calculation of the score for a given question $Q_n(x)$, where n is the question number and x is the answer value between 1 and 5, is given by:

$$Q_n(x) = \begin{cases} (x-1) \times 2.5, & n \text{ odd} \\ (5-x) \times 2.5, & n \text{ even} \end{cases}$$

Thus, with a set of answers $\{x_n : 1 \leq n \leq 10\}$, the total score S is then given by:

$$S = \sum_{n=1}^{10} Q_n(x_n)$$

3
Methodology

This project aims to reveal more insights and increase our knowledge about driver behaviours when partial automation is active. Therefore, we used methods mostly for developing concepts, conducting evaluation studies, as well as performing user research [2, 3, 42, 44]. Some methods for digital prototyping (software or hardware) have also been used, in order to create a prototype around a particular technology [42]. We worked iteratively by first finding a concept for a particular technology or communication form, and then tested it by conducting simulations and user observations in a controlled laboratory setting, looking at different measures for attentiveness [44]. Our target driver group include professional, experienced, intermediate, and beginner drivers, of varying ages and familiarity with technology. The results were evaluated and used for the next iterations of the concept. Several user tests were conducted, so that meaningful conclusions could be drawn from the conceptual designs.

Our design process consisted of practical research methods, such as observations and data gathering, and ideation methods such as brainstorming sessions and making scenarios, in order to spark ideas for potential HMI concepts [41, 45]. We looked at similar studies and their methodology when designing the concept, but were not bound to follow their process in all aspects [10]. We adapted our process to fit our requirements, not worrying too much if our exact process has been done before. Looking at current HMI designs in semi-autonomous vehicles such as Tesla, Volvo, and BMW was also helpful to us when designing the concept.

The entire workflow of our design process can be described using Jones' model [15]. The Jones' model describe three phases: divergence, transformation, and convergence. During the divergence phase, the understanding of the domain is improved, and several ideas are generated using some form of ideation method. The transformation phase is meant to refine and more closely define the ideas generated from the divergence phase. Finally, the convergence phase is meant to test out the concepts in the form of prototypes.

3.1 Literature research

The initial phase of the project involved a couple of stakeholder meetings with Volvo and Semcon. In addition, each member of this project performed a simulation conducted by the stakeholders of the SEER project, which tested different types of typing interfaces during manual and automated driving. To get a better understanding of the problem domain, several pieces of literature, articles, technical reports, and internal documents, have been read [5]. Most of the literature research was done in the beginning of the project, but an ongoing research effort was made as we went on to develop the concepts and plan for the user tests.

3.2 User research

Before developing a concept, we needed to specify the driver needs. One way to do that was to perform ethnographic interviews and observations around drivers and drivers of semi-autonomous vehicles, if participants can be found early on [5]. Another way was to study already existing reviews and perform task analyses on various semi-autonomous vehicles, such as Tesla, BMW, and Volvo [43]. A combination of these methods gave us relevant data regarding driver behaviours and expectations with automation systems, as well as these systems' potential flaws and quirks.

The user research data was compiled into several user roles, describing a class of users in terms of their needs, interests, expectations, and behavioural patterns in relation to semi-autonomous driving [3]. By looking at these qualities, we were able to identify the experience and end goals of the drivers, and prepare to design for the visceral and behavioural aspects of the concept, respectively. Experience goals describe the sensations of the interface, for instance how safe it feels or how well it keeps the driver focused. End goals describe what motivations lie behind the tasks being performed on the HMI.

3.3 Concept development

The HMI concept was first manifested by having a brainstorming session, from which user requirements have been established prior in the user reseasch phase [45]. To refine the concept, we took the knowledge from the user research, i.e. the driver goals, and used it to form various scenarios [4]. The scenarios described different situations and contexts in a driving environment, giving us additional design requirements, in addition to the safety, efficiency, and comfort requirements given by our stakeholders. To get further understanding of the driver engrossment in a driving environment, methods such as scenario mapping was utilised [9]. This was useful for solidifying our thoughts onto paper, and to use it to draw conclusions from.

During the project, we came up with ideas that involved a specific kind of interaction, not currently found in an mobile phone application or some other form of interaction device. Due to this, we built and programmed a digital prototype capable of carrying out the core aspects of what we wanted to test [42]. The main purpose was to recreate the desired interaction, not create a fully functional prototype, thus the Wizard of Oz method was used in conjunction [42].

3.4 Prototyping

For testing out the functions of the concept, low-fidelity and high-fidelity prototyping was used [42]. This is useful in order to convey the initial impression of the design to users, without having to explain it to them through conversation. Instead, they can try out the design themselves and get a feel for it. This also helps when getting more relevant feedback from the user tests.

When making low-fidelity prototypes for physical products, it is usually made with simple materials, such as paper and cardboard, that are fast and easy to get done [42]. When prototyping software, there are special tools and software which specialise in making it as easy as possible making a visual or interactive substitute of the system. Often there are only a few core functions which are mimicked and implemented this way. The high-fidelity prototypes are implemented by code, in order to get richer response from the system you're designing, also by focusing on the most important and central aspects to test.

3.5 Evaluation

When an iteration of the concept had been completed, we used it and its prototype to evaluate it with driver test subjects, as outlined in this section. During the evaluations, we gathered data through different ethnographic data gathering methods and analysed them for the next iterations.

3.5.1 User tests

For the evaluation of the concepts, empirical research methods were employed. We used simulations as one method, which worked as a usability test, to test how efficient the HMI was [2]. After the simulation, we collected answers from the SUS metric, as described in Section 2.4.2, to be able to compare between the different prototype iterations.

During the simulations, observational and correlational methods was used to identify and confirm links between driver inattention and traffic safety, when using a particular interface for communication [41, 21]. Other studies have used glance time and number of glances away from the road as a measure of driver distraction. We asked control questions during the simulation regarding the traffic environment, in order to measure the attentiveness of the test subjects. In order to catch other observational data, we asked for the test subjects consent to be filmed, in order for us to use this footage later to extract relevant data [41].

To find driver test subjects, we asked different people of different ages and experiences to participate. Some subjects were asked to participate again during a later iteration, to see whether their performance on the system had changed.

3.5.2 Data gathering

During the user tests, we mentioned that we were filming (qualitative data) and collecting SUS data (quantitative data) from the test subjects [41]. As an addition to this, we directly observed the participants regarding their actions and reactions, by taking notes and asking them questions [41]. We also prepared questionnaires that participants filled in after the user tests, as well as having short interviews prior and after, in order to gain insights not captured by the invitation forms, observations, and questionnaires [41].

3.6 Tools

During the design process, we used several tools to aid us in different ways. The graphical designs were created in Figma and Inkscape. Inkscape is a vector based drawing tool, used to create more detailed designs and figures, many of which are featured in this report. Figma is a digital prototyping tool, aimed more towards the interaction of a digital system, mainly for smart devices and personal computers. Figma was used to create larger concept illustrations which we used to create graphical story boards, i.e. linking together several concept images to create a story, which showcases the features of the prototype. For all the programming of the high-fidelity prototype, Android Studios was used. Android Studios facilitates all the necessary tools to create an android app.

Several of Google's tools and services were used. Google Docs was used to write our common diary, collect information and documentation images, and prepare lists of data of various sorts. For the survey, we used Google Forms to send out to drivers. For the data received, we used Google sheets, which we used for calculating the various statistics, such as the chi-squared values. Additionally, scripting languages like *Python* was used to create simple calculation programs for the SUS scores.

4
Planning

In this chapter, we will describe the overview of the different activities in the project and how much time was planned to be spent on them. The milestones set up before the project started are also presented here. Finally, a Gantt chart of the initial planning is also shown. For the most of the project, the planning was followed, so only minor things have been altered in the planning since the planning report.

4.1 Activities

In Table 4.1, all the activities of the project are shown, as well as how many man-hours were planned to be dedicated towards them. As can be seen in the table, the project consisted of three phases: **preparation**, **project work**, and **delivery**. Preparation activities include planning out the project, doing literature research, preparing user test invitation forms, attend stakeholder meetings (both SEER stakeholders and Chalmers University of Technology), as well as writing the planning report. During the project work phase, activities included user research, concept development, prototyping, and user testing. The delivery phase includes all non-project related activities required for the delivery, including the project report, presentations and oppositions.

Most activities that were planned, were also performed during the project. The only exception is the invitation of participants activity, which was transformed into preparing a user survey for the user research instead. The user survey contained a section which asked for contact information for future user tests, but these were never used in the project. Instead, participants were found in the area around Lindholmen, Gothenburg, where the project was conducted.

4.2 Milestones

The different milestones and deadlines for the project are listed in Table 4.2. Deadlines are for activities related to the delivery of the reporting of our work, while milestones are related to the project work. The milestones for the concept iterations include everything from coming up with or improving the concept to the evaluations of the user tests of that iteration. While we did not meet the exact milestones for each iteration during the project, we did complete three iteration cycles, one for a low-fidelity prototype and two for the high-fidelity prototypes, as described in Chapter 5.

4.3 Timeline

As mentioned, the project consist of three phases. The first phase, the preparation continued until 4 weeks after the project start date (January 22nd thru February 16th). The project work phase spanned for 13 weeks (February 12th thru May 11th), starting on the last week of the preparation phase. The last phase, the delivery, was partially overlapping the project work phase, spanning for 7 weeks (April 23rd thru June 8th). Originally, 2 weeks were inserted between the first hand-in of the project and the start of the demo preparation phase. Ultimately, these weeks were removed, since we could plan for an earlier demonstration date. To get a better overview of the phases, a Gantt chart has been made, shown in Figure 4.1.

	Activity	**Man-hours**	
Preparation	Literature research	100	**320**
	Planning report	120	
	Invite participants	80	
	Stakeholder meetings	20	
Project work	User research	160	**880**
	Iterative design	480	
	Prototyping	120	
	User evaluation	120	
Delivery	Project report	320	**400**
	Presentation and opposition	80	
	Total	**1600**	

Table 4.1: Distribution of man-hours over the different activities in the project.

Activity	**Milestone**	**/ Deadline**
Planning report		February 16th
Concept iteration 1	March 23rd	
Concept iteration 2	April 20th	
Concept iteration 3	May 11th	
First report hand-in		May 25th
Demonstration		June 5th
Final project report hand-in		June 8th

Table 4.2: Milestones and deadlines of the project.

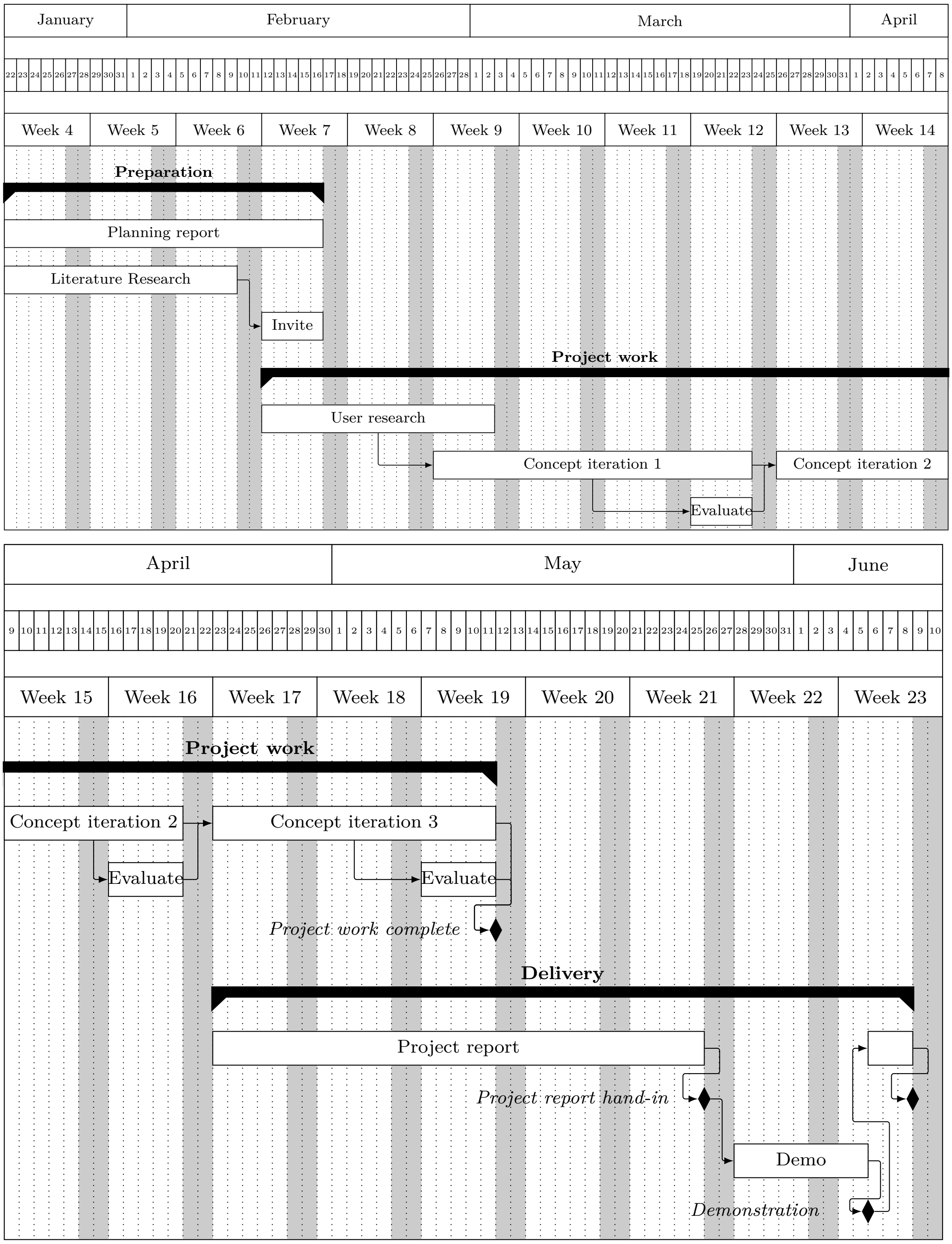


Figure 4.1: Gantt planning chart of the project.

5
Design Process

In this chapter, we will describe how the project was carried out and what design decisions was made along the way. The project consisted of several phases, including preparation and planning, user and market research, concept ideation and prototyping, and finally user testing and evaluation. The preparation phase of the project, described in Section 5.1, consisted mainly of doing literature research and gaining general knowledge from the automotive industry, specifically in the field of autonomous driving. In Section 5.2, we describe the process of collecting initial user expectations of in-vehicle HMIs, as well as current market solutions. After this, the creative process for finding concepts started, as described in Section 5.3. The concepts ideas taken from the ideation process were refined and implemented as working prototypes, as described in Section 5.4. Finally, in Section 5.5, we will go through the process of testing our low and high-fidelity prototypes, and using the feedback to improve and iterate over the concept.

5.1 Project preparation

The initial phase of the project were dedicated mainly towards literature research in the domain of STs and semi-autonomous vehicles. Additionally, the structure of the project was planned during this phase as well, by specifying critical deadlines and milestones, as well as grouping the project into distinct phases.

We started reading up on several different subjects regarding human cognition and driving behaviours, such as MWL, LOC and SA, as explained in Section 2. During the early stages of the project, we worked closely with our peer group when gathering relevant literature, as we at that point had yet to decide which contexts we would choose, namely either city driving or highway driving. As the literature research progressed, it was decided that we would develop a concept for city driving, while our peer group worked with highway driving. City driving and highway driving are different enough contexts to impose different challenges. As the research we read suggests, city driving is more likely to lead to MOL due to the stressful environment. In addition, there are likely to be many interruptions if the driver would be engaging in STs during city driving. In contrast, highway driving and long distance drives can instead lead to MUL, due to fatigue of monotonous driving.

With this knowledge in mind, we got the insight that our solution for the concept should preferably be as simple as possible, minimising navigational (the HUD) and manual (input methods) excises, while still remaining usable. To address the manual excise, we wanted the input method for the HMI to be as close as possible to the steering wheel, in order to prevent the user from moving there hands from the wheel frequently. This is especially necessary for traffic driving, due to its interruptibility nature. We also decided that the system we were to design should compliment the main infotainment system of the car, with our system being a tool for STs, with a focus on digital communication.

5.2 User research

After the planning phase with the literature research of the project had concluded, we began to do the user research as a basis for the user requirements for the concept. Part of the derived user requirements was based on market research, by looking at existing car manufacturers, and partly based on our own survey, which we sent out to car and truck drivers.

5.2.1 Market research

In order to get an initial starting point for our user requirements, we first set out to look at existing solutions on the market regarding navigation in infotainment systems and similar systems in the DIM. By looking at the interior designs from the web sites of various semi-autonomous cars, such as Tesla, Volvo, and BMW, we got a rough idea of what to expect in these types of cars. Since we were researching for the city driving environment, we did not put as much emphasis on researching semi-autonomous trucks, since their self-driving capability in cities are still limited. We did however drive a Volvo XC60, which had *pilot assist* (PA), in both light and heavy traffic environments, in order to get a better understanding of the current state of semi-autonomous cars in cities.

To get an overview of how the navigation structure of an infotainment systems might look like, we performed an *hierarchical task analysis* (HTA) of the Volvo XC60 model that we drove. We could later use this analysis as a reference when implementing the information architecture of our concept. Ultimately, we wanted to have an architecture more concise than an infotainment system. A full description of the analysis can be seen in Appendix A.

5.2.2 Survey

To compliment the market research, we prepared a survey to send out to car and truck drivers with different driving skills. The purpose of the survey was to get close feedback from the core target group, and to gain insights about what their goals might be with a new form of HMI for semi-autonomous motor vehicles. The survey was prepared using Google Forms, which supports the functionality to conditionally show questions depending on previous answers. This was appropriate for us, since we had two different areas of interests (highway and city driving, respectively) between us and our peer group of the SEER project.

Before sending out the survey to the relevant target group, we prepared a pilot survey, which we sent out to friends and colleagues, in order to ensure that the survey was properly written.

5.2.2.1 Preparing questions

There were several different sections of related questions for the survey, with conditional paths that the survey could take depending on the answers. For the first section of the survey, we asked general questions about their background, such as age, nationality, and how long they have had a driver's license. The second section asked questions about their driving habits, such as how often they drive, what type of vehicle they drive, and in what environments (city driving, highway driving, or both). The third section had questions specific to their experience with vehicles with *advanced driver assistance system* (ADAS). Depending on what they answer, the survey will take two paths. If they answer that they primarily drive a vehicle with ADASs, they will take a path with questions specific to ADAS. If they answer that they do not drive a semi-autonomous motor vehicle, then their path will have questions more open-ended questions regarding their assumptions or desires with a more autonomous vehicle. The flow of the survey can be more easily understood by looking at Figure 5.1. The figure shows what different sections (numbered from 1 to 17) the respondents will see, depending on what they answer. The questions in these sections are outlined in Appendix B.

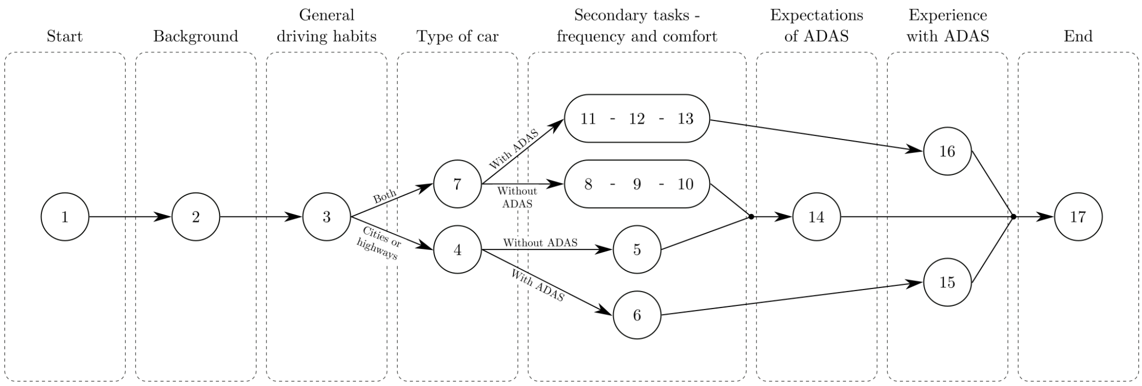


Figure 5.1: A flow chart representing the logical flow of the survey.

Regardless of which path they take, they will end up in a section answering questions about the frequency and comfort of engaging in STs while driving, such as making phone calls, text messaging, reading email, etc.

The survey was distributed through several forums on the Internet, mainly on Facebook groups administrated by truckers and semi-autonomous car enthusiast. This way, we were able to get responses from several different parts of the world. An overview of the 153 responses we got can be found in Appendix B.

5.2.2.2 Analysing the responses

After we had gotten enough responses, we exported the data into a spreadsheet, where we could better analyse potential correlations of some part of the data. We wanted to see if there were any connections between performing STs and any nominal data, such as whether they drive with ADAS or not, or if they drive regularly or occasionally. To compare nominal and ordinal data like this, we used the chi-squared method as described in Section 3.2. The chi-squared method gave use an statistical assurance regarding which STs are more prevalent in certain situations. We could then use these insights to construct user goals to use for the ideation phase of the project. A more detailed explanation of how the statistics were calculated can be found in Section 7.1.

5.3 Concept ideation

The research phase of the project was for us to have a better understanding of the target group and their requirements. The insights we gained from the research was then used as a starting point when setting up for the development of the concept. The requirements were formalised into user goals and categorised into user roles, which we used for the brainstorming session. An example of one of the user roles we constructed is shown in Figure 5.2. In the user roles, we have collected the common responses from a subset of the target group, which in this example are casual car drivers using ADAS features. We summarised the responses into a paragraph describing the target group, and condensed them into concrete one or two word goals, shown in the green bubbles. The most commonly mentioned goal of the survey respondents, referred to as their *main goal*, are shown in dark green, while the less commonly mentioned goals, referred to as their *secondary goals*, are shown in light green. All the other roles created are collected in Appendix C.

5.3.1 Divergence: brainstorming

We started to prepare for a brainstorm session by writing down all the survey respondents' main and secondary end goals with secondary tasks in the motor vehicle on a whiteboard. This way we would always have their goals in mind when coming up with ideas. We also wrote down different existing technologies, which we would use as a base when coming up with different interaction cases for the brainstorm. Our goal was to come up with a couple of potential concepts, that we would determine to be most interesting for further investigation.

During the brainstorm session, we wrote down the ideas on post-it notes and numbered each note, to better keep track of the order the ideas were brought up. After the session, we sorted the ideas into two main categories: *input*, and *output*. Ideas that belong to the input category put an emphasis on how the user would interact and deliver information to the system, for instance touch surfaces with swiping gestures, gaze-and-speech, and tactile buttons like knobs and keyboards. Ideas in the

Median driving experience	20+ years
Median age	35-44 years
Genders	12.5% female, 87.5% male
Demographics	Mostly Sweden and US
Driving routines	Mostly daily, some once or a few times a week
Driving sessions	Almost all less than 1 hour, some less than 30 minutes

They are very comfortable using voice calls and are generally more prone to engage in non-auditory tasks, compared to non-ADAS drivers (DMs, email, web browsing). They have some trust to ADAS functions and appreciate that technology is used as a safety mechanism. They would perhaps like the system to allow for better integration for non-auditory tasks with the car. Their goal might then be to increase their efficiency while driving.

Integration **Efficiency**

Figure 5.2: A user role constructed for casual car drivers using ADAS features. Symbols: [19].

output category instead emphasised on how to deliver information for the user, for instance displays, sounds, and haptic feedback.

We took a couple of ideas from the brainstorming, which we believed could be improved upon and made into a full concept. The next step for these ideas was to see which of them violate common guidelines (mostly from NHTSA) for in-vehicle equipment, and then condense the ideas into around four main concepts to continue to iterate upon.

5.3.2 Transformation: choosing and refining ideas

Previously, we had compiled all the relevant in-vehicle equipment guidelines into one cohesive document. This helped us identify which of our ideas had the least number of violations to these guidelines, and thus choose the most suitable ideas. By modifying or rejecting ideas in the early phase, we would save time and effort in the later development stages. The next step was to take the viable ideas and construct four rough concept ideas, which we will describe in the following sections, starting with the two input concepts and ending with the two output concepts. The concepts describe the general setup of the device, its different input and output modes, as well as its advantages and disadvantages. This helped us get a rough overview of the different interactions that might be performed by the users.

5.3.2.1 Trackpad

One of the early input concepts that we constructed, was the use of one or a pair of trackpads mounted on the steering wheel, as the main input for our system; see Figure 5.3 for the related ideas from the brainstorming session. This concept was inspired by the *Steam Controller* and the *Steam Big Screen GUI*, which is made for playing PC games without the need to use keyboard or mouse for navigation or moving the on-screen cursor. The trackpads are circular, touch sensitive areas, also having areas working as tactile buttons. This combination allows for both touch gestures, and the physical affordances of tactile buttons, to be blended into one input interface. Taking inspiration from this interaction method, we decided that the trackpad input interface would be our first concept that we would work further on.

We had several ideas in mind as how to write text using the trackpads. One of the ideas was to use the trackpad as a drawing area to draw individual letters or words, which we referred to as *Scribble*. Another idea was also inspired by the Steam Controller, where each trackpad would control separate cursors of a split QWERTY keyboard, and have the user press down on the trackpads in order to type a character. Lastly, we also had an idea to adapt the T9 input method, commonly used in older mobile phones, into the layout of the trackpads. We refer to this idea as *Circular T9*. Instead of having the T9 buttons placed in a grid, they are instead placed in sectors, with the space button placed in the middle.

We imagined the trackpads having some form of display on them as well, showing icons for the different functions available on them. The icons would change depending on the context, that is, if the user navigates to a certain menu in the system, the relevant icons for the functions in that menu would appear.

The trackpads have the advantage of being configurable to the users' liking, whether it is to turn of certain functions, or flip the left and right trackpads, if two of them are present. One disadvantage may be that the interactions can be confusing to new users or occasional drivers, especially those who are generally not comfortable with new technology, such as smart phones.

5.3.2.2 Touch surface

Another form of input method that was considered, was a touch surface placed in the middle of the steering wheel; see Figure 5.4 for the related ideas. As we imagined the surface to be relatively large, it could facilitate a lot of methods of input, theoretically even output in the shape of a touch-screen instead of just a surface.

The input methods imagined for this interface included using a standard QWERTY keyboard layout, not to different from a smart tablet interface. Other input methods,

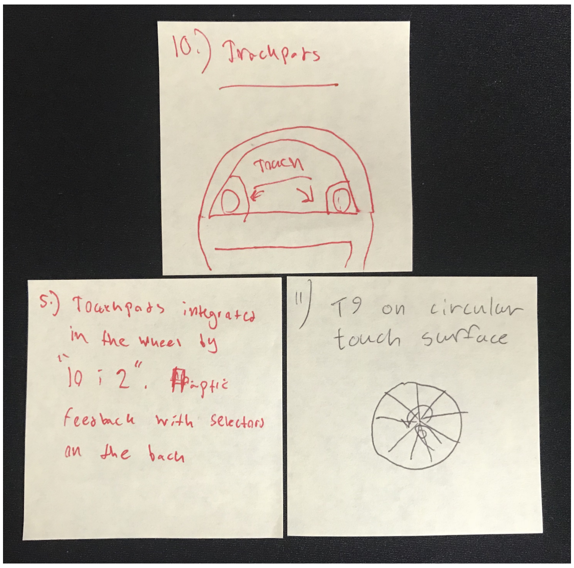


Figure 5.3: Ideas related to the trackpad concept.

such as the Scribble idea, could also be used with this interface.

The advantage of having a large tablet-like touch area, was that it allowed for a richer typing interface, using common writing interfaces like QWERTY, and thus preventing the users from learning an entirely new text input method.

There were some problems with this concept, however, with one of them being that the placement of the surface could get in the way of airbag. Furthermore, the user would not have a steady and safe grip of the wheel when using it, and it may result in a unnatural position of the hand and arm.

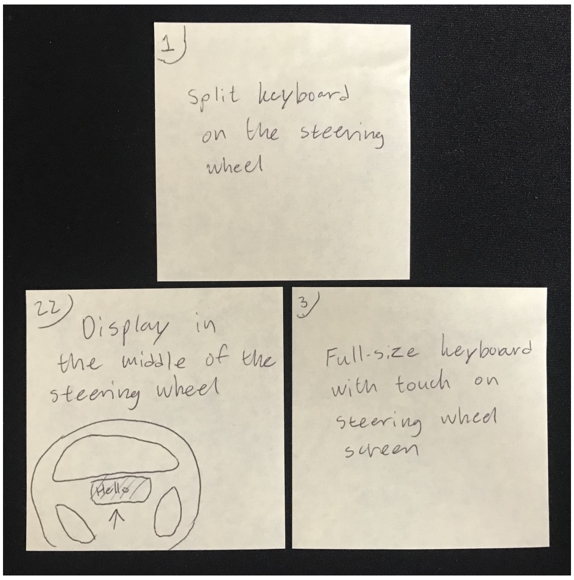


Figure 5.4: Ideas related to the touch surface concept.

5.3.2.3 Secondary HUD

One of the output concepts imaged, was to have a secondary HUD to use for entertainment and communications related tasks, while a main HUD (which is present in some cars) would have all the driving related information shown, such as the current speed of the vehicle. The secondary HUD was imagined to work as a compliment to the infotainment of the motor vehicle, showing condensed versions of the relevant apps; see Figure 5.5 for the related idea.

The advantage of having a HUD is that it keeps the driver's line of sight close to the road. It can also have a potentially large display to work with, allowing to shoe more information in one frame at a time. However, a disadvantage is that it may be difficult to show content when having direct sunlight on the windshield, as well as having enough contrast compared to the road to show information. It can also occlude parts of the road, which is not desirable in highly congested traffic areas such as cities.

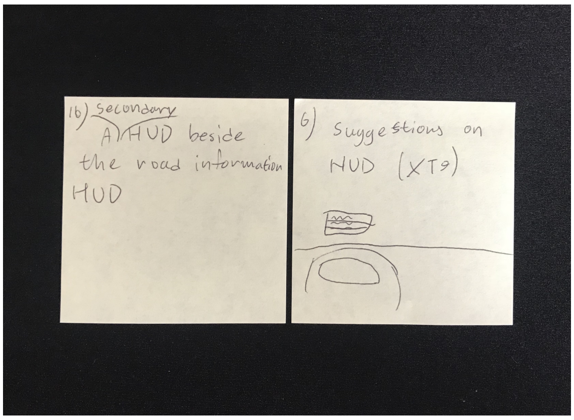


Figure 5.5: Ideas related to the secondary HUD concept.

5.3.2.4 Steering wheel display strip

The other output concept we constructed, was to have a thin display strip on the top of the steering wheel; see Figure 5.6 for the related idea. This display strip was imagined to be a small LCD-display, which could be used to display messages, simple menus and notifications.

One benefit of having a display at the top of the steering wheel, is that it closer to the driver's line of sight to the road, which is compliant with the NHTSA guidelines of a maximum downwards viewing angle of 30°. However, since the screen real estate is fairly limited, the information resolution, i.e. the amount of information fitted in one screen at a time, goes down as well. Furthermore, there is also a question about the cost of having a display on top of the steering wheel.

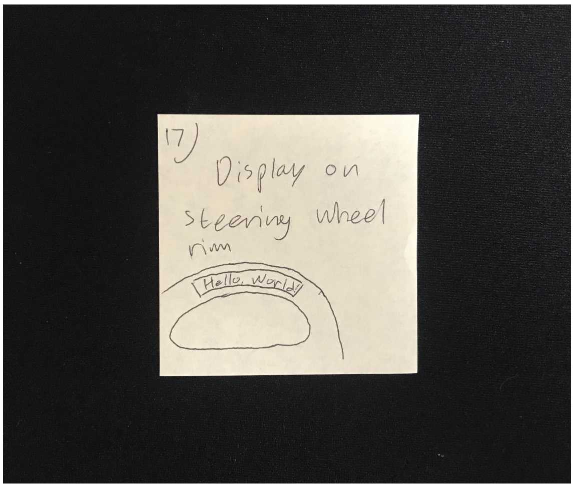


Figure 5.6: Ideas related to the display strip concept.

5.3.2.5 Scenario mapping

When we had our four concepts, we looked at some driving situations and investigated the interactions of our concepts more deeply, by using scenario mapping. Scenario mapping was used, so that we could put ourselves into the scenario of the user and detect potential problems and provide solutions for them. Scenario mapping is useful to find out what the users can and probably will do using a particular system. The insights gained from the scenario mapping were used to choose one input concept and one output concept to use for the concept development phase. Insights from the scenario mapping were brought into the design of the interactions, when making the digital storyboards and low-fidelity prototypes of the concepts.

When we performed the scenario mapping, we divided it into four different scenarios, using one of the permutations of one input and output concept, respectively:

1. **Input:** Trackpad, **Output:** Steering wheel strip display
2. **Input:** Trackpad, **Output:** Secondary HUD
3. **Input:** Touch surface, **Output:** Steering wheel strip display
4. **Input:** Touch surface, **Output:** Secondary HUD

One of these scenarios can be seen in Figure 5.7, where we perform the mapping on a professional car driver, who is not using any ADAS features of the car. The scenario is that the driver should read a text message from a colleague, using a system with the trackpad and display strip concepts.

5.3.2.6 Evaluation of the initial concepts

Having specified four potential concepts, it was then time to visualise them in different forms. We put an emphasis on drawing low-fidelity illustrations in the beginning,

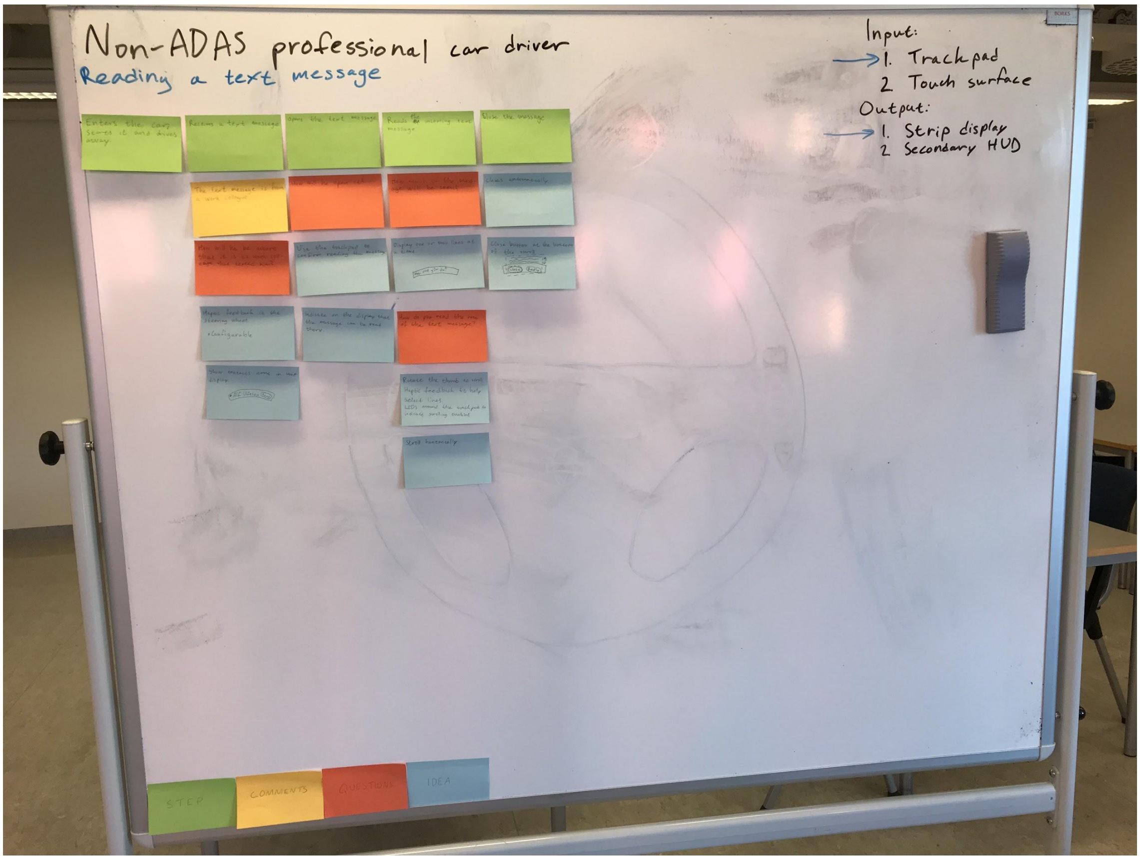


Figure 5.7: Scenario mapping allowed us to go through our ideas and discover how they work in different scenarios.

to show to each other the look and feel of our respective mental models of the concepts; an example can be seen in Figure 5.8. It also helped us find and solve certain design quirks that we had not thought about earlier. For instance, the size and placement of the trackpads were altered after early prototyping, as well an addition of physical buttons to satisfy some needs we did not realise that we had before.

With our mental models synced, and an agreed upon conceptual model developed for each of the four concepts, we began an early evaluation. The purpose for this evaluation was to process the concepts one more time and decide if we wanted to take them further to the next phase, to make actual physical and tangible representations of the concepts, or discard them all together. Each of the concepts was evaluated on their assumed strengths and weaknesses.

The result of the evaluation process resulted in us discarding two out of the four initial concepts. Our reasoning was that we only needed one input and one output method respectively, and the discarded methods had to many quirks that made them inferior to the two other methods. Our main goal was to ensure comfort, safety and efficiency and the discarded methods lacked in most of these areas.

The touch surface input had some promising properties. But there were several problems with the concept that we initially thought that we could find a solution for. The problems however, were not that easy to solve. The placement of the

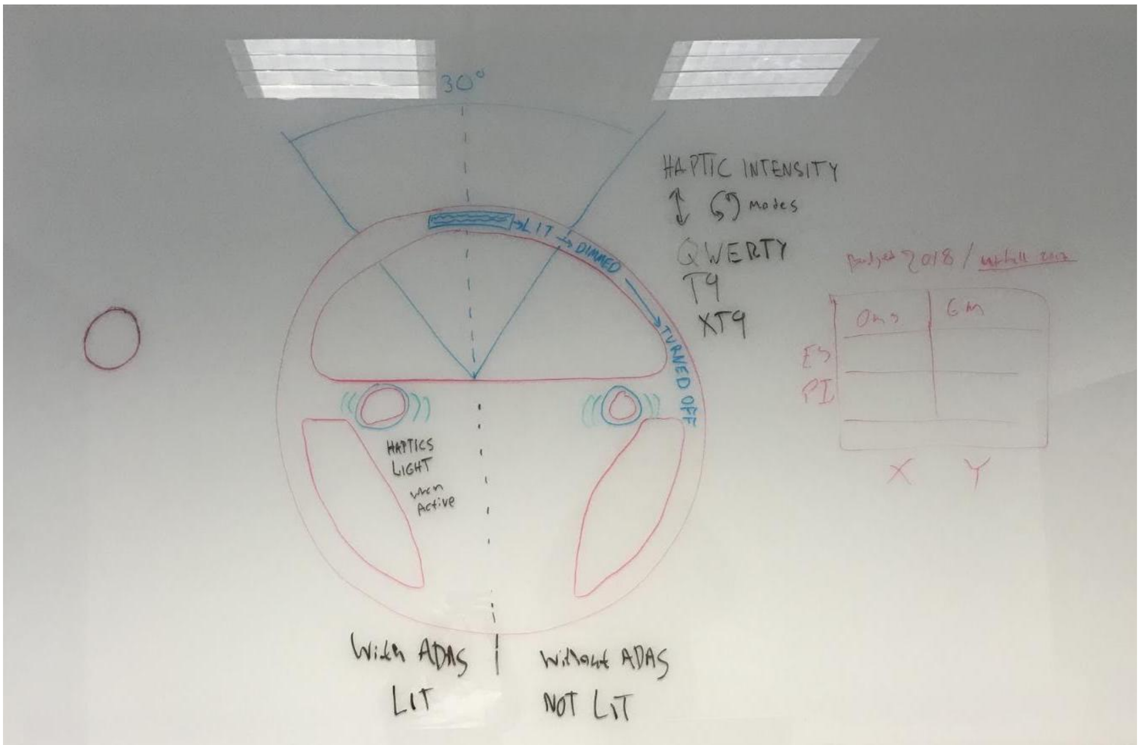


Figure 5.8: Early concept of the trackpad idea.

touch surface was intended to be in the centre of the steering wheel, which we at the time thought was an under utilised area which we could use to increase efficiency and comfort when interacting with the infotainment system. This was all highly theoretical, but we realised that the placement of the touch surface could have the reversed effect.

To use the surface, the user have to remove one hand from the steering wheel, which in our case with city driving was not the safest option in comparison to the trackpads, which enabled the user to always have both hands on the steering wheel and still be able to use the system. We evaluated that it was less comfortable as well, as the user had to have the arm in a position which was straining for the user, as there is no arm rest, which would be a problem when performing prolonged tasks. Even if we could find ways to solve these issues, there was a problem with the construction, as the centre of the steering wheel is where the airbag is placed in almost every car. Perhaps this was an issue that could have been solved, but the other problems with the method, and the realisation that the trackpads was in almost every way a far more interesting idea to the touch surface, resulted in the decision to discard the concept entirely.

A similar argument for the display strip on the steering wheel was made, and was also discarded in favour of a more appropriate design. In theory, the idea of having a display on the top of the steering wheel was intriguing, but there were several limitations to this design, however. For instance, when turning the steering wheel, it would be increasingly difficult to use the display, as it will follow the motion of the steering wheel, and thus making it cumbersome and potentially dangerous to use.

It is also a potentially expensive solution, which might make the trade-off between cost and efficiency not worthwhile. The size of the display would also be a limit, if it was to be implemented it would not pass as a primary display, perhaps in the form of a support display instead. This would make the the display strip complementary and perhaps redundant by the nature of its design, i.e. there are other displays in the car that could achieve that the display strip can and even more.

With both the display strip and the touch surface discarded, we decided to take the trackpad and the secondary HUD concepts to the next step in our design process, which was the low-fidelity prototyping. We decided to make both tangible and digital representations of our concepts to make them as clear as possible to our stakeholders.

5.3.3 Convergence: low-fidelity prototyping

Having agreed on what concepts to continue to work on, we began planning for the low-fidelity prototype, which would be used to get an initial look and feel of the concept, which would make it easier to show and test with test subjects later on for the user tests. We also began thinking about the navigation structure of the HUD, with some of the sketches drawn for it shown in Figure 5.9.

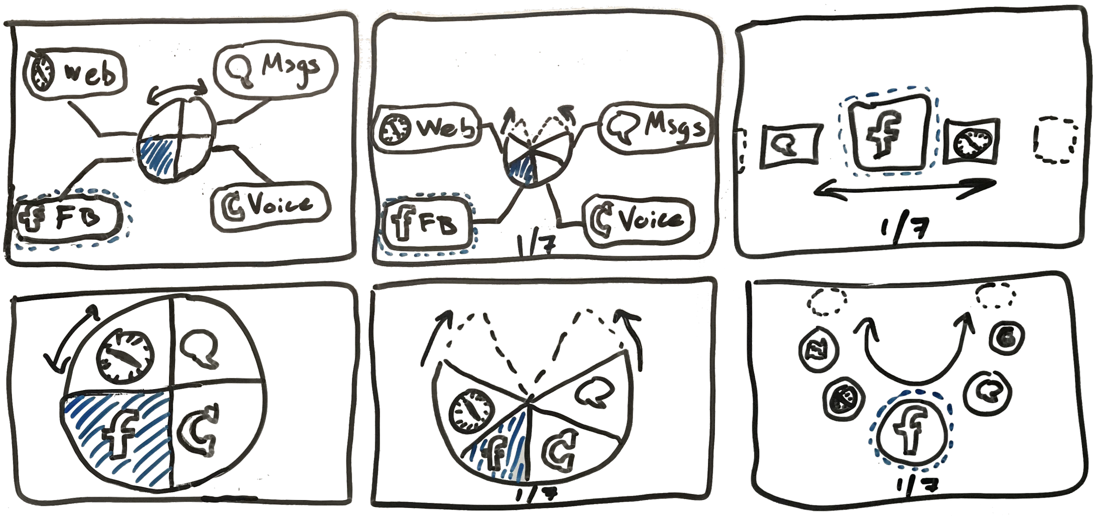


Figure 5.9: Some sketches for different navigation structures of the HUD, before making the first digital prototype.

5.3.3.1 Prototyping

We began by taking the real measurements of a typical steering wheel (in our case a standard Volvo steering wheel), and created a 1:1 template. The template was then cut out of Styrofoam, and polished by adding a layer of black paper on top, to make it smoother to hold and have a unified look. This wheel prototype served as the basis when we measured where to put the trackpads. Once we decided where to put the trackpads, we created paper representations and put them on the steering wheel prototype. The prototype is shown in Figure 5.10.

Figure 5.10: The tangible prototype of a steering wheel with the trackpads. Symbols: [54].

With the trackpads at the desired position, we realised that there were some issues with the comfort and usability of the current placement of the trackpads when AS is active. The placement of the trackpads had the potential to be tiring for the driver, as when the car is taking control over the steering wheel. Furthermore, it might disable the semi-autonomous driving mode by accident, if the driver is firmly holding on to the steering wheel while using the trackpads. As the trackpads positions were initially persistent, it could become cumbersome when the steering wheel turns by itself and the driver had to adjust their grip to accommodate for this. One possible solution to this, was to make the placement of the trackpads independent of the motion of the steering wheel. But there were some issues with this idea, as the construction could be rather complex and interfere with critical systems of the car, for instance the airbag. Nevertheless, a concept was made as a preliminary fix for this issue.

The conceptualisation of the new construction concept was created in Figma, as can be seen in Figure 5.11. With the new concept, the driver can adjust the positioning of the trackpads into a more comfortable position depending on their current task. If the users is in semi-autonomous driving mode, they might not want to have their hands on the steering wheel in the standard quarter to three, but instead in a more relaxed state where the user have their hands lowered and resting their arms on the armrest or similar comfortable positions.

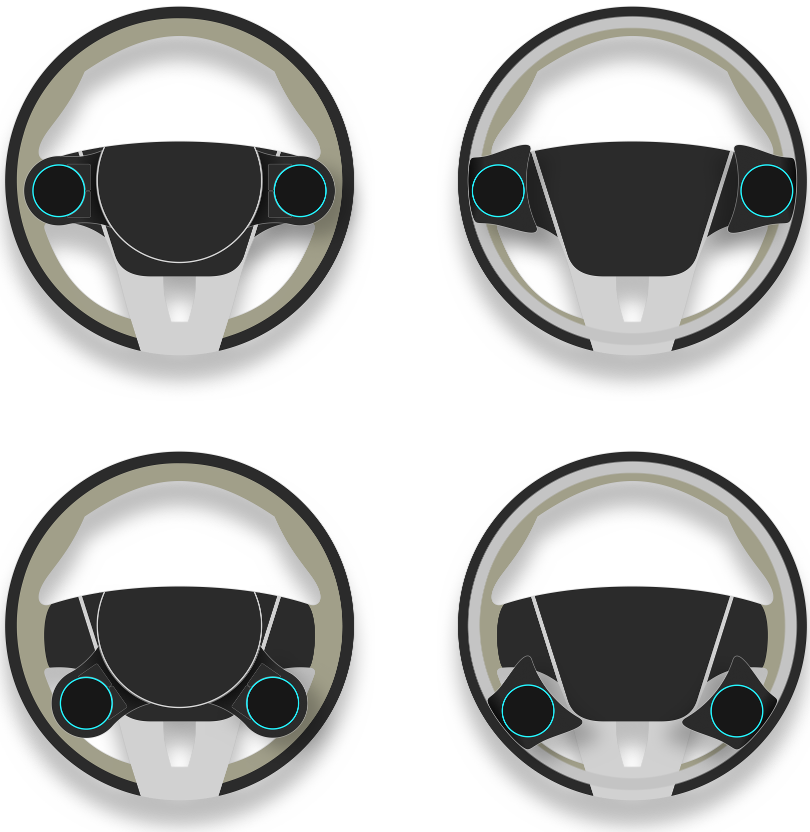


Figure 5.11: Digital prototypes showing the different installations of the modular trackpads. The left illustrations show an inner rim construction for the trackpads, while the right illustrations show an outer rim construction. The upper illustrations show a quarter past 9 formation of the trackpads used for manual driving, while the lower illustrations show an angled formation of the trackpads used for autonomous driving.

In theory, the installation concept worked well, but in practice it seemed like an engineering task which was too much out of scope for this project, as the construction would potentially be complex. Additionally, it might be very expensive, and interfere with the standards of how steering wheels in cars should look and behave. Therefore, we decided to move on with the trackpads in their original positions, without the additional construction of the modular placement.

With the help of Figma, we created a detailed digital representation of the trackpad concept, as can be seen in Figure 5.12. We decided to create a storyboard of the trackpad concept, and describe it using different use cases. For instance, one of these use cases might be: “if the user would like to increase or decrease the volume of our system, how would they do it?”. Since the input interaction with the trackpads are unusual to have in a car, we put an emphasis on how these interactions would behave. The output of the system, the secondary HUD is more straightforward when it comes to placement and the technology, as they have been a part of the automotive industry for a while. For us, it was a matter of coming up with a design which seamlessly integrates the trackpads with a system of entertainment and communication applications. As a simple example, if the user scrolls anticlockwise on the trackpad, the menu in the HUD would preferably scroll anticlockwise as well to mimic interaction of the input.

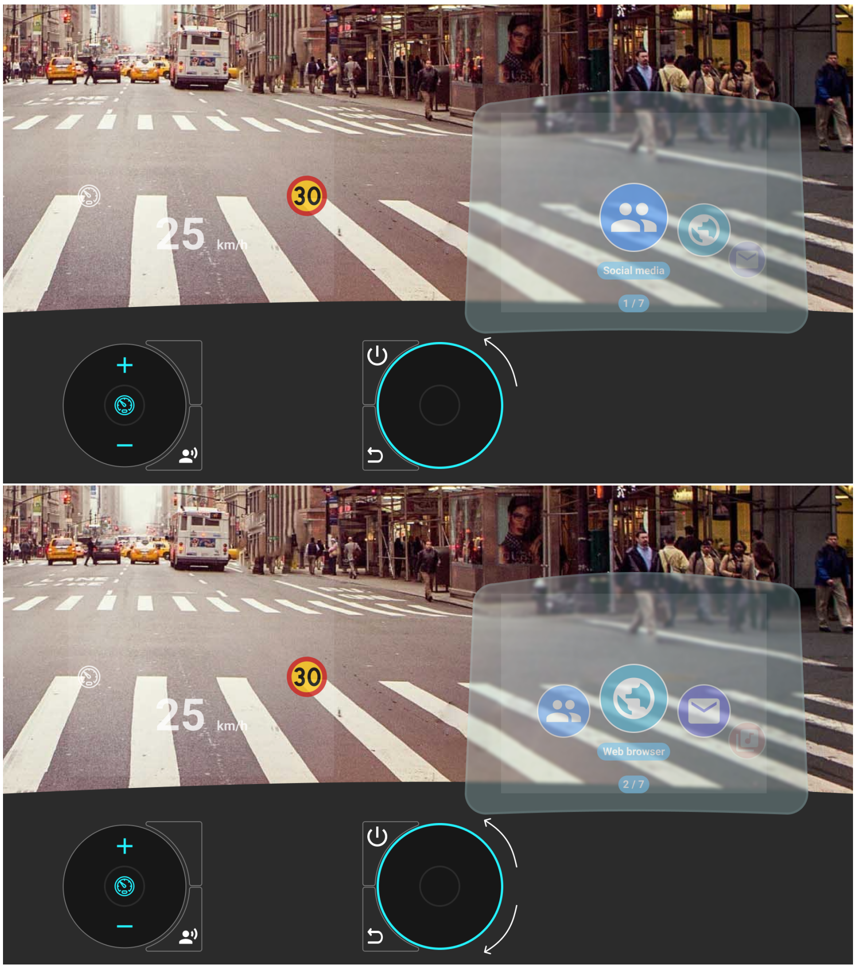


Figure 5.12: One transition in the digital storyboard, which shows the interactions of the input (trackpads), as well as the response and information visualisation of the output (HUD). The first frame shows the state of the system before scrolling anticlockwise, and the second shows the state after this action. Images and symbols: [11, 12, 13, 14, 22, 28, 29, 30, 33, 34, 35].

During this phase, we discovered that we were missing out some essential features in our conceptual system. One of those things that we missed was that there were no back method. That means that if the user was navigating the text messages, there were no obvious way in how the user would go back to the previous menu. There were other issues as well, for instance there were no obvious way of putting the system into sleep, or quick access to some of the essential functions, like *cruise control* (CC) or media control, which are commonly present on steering wheels in cars. The solution for this was to add a set of buttons on the inner side (towards the centre of the steering wheel) beside each trackpad. The buttons was intended to be tactile, and in that way the user would always know what to expect when pressing them, since they only have one function associated to them. In comparison, trackpads are contextual, which means that they change functionality depending on where in the system they are.

5.3.3.2 Concept walkthrough

After the addition of the buttons on the side of the trackpad, the functionality stayed the same throughout the project, which is why we will describe the specifics of the trackpads in this section. However, since the trackpads are contextual, the functions will change depending on the mode. These modes are more specific to the high-fidelity prototypes, so they will be explained in more detail there instead. For now, we will describe the side buttons and the standby mode functions of the trackpad, which are shown in Figure 5.13.

Figure 5.13: The digital storyboard showing the standby mode, with the side buttons and trackpads shown in the bottom. Images and symbols: [11, 12, 13, 22, 31, 32, 33, 34, 35, 36, 37, 38].

As mentioned before, the two pairs of side buttons positioned in between the trackpads, are tactile buttons and have the same function associated to them regardless of mode. On the left side, the upper button is unspecified and reserved for any arbitrary car specific function, and is not used in any of the prototypes. The lower button is the *voice dictation button*, which is an input method which allows the driver to dictate any message to write using our system. However, since this is a deliberate delimitation of the project, we haven't defined or implemented any behaviour for it in the system.

On the right side, the upper button is the *hibernation button*, which is used to put the system into *standby mode*. When the system is in standby mode, the HUD is disabled and the contextual buttons on the trackpads change to the default, which is the media controls shown in the figure. Whenever this button is pressed, the mode of the system is toggled between standby and the last mode before going into standby. The lower button is the *back button*, which is used to go back to a previous mode in the system. If the user keeps the button pressed for a couple of seconds, the system will go back to the home screen instead. However, the latter was not implemented later in neither the low-fidelity nor the high-fidelity prototypes, respectively.

The left trackpad will mostly show the car specific controls shown in the figure. For some iterations of the different prototypes, however, this may temporarily be replaced with controls for writing a message, which is explained in the corresponding prototype section. In the figure, several icons can be seen placed around the trackpad area. In general, there is always a slot for an icon in the middle, as well as two, four or eight sectors distributed around it. In the case for the left trackpad in the standby mode, the middle button is active, with one button above and one button below. The middle button is a button for activating the ADAS of the care, which in our concept meant the ACC and AS systems. The upper and lower buttons of the left trackpad is for increasing and decreasing the distance to the car in front, respectively, when using the ACC system.

The right trackpad has no middle button, but four buttons around it that are active. These are the media controls, and they control the current music which is playing from the infotainment system, exactly as how it would work on normal steering wheel controls. The upper button is for mute / unmute, the left and right buttons are for rewinding and skipping songs, respectively, and the lower button is for playing / pausing music. Additionally to this mode, the driver can scroll the track pad clockwise to increase the volume, and anticlockwise to decrease it.

5.4 High-fidelity prototyping

After we had tested our low-fidelity prototypes made in Figma with a small group of test subjects, we then proceeded to plan on how to implement a prototype of higher fidelity. The decision was to use the Android platform as our choice for the prototype, since our concept idea has relatively uncommon input methods and was therefore difficult to find existing solutions from. We also made a deliberate decision to not focus to much on developing the HUD interface, because it would be more valuable for us to have a prototype which better simulates the input behaviour than what our low-fidelity prototypes had done.

5.4.1 Architecture overview

For the high-fidelity prototype, we decided to develop a simple app which would act as our simulator for the concept. The app was developed for an Android phone and tablet, where the phone acts as the trackpad input and the tablet acts as the HUD.

The devices talk to each other and send messages via Bluetooth in order to make the interaction work. The code for making the Bluetooth connection was borrowed from a previous project by Joel Hammar and Andreas Karlsson, who researched in the same area as in this project at Semcon. Figure 5.14 show how the devices are set up and how they interact with each other.

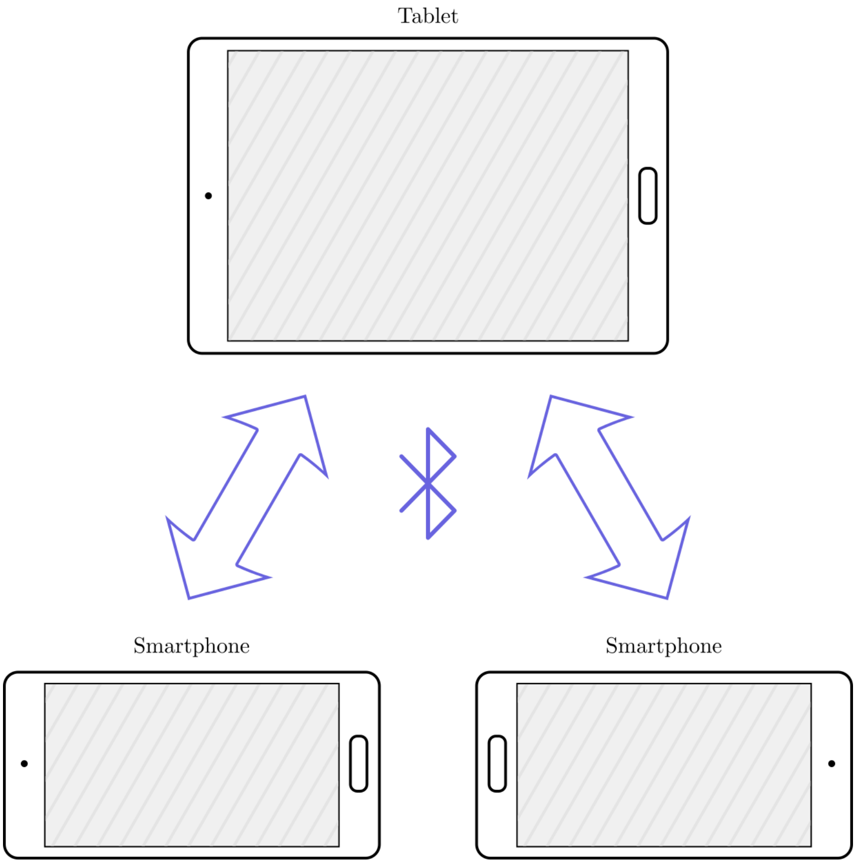


Figure 5.14: The setup of the devices used for the prototypes. The tablet (acting as the HUD at the top is where the connections to the two phones (acting as controllers) are initiated. The controllers then send input commands to the HUD, which updates its state accordingly, and finally sends a response back to the controllers, which in turn update their states.

The most important goal with the high-fidelity prototype was to get a working solution as soon as possible, since we wanted to have time to test it on people, get feedback and improve on the concept. Contrary to the low-fidelity prototype tests we had done, the tests for this prototype would focus more on the affordances of the interactions, regarding manual-visual feedback and the navigational excise of the HUD menu.

In conjunction with the application development for the prototype, we also refined our original concept from the first design iteration cycle, and tweaked the design to meet the new criteria, as described in Section 5.3.3. The hi-fi prototype, however, was still initially designed according to the first concept, in order to reduce development time and start testing sooner.

The following two sections will describe what was implemented for the respective concept versions. Hereafter, we will refer to the phones as *left* and *right controllers*, respectively, and the tablet as the HUD. Each controller include two different kinds of input methods: two *side buttons*, and a *trackpad*. The two controllers and the HUD will together be referred to as the *system*.

5.4.2 Implementation of the first concept

The first prototype had three modes: *inactive mode*, *main menu mode*, and *text writing mode*. The driver can transition through the different modes by pressing on the various buttons in the controllers. The circular trackpads are intended to work as normal touch surfaces, with gestures such as rotational scrolling and touching being the available actions. The buttons on the side of the trackpad, are intended to be regular, physical, tactile buttons, and only respond to single presses. An overview of the transitions between the different modes is shown in Figure 5.15. In order to better simulate our vision of the feedback that the driver would get after pressing or scrolling, the controllers are vibrating shortly after each press or some amount of scrolling, to give the driver some haptic feedback.

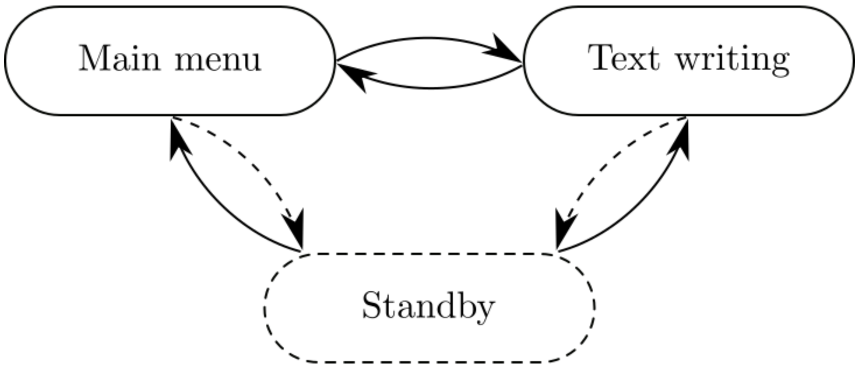


Figure 5.15: The state machine of the prototype for the first concept. There are three modes in which the driver can operate: standby mode, main menu mode, and text writing mode. The last mode, before a transition to the standby mode occurs, will be the mode transitioned to when leaving standby mode.

The interactions acted on the trackpads will be different depending on which mode the system is in. The side buttons, however, only have one meaning associated with them. The left side buttons are reserved for vehicle specific actions, and are not implemented in our prototype. The right side buttons control the system. In order to activate the system, the driver presses the upper button, which shows an on/off button. The HUD will then be in whatever mode the system was when it was previously deactivated, but the default is to launch into the main menu. The lower side button will go back to the previous mode, much like what you would expect when you navigate an Android phone.

The inactive mode is the default behaviour of the system, where the HUD is turned off and the trackpads are in their default modes, i.e. not controlling the HUD. In this mode, the driver can adjust the ADAS settings with the left controller, and control the music with the right controller. The HUD will only show a dimmed screen, indicating that it is not currently in use. An image showing the views of the whole system in this mode are shown in Figure 5.16. The behaviour for the left controller had not been implemented for this prototype version, except for the visual and haptic feedback received when buttons are pressed. The trackpad in the right controller, however, supports tasks including playing, pausing and replaying a song, as well as toggling and adjusting the volume. All actions have a corresponding icon to press, except for the volume, which the driver can adjust by rotating their thumb clockwise or anticlockwise in the trackpad. Pressing the right upper side button from this mode will by default launch into the main menu.

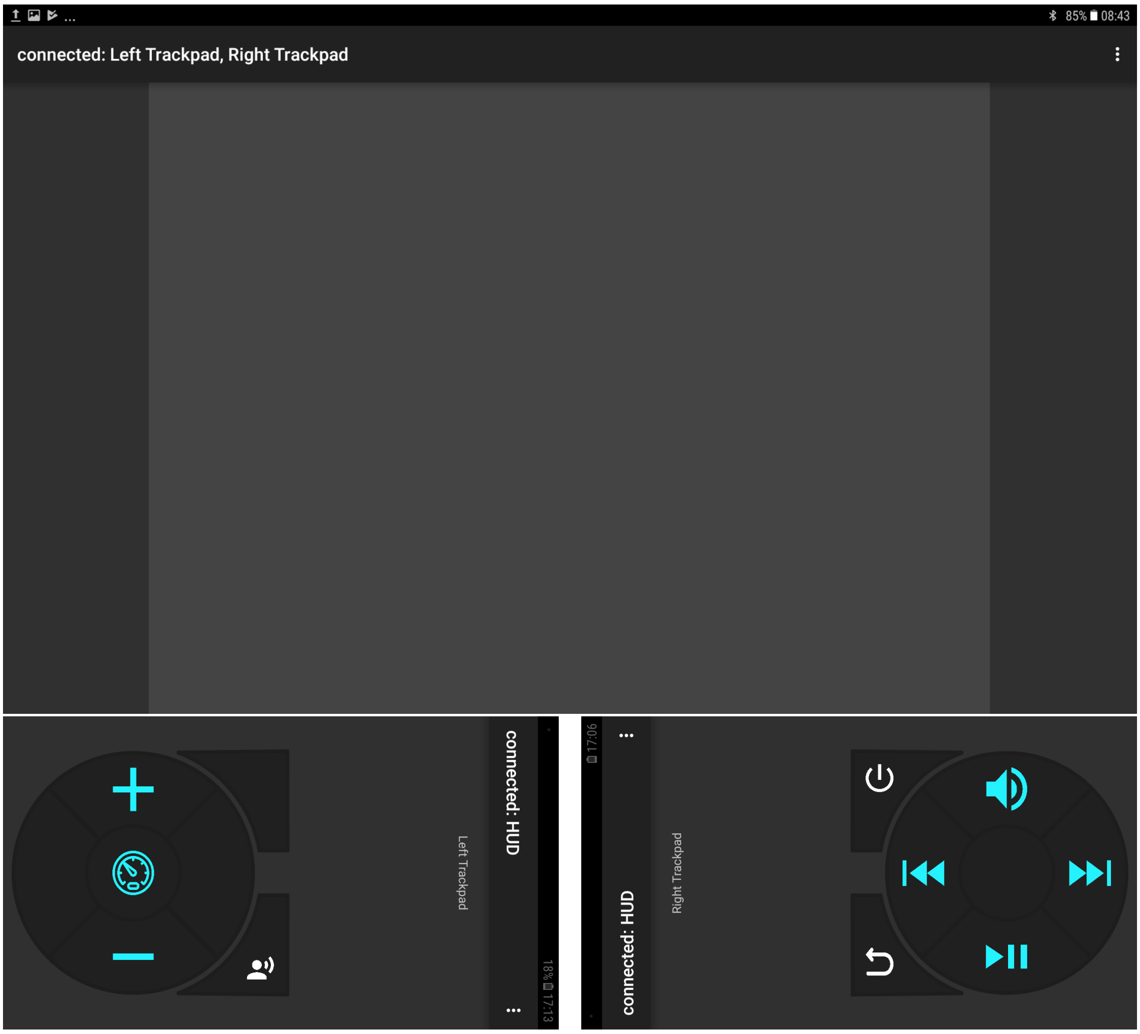


Figure 5.16: The views of the first prototype, when in standby mode. Symbols: [12, 13, 22, 31, 32, 33, 34, 35, 36, 37, 38].

The main menu mode is the hub mode housing all the applications available to the driver, such as the phone and text messaging apps. The left trackpad will show the same view as in the inactive mode; in fact, it will be the same view for all the modes, since no mode that have been implemented uses both trackpads. The right trackpad will have a circular light turned on around the touch pad area, as well as having all the icons disappear. The HUD will show the available apps in a curved list view. These views are shown in Figure 5.17. The driver can scroll through the list by rotating their thumb on the right trackpad (equivalently to when adjusting the volume), and the HUD will flick through the apps. They can go into an application by pressing in the middle of the trackpad. Since we had only implemented text messaging for this prototype, only that app will respond to a button press.

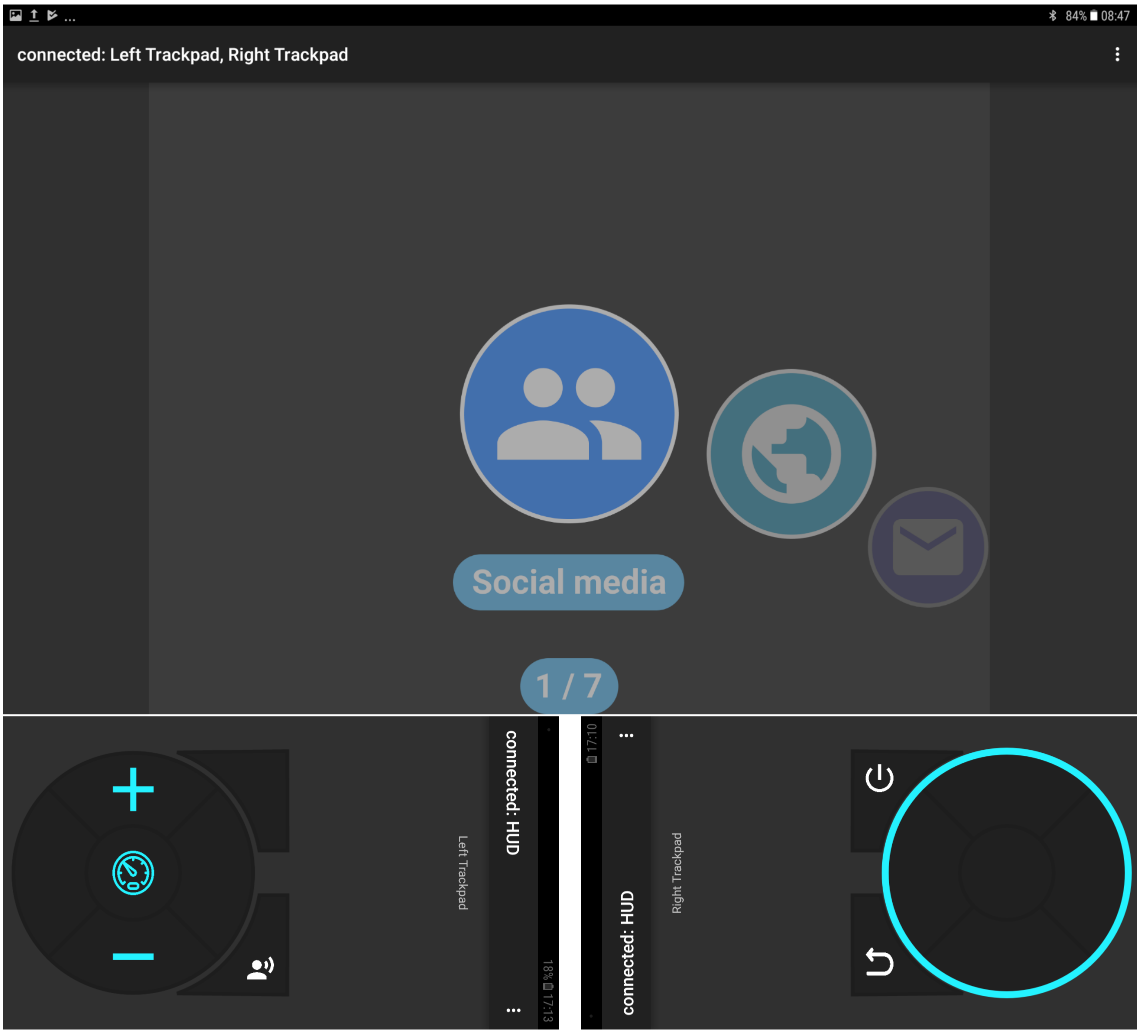


Figure 5.17: The views of the first prototype, when in main menu mode. Symbols: [12, 13, 14, 22, 28, 29, 33, 34, 35].

The text writing mode will immediately jump into a text editing mode, where a text box is shown in the HUD. The only text input method that was implemented was our circular T9 idea. The HUD shows the mapping of the trackpad sectors that correspond to a specific T9 group, as shown in Figure 5.18. The figure also shows how the right track has the corresponding T9 sectors displayed on it. Since we didn't have the full T9 prediction software at our disposal, we implemented the actual writing to a fixed sentence. The driver could only write this sentence by performing the correct combination of presses on the circular T9 area. For the first concept, we hadn't specified how the driver would correct mistakes, so whenever the driver pressed the wrong button, nothing would happen, and they would have to try until they got it right. For simplicity's sake, showing the text in the HUD was done by, after each correct button press, showing a pre-rendered view in the HUD of the current state of the written message.

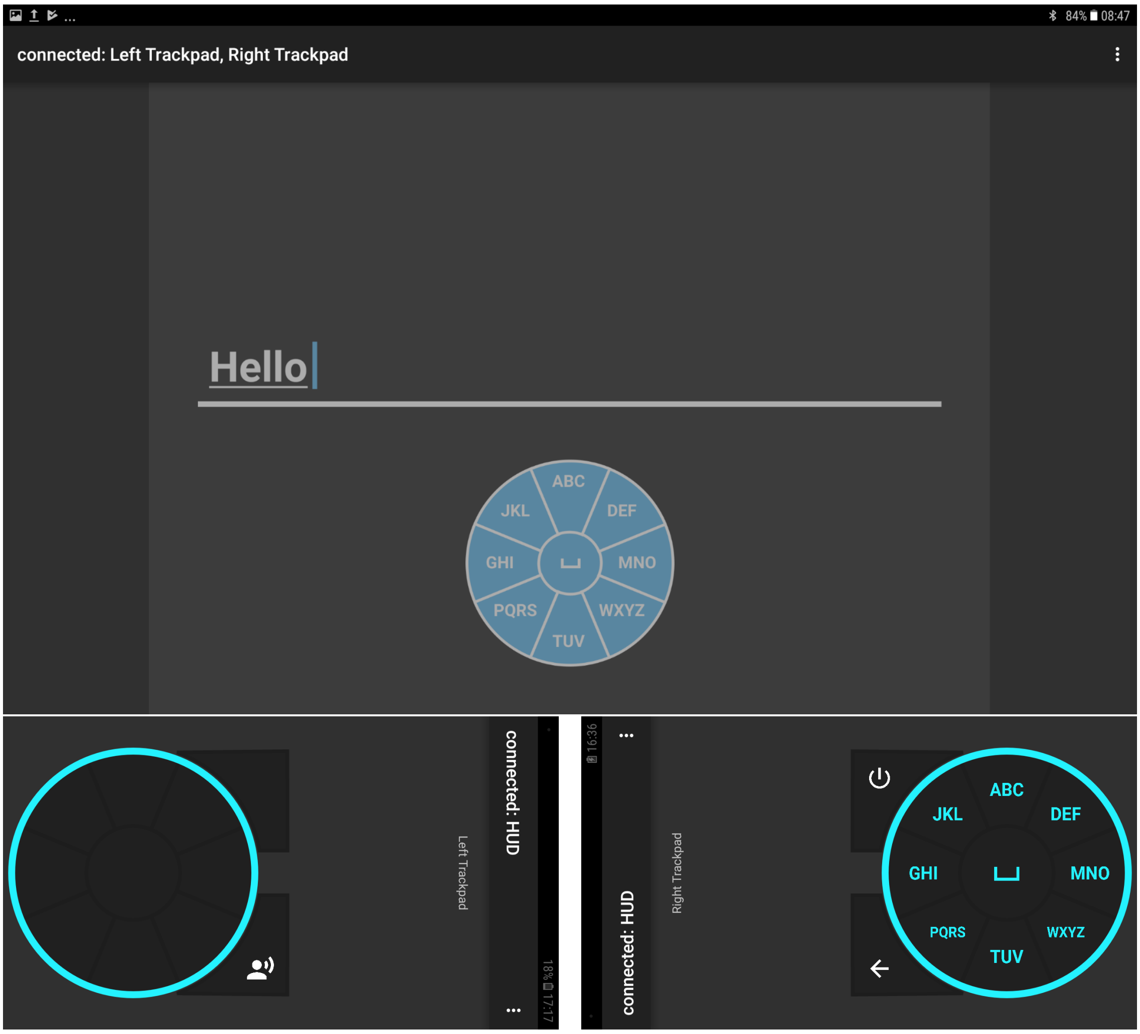


Figure 5.18: The views of the first prototype, when in text writing mode. Symbols: [13, 33, 34].

5.4.3 Implementation of the second concept

After having done user tests on the first implementation of the hi-fi prototype, as described in Section 5.5, we collected the feedback and used it for the implementation of the second concept. In addition to address the issues pointed out by the test subjects, we also implemented one new mode, namely the *text edit* mode, as described in Section 5.3.3. As a reminder, this mode appears in between of the main menu mode and the text writing mode, as can be seen in Figure 5.19. This mode enables the driver to edit the text they have written, without having to use both trackpads, and thus catering to the issue where the driver doesn't have to deactivate the system before accessing vital functions related to the driving, such as the PA.

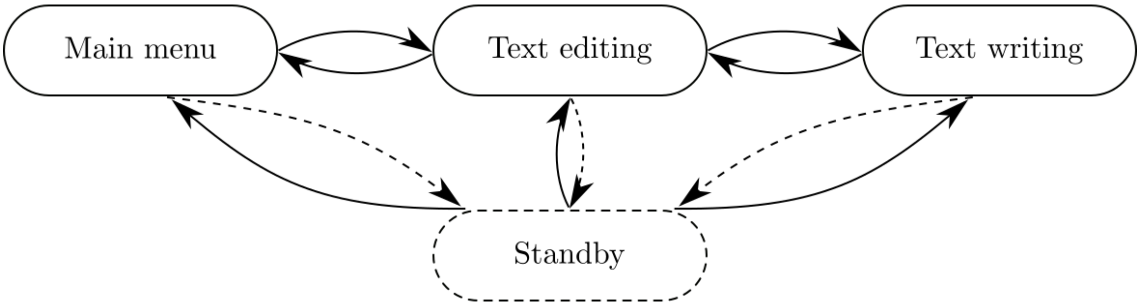


Figure 5.19: The state machine of the prototype for the second concept. It is similar to the first concept, with the addition of the text editing mode.

The driver will enter the text editing mode after selecting the text messages app in the main menu, instead of going straight into text writing mode, as the case was for the first concept. There are five buttons available on the right trackpad in this mode, as shown in Figure 5.20. The driver can also move the cursor by performing a rotational motion around the trackpad, equivalent to adjusting the volume, allowing them to place the cursor anywhere in the previously written text. By pressing the left button (*backspace*), the driver can delete the character before the cursor, and by pressing the right button, the driver can move the cursor all the way back to the right of the text. Pressing the middle button will launch the driver into text writing mode, and the driver can start typing characters from where the cursor currently is at. In order to get back to editing, the driver presses the right lower side button (the back button), as they would do to go back from any other mode. There are also the top and bottom buttons on the right trackpad, which are meant to navigate through the different suggested words for the word where the cursor is currently at, but this functionality has not been implemented for the prototype.

The text writing mode got minor revisions as well. The trackpad legend shown on the HUD was enlarged and made clearer to see, as per the user feedback. This can be seen in Figure 5.21. More sentences was added as well, in order to better test real use cases for the next user test. When the driver has completed writing a message, the text will turn green for a few seconds, indicating that they successfully wrote the message. Note that having the text turn green was only part of the prototype for testing purposes, and is not part of the behaviour of the original concept. The can then proceed to write another message. Since we did not have time to fully implement T9 into the prototype, or at least a subset of it, we had to mimic only some of its behaviour. The way that we did that, was to show the correct or expected text to the driver, as long as the previously written text is correct, in terms of the driver pressing the correct T9 buttons. If the driver would press the wrong button (for example pressing the "JKL" button when typing the first character in the sentence "Hello there"), then the first letter of the T9 button will be written out. In order to get T9 to write the correct text again, the driver would have to remove enough characters, so that the current text matches the beginning of the message expected of the driver to write. This way we were able to test how much impact the editing mode has on their driving performance / traffic awareness.

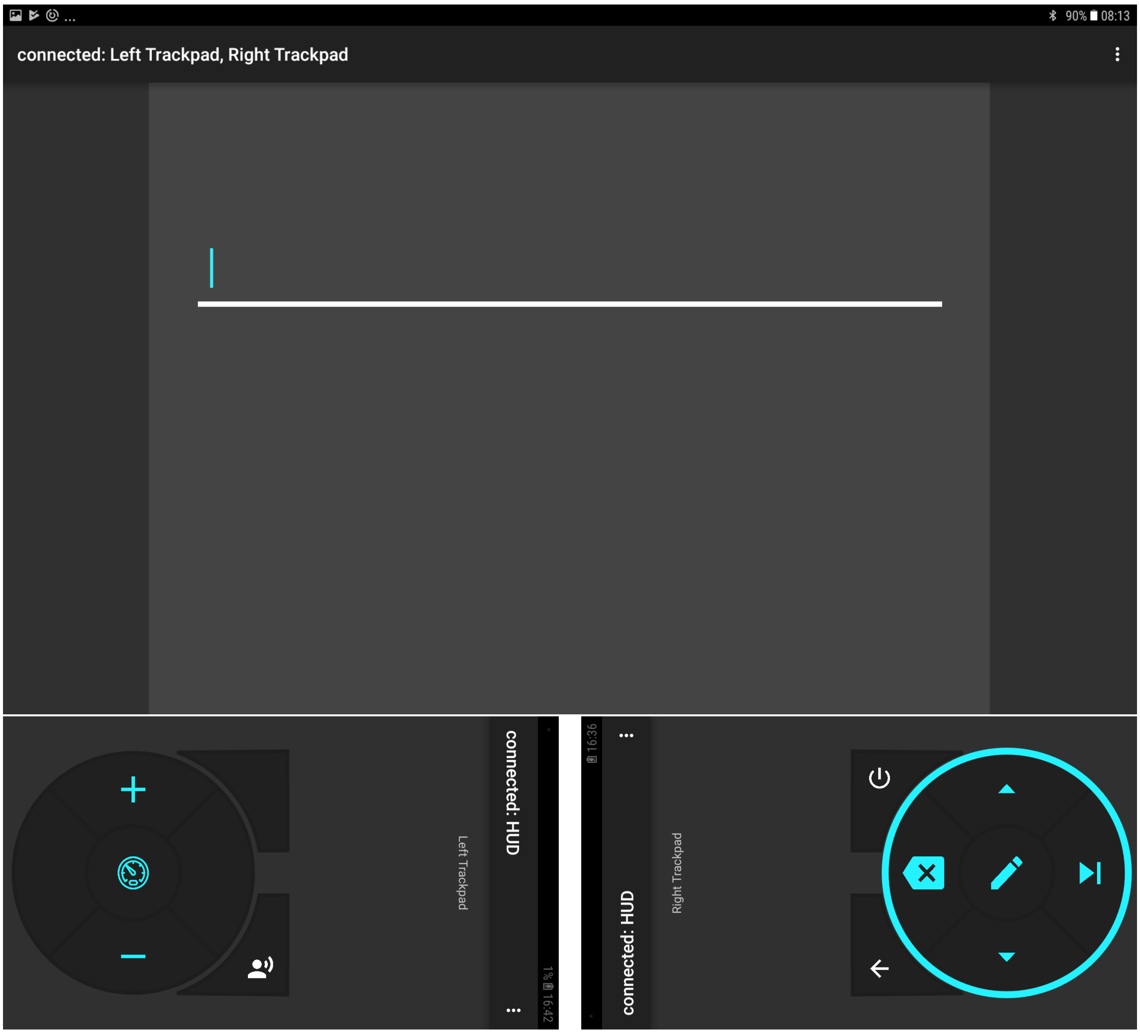


Figure 5.20: The views of the second prototype, when in text editing mode. Symbols: [12, 22, 23, 24, 25, 26, 27, 33, 34, 35, 36].

5.4.4 Limitations of using standard touch devices

Our initial vision for the concept, was to combine haptic feedback with an input method that uses pressure on a touch surface, in order to simulate the press of a physical, tactile button. The reason for this was to let the driver completely or largely rely on the manual feedback of the trackpads when performing familiar actions. Since most phones do not have the pressure touch feature present (the only widespread phone that has this feature are iPhone models 6S and later), our prototype was limited to only vibration.

5.5 User testing

During the project, we have conducted 3 user tests, each of them testing different aspects of the concept. The first user test was done on the low fidelity prototype,

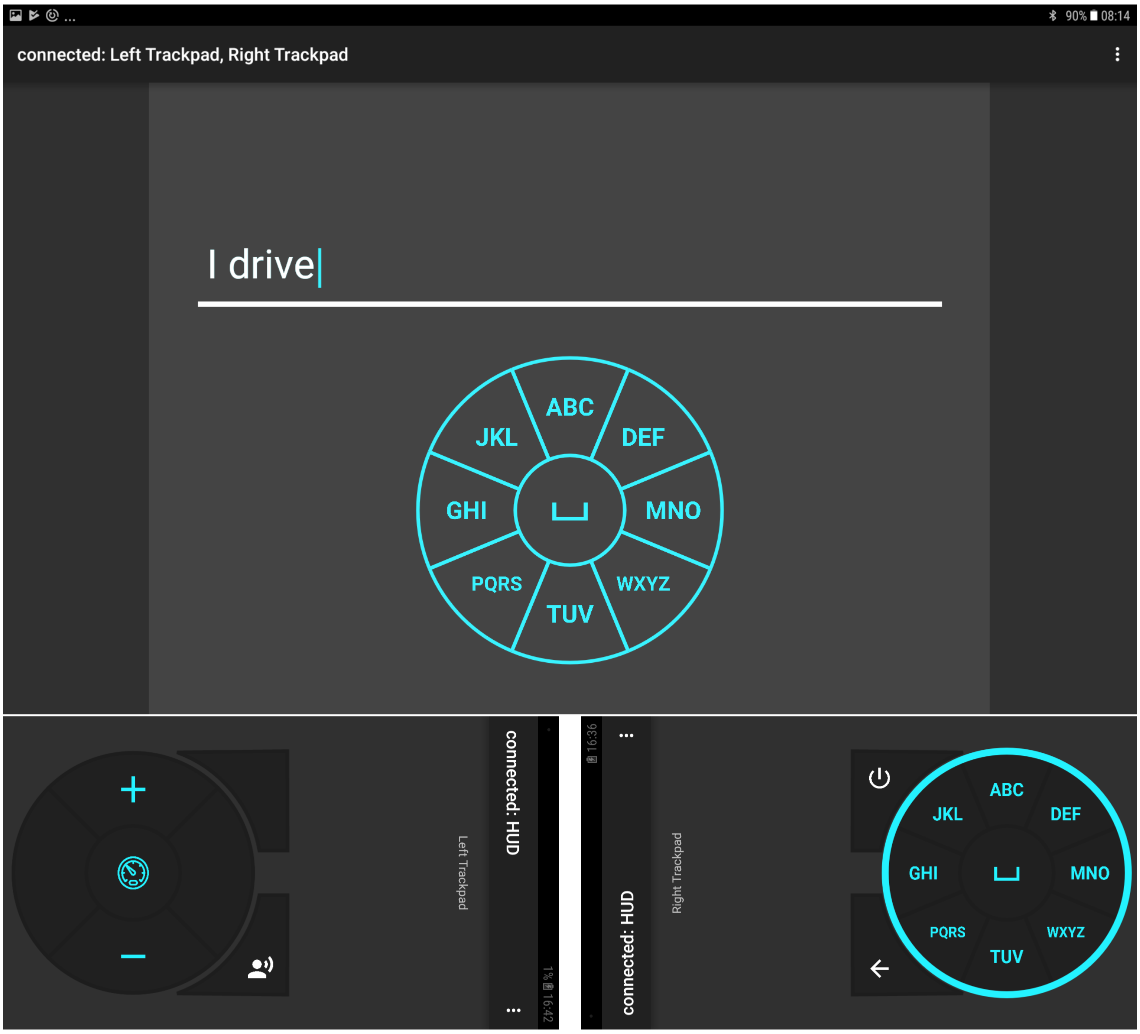


Figure 5.21: The views of the second prototype, when in text writing mode. Symbols: [12, 22, 23, 33, 34, 35].

while the latter 2 was done on the high fidelity prototype. While the user tests had different intentions, there were some form of simulation associated to all three tests, as will be described in the next section. After the participants had done the simulations, they answered on some follow-up questions, either through a questionnaire or an unstructured interview. The purpose of the simulations was to test out expectations and affordances of our concept in general and prototypes in particular, respectively, from the test subjects' point of view. Some test subjects participated in one test, while other participated in two.

Before each test, we would give the test subjects an introduction to the simulation environment. In all three tests, we used a monitor or a TV screen to act as a windshield. We also described what our system was meant to do, how it worked, and how the system was intended to be built if it had been fully realised (such as using actual tactile buttons instead of a touch surface). We asked for their consent to be filmed, so that we could go back and collect any feedback that we might have missed during the test.

5.5.1 User test of the low-fidelity prototype

The first user test was done early in the project in order to catch errors and get feedback. The test was done using Wizard of Oz with a mock-up steering wheel, as can be seen in Figure 5.22. As the test subjects performed operations on the steering wheel, the user test operator clicked through different views of the low fidelity prototype mad in Figma. The test subjects were instructed to talk out loud what they were thinking, as the operator gave them tasks to perform. The tasks included in the first test was only navigation in the HUD, and controlling music. The operator asked questions as the subjects performed the simulation.

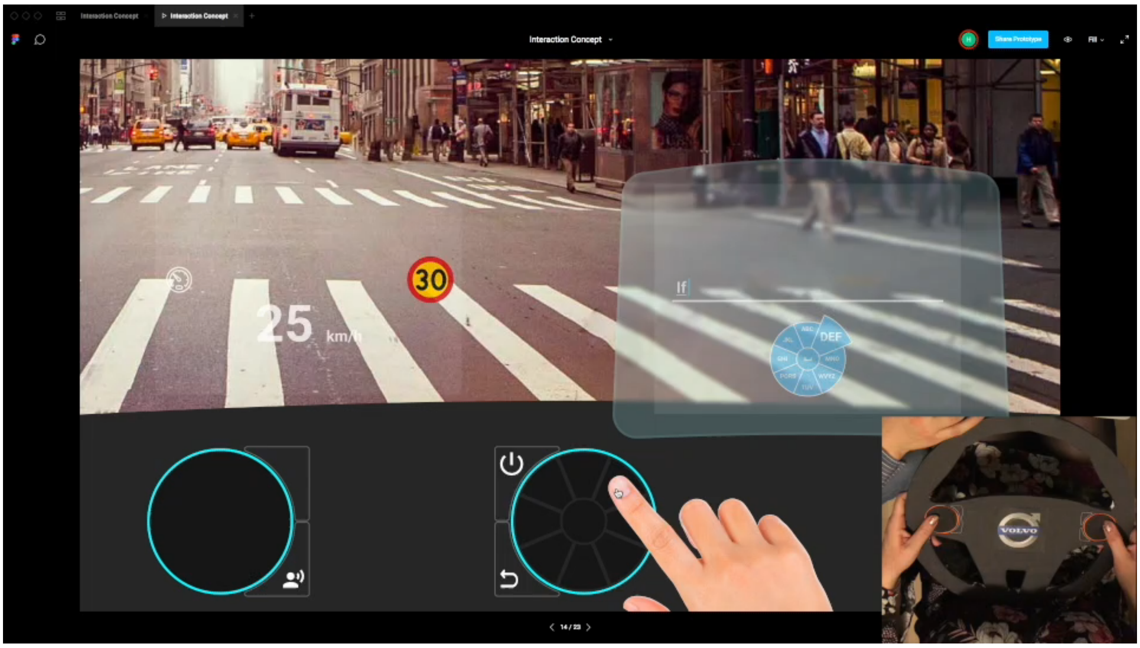


Figure 5.22: A snapshot of a video of one of the test subjects for the first user test simulation. Images and symbols: [11, 12, 13, 33, 34, 54].

5.5.2 User tests of the high-fidelity prototypes

The second user test was done later, when the high fidelity prototype started to take form. This test aimed more to try out the affordances of the interactions (mainly rotational scrolling), as well as typing basic text messages. The test subjects was first asked to answer some questions about general driving habits and experience, similar to, but more condensed than, the user survey done earlier in the project, as described in Section 5.2.2. After that, they were asked to perform the simulation. This simulation was different from the first, in that we had an interactive steering wheel (see Figure 5.23), and a video of a dashboard camera in a car driving in a city environment. Since this test was mimicking semi-autonomous driving, the test subjects was told to always keep focus on the road, while performing tasks best to their ability. The tasks included were the same as for the first user test, in addition to writing one simple word, “Hello”, using the circular T9 input method. Afterwards, the subjects were asked to fill in a questionnaire with questions taken from the SUS.

Figure 5.23: The steering wheel prototype used for the second and third user test. Symbols: [12, 22, 23, 33, 34, 35, 54].

The third and final user test was the last phase for the concept design, and it's purpose was to test more in depth the T9 input method with different sentences and the ability for the test subject to make mistakes, with the introduction to the text editing mode in the prototype. In this test, we didn't include any other tasks than writing messages, since the navigation of the system hadn't changed between the iterations. The last iteration of the high-fidelity prototype allowed for more than one sentence, ever increasing in difficulty, so the test subjects were asked to write four messages in succession ("I drive safely", "It is sunny today", "Gothenburg is beautiful", and "The coffee tastes very good").

For both the prototype tests, while the test subjects were performing the tasks we gave them, we asked certain control questions about the traffic environment, in order to affirm the attentiveness and traffic awareness of the test subjects. An example of a question that was asked was: "Did you see a yellow bus on the side of the road?". Note that we, grammatically, precede the object "yellow bus" with an indefinite article, since there might be questions where the object in question does not exist. This is so to prevent the test subjects to answer "yes" impulsively on all questions.

The control questions (in chronological order) that were asked at different points during the simulation are:

1. **Did you see a yellow bus on the side of the road?**
2. *Did you see a speed sign at the crossroads?*
3. **Did you see a fire truck before the crossroads?**
4. **Did you see a cyclist crossing the road?**
5. **Did you see a speed sign by the side of the road?**
6. **Did you see a person crossing the road?**
7. *Did you see police cars at the side of the road?*
8. *Did you see a person crossing the road?*
9. **Did you see road workers in the middle of the road?**
10. **Did you see a tram on the opposite side of the road?**
11. *Did you see a cyclist on the road?*
12. **Did you see persons crossing the road?**
13. **Did you see a cyclist on the road?**

A question written in bold style asks about an object that exist in the simulation, while a question written in italics asks about a non-existent object. They get scored according to how many of the objects they noticed were there and objects they noticed were not there.

5.5.3 Evaluation

Using the subjective feedback from the unstructured interviews of the user tests, we could inject that feedback into the next iteration of the concept and / or prototype. We would first address immediate issues which were simple to fix in the prototype, and were not required to do a full reiteration of. All the other issues required us to tweak the concept, and we could then at the same time add additional features that we wanted to test. Also, by using the subjective data from the SUS questions, we could in the end compare the iterations of the prototype, to see if the new features have an impact on their performance.

6

Results

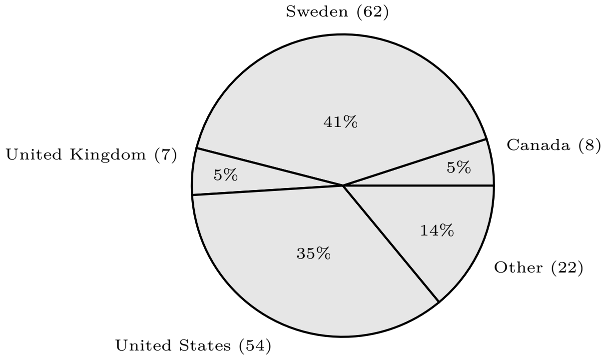
We have gotten several intermediary results during the project, which we have used to further our work in the different design iterations. Some of the results come from the survey we did for the user research phase, while the rest of the results come from the user tests for the different concept iteration phases. In this chapter, we will present the relevant data for these phases, where one part of it, the quantitative data, will lay a foundation when performing statistical analysis later in Chapter 7, and another part of it, the qualitative data, will be used for the discussion in Chapter 8.

6.1 Survey responses

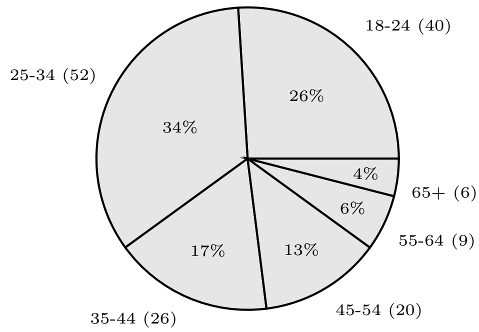
General background information of the respondents are shown in Figures 6.1a, 6.1b, and 6.1c. In total, we got 153 responses, where 83.7% are male, 15.0% are female, and 1.3% would rather not say. In Appendix B, you can find more raw data from the survey. Further data presented in this section, will have been cross-referenced between different data points derived from the raw data of the survey.

Out of the 153 respondents, 106 answered that they either mainly drive in city environments, or in both cities and highways. In other words, we have filtered out the responses from those who only drive in highways. Out of these 106 respondents, 79 are driving without ADAS features in their motor vehicle, while 27 are driving with ADAS. A comparison between daily and occasional drivers, who may or may not be using ADAS, is shown in Table 6.1.

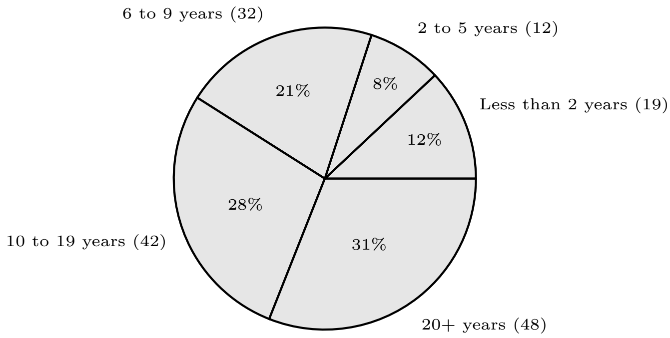
Questions that were asked later in the survey, regarding secondary tasks, were about the frequency and comfort of use for specific STs, such as voice calls and text messaging. The general case for other tasks, such as social media, email, and games, were that respondents didn't perform nor feel comfortable performing these tasks, so they were excluded for further analysis. Figure 6.2 shows the frequency and comfort of voice calls, comparing between different categories of drivers. The question about the frequency of use for the STs was obligatory, so there are 106 data points in total for this measurement. However, the question about comfort of use for the STs was non-obligatory, which means the number of data points varies between different STs. In the case for voice calls, there were 100 data points collected. The data for text messaging was the second most utilised ST, but did not vary enough in the data points for us to draw any insights from. The data can however be found in Appendix B.



(a) The nationalities of the respondents.



(b) The ages of the respondents.



(c) How long the respondents have had their driver's licenses.

Figure 6.1: General information from the 153 respondents.

	Daily drivers	Occasional drivers	**Total**
Without ADAS	48	31	**79**
With ADAS	22	5	**27**
Total	**70**	**36**	**106**

Table 6.1: A comparison between daily and occasional drivers, driving to some extent in city environments, who may or may not be using ADAS.

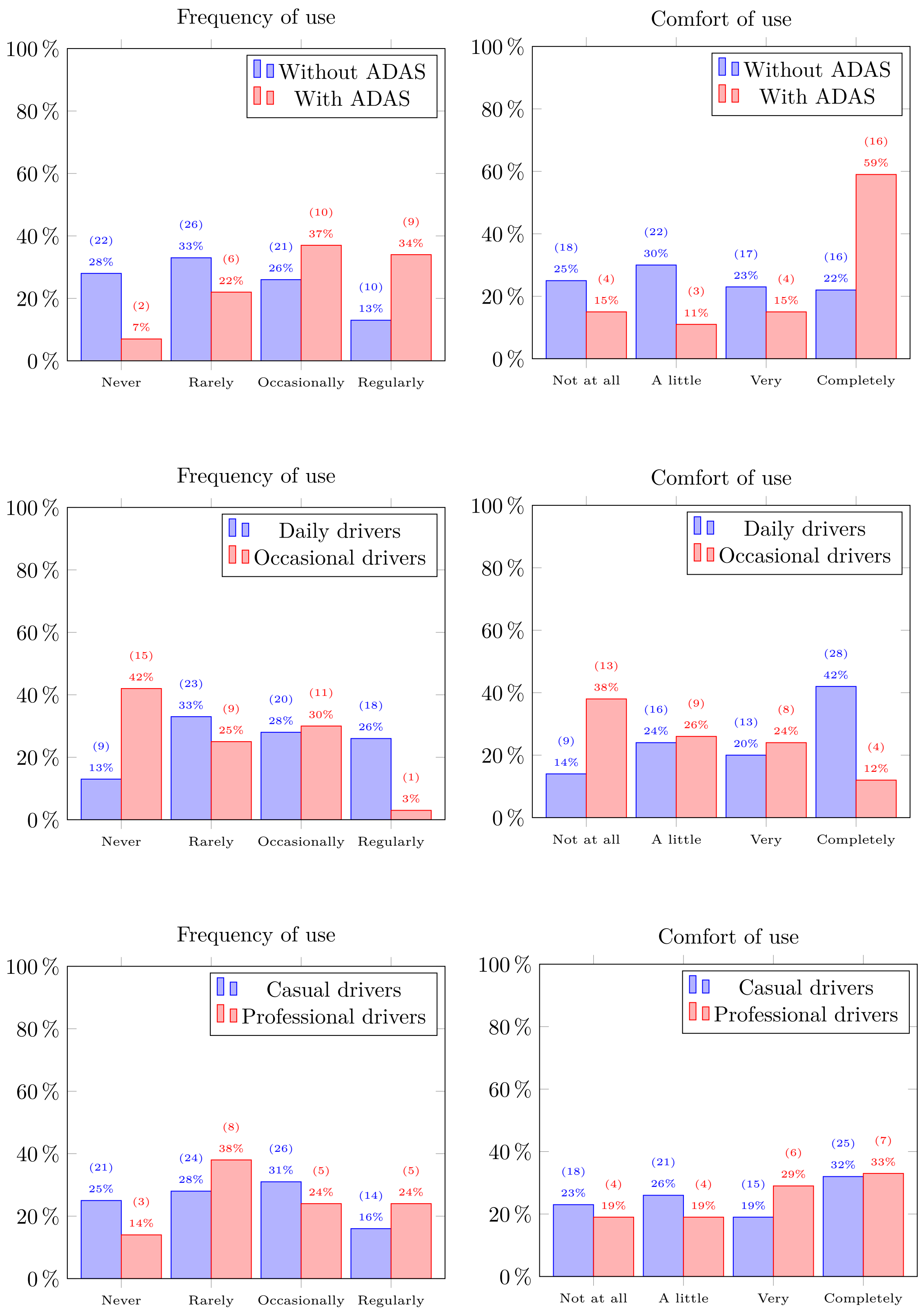


Figure 6.2: The respondents' frequency and comfort of voice calls, driving to some extent in city environments, comparing between different categories of drivers.

6.2 Data from high-fidelity user tests

The second and third overall user tests was done on the high-fidelity prototype. These tests will in this section be referred to as *prototype test 1* and *prototype test 2*. The data that was collected was partly from the test subjects responding to the control questions, and partly from the follow-up questionnaire with SUS questions.

6.2.1 System usability scores

For the tests, we collected a SUS for each test subject after they had performed our simulation test. For prototype test 1, there were 6 test subjects, and their responses are shown in Table 6.2, while for prototype test 2, we had 7 test subjects, and their responses are shown in Table 6.3. The results from each SUS will be calculated and compared in Section 7.2.

Subject	Gender	Age	Driver's license	SUS question response									
				1	2	3	4	5	6	7	8	9	10
1	M	18-24	2-5 yrs	5	1	5	2	5	2	5	1	5	4
2	M	25-34	6-9 yrs	4	2	4	1	4	4	5	2	5	1
3	M	18-24	6-9 yrs	4	2	4	1	5	1	3	2	4	1
4	M	18-24	< 2 yrs	3	1	4	1	4	1	3	2	3	2
5	M	18-24	< 2 yrs	3	3	4	2	3	4	4	2	3	2
6	M	25-34	10-19 yrs	2	4	3	1	4	2	3	3	1	4

Table 6.2: The test subject responses from the follow-up questionnaire for prototype test 1.

Subject	Gender	Age	Driver's license	SUS question response									
				1	2	3	4	5	6	7	8	9	10
1	M	45-54	> 20 yrs	2	2	5	1	3	2	5	5	5	1
2	F	45-54	> 20 yrs	1	3	5	2	5	1	5	2	2	3
3	M	25-34	6-9 yrs	3	2	4	1	3	2	4	2	4	2
4	M	18-24	6-9 yrs	4	2	4	1	5	1	4	3	3	1
5	M	18-24	< 2 yrs	2	4	2	1	3	3	2	4	2	3
6	M	25-34	10-19 yrs	1	2	2	4	3	3	3	5	1	4
7	M	25-34	10-19 yrs	3	1	3	1	4	2	4	3	3	1

Table 6.3: The test subject responses from the follow-up questionnaire for prototype test 2.

6.2.2 Control question performances

Tables 6.4 and 6.5 shows the performances of the test subjects when answering the control questions for prototype test 1 and 2. A cross (X) indicates that the test subject answered the question correctly, and a hyphen (-) indicates an incorrect answer. If the cell is blank, then the question was never asked. The score is calculated by taking the number of correct answers divided by the number of questions asked.

Looking at the control question data, the mean score between all test subjects for prototype test 1 was 45%, with the highest, median, and lowest scores at 78%, 49% and 33%, respectively. For prototype test 2, the mean score between all test subjects was 60%, with the highest, median, and lowest scores at 86%, 75% and 50%, respectively.

Subject	Control questions													Score
	1	*2*	**3**	**4**	**5**	**6**	*7*	*8*	**9**	**10**	*11*	**12**	**13**	
1	-	X	X	X	-	X	X	X	X					78%
2	-	X	X	-	-	X	X							57%
3	-	X	X	X	-	X	X	X						75%
4	-	X	-	X	-									40%
5	X	X	-	-	-									40%
6	-	X	-											33%
Mean														54%

Table 6.4: Control question performances of the test subjects for high-fidelity prototype 1.

Subject	Control questions													Score
	1	*2*	**3**	**4**	**5**	**6**	*7*	*8*	**9**	**10**	*11*	**12**	**13**	
1	X	X	-	X	-	X	X	-						63%
2	-	X	X	X	X	X	X							86%
3	X	X	X	X	-	X								83%
4	-	X	X	-										50%
5	-	X	X	X	-									60%
6	-	X	X	X										75%
7	-	X	X	X	-	X	X							71%
Mean														70%

Table 6.5: Control question performances of the test subjects for high-fidelity prototype 2.

6.3 Feedback from follow-up interviews

After each user test, including the first one done on the low-fidelity prototype, we have asked questions regarding the test and the system. In this section, we will give a summary of that feedback, but we'll go into more detail in Appendices D, E, and F. For the high-fidelity prototype tests, each person got a score based on how many of the control questions they answered correctly. The score is calculated by taking the number of correctly answered questions divided by the number of questions asked. Each test subject may have different number of questions asked to them, depending on how fast they completed the tasks given.

For the first user test, there were 3 test subjects. They thought that T9 was cumbersome to use, based on past experience, but generally thought that the trackpad idea was interesting. They thought it was good that it allowed them to keep their hands on the steering wheel. All test subjects thought that Scribble was a good method for input, since it allowed them to write without looking on the steering wheel. Some thought T9 could have been improved, if there were more visual feedback on the trackpads, as well as having the HUD near the windshield.

For the second user test, test subjects thought it felt good to use the system, after some amount of practice. They said that the system was simple to use overall, although it did not have much functionality. They felt that they got used to the simple interactions used for the system. However, they also said that they wanted more feedback for the T9 input. They often had to look down in order to know where they are holding their finger. One also said that the letters on the HUD were too small. Having to look down all the time made the test subjects more focused on the trackpads than the road.

For the third and last user test, test subjects found that there was not enough feedback when using T9. Most of them thought it would be better with more feedback both in the HUD and on the trackpads, by showing where there finger is in the HUD and by using haptic feedback, for instance. Some of them also confused the back button with the backspace button in the editing mode. Some said that they would prefer to have the backspace button in the editing mode. They felt, however, that they became more used to the system the more they used it.

7

Data Analysis

During the project, we have conducted surveys and interviews, where some form of data have been collected. For the user survey, we collected data about driving habits, and wanted to see if there were any correlations between performing secondary tasks (in regard to frequency and comfort), and some nominal data (the presence of ADAS in the motor vehicle, how often they drive, and whether they drive professionally or not. When doing the user tests, we asked questions regarding the usability of the system, so that we could later find any potential differences between the two iterations of the high-fidelity prototype. In this chapter, we will describe how we derived the statistics from this data, using the chi-squared method for the user survey, and the SUS for the user tests.

7.1 Analysis of the survey data

We gained insights from the survey data by using hypothesis testing and calculating the chi-squares for the relevant categories. One of the insights we got from the survey is that people who use ADAS features in their motor vehicle tend to more frequently make phone calls. The intermediary results for the calculation of the chi-squares, for this insight, are shown in Tables 7.1, 7.2, and 7.3. Table 7.1 shows the distribution of answer samples across the different categories. The answers are divided into its numerical value, and the categorical names that appeared in the survey. The numerical value is used to calculate a weighted mean, to see which direction the answers of the respective categories tend to go towards.

For a given answer sample x in each category, the expected value can be calculated, as shown in Table 7.2. The expected value is given by the product of the total sum of the corresponding category and the corresponding answer, respectively, divided by the total number of responses. For instance, in order to calculate the expected value for people who never make voice calls and don't use ADAS, the calculation would be $E(X) = (79 \times 24)/106 \approx 17.89$.

The expected values are then used to calculate the χ^2 values for each answer sample point, which is given by $\chi^2 = (x - E(X))^2/E(X)$. The result for each sample point is shown in Table 7.3. Using the previous example, this calculation would be $(22 - 17.89)^2/17.89 \approx 0.9459$. Given the calculated χ^2 values, 3 degrees of freedom (2 categories, 4 answer options implies $(2-1)(4-1) = 3$ degrees of freedom), and $\alpha = 5\%$, we obtain a P-value of $P = 1.83\%$. Since $P < \alpha$, it indicates a significant, statistical difference, and we can reject the null hypothesis in favour of the alternative hypothesis. The null hypothesis in this case is that people who drive with ADAS, use voice calls as often as people driving without ADAS. The alternative hypothesis is then that people who drive with ADAS, use voice calls more often than people driving without ADAS. We can affirm that this alternative hypothesis is valid by comparing the weighted means between the categories. The rest of these findings can be seen in Appendix B.

Frequency, voice calls		Category		**Sum**
Value	Description	Without ADAS	With ADAS	
0	Never	22	2	**24**
1	Rarely	26	6	**32**
2	Occasionally	21	10	**31**
3	Regularly	10	9	**19**
	Sum	**79**	**27**	**106**
	Weighted mean	1.24	1.96	1.42

Table 7.1: Samples of answers from motor vehicle drivers, when asked how frequently they make voice calls. The answers are categorised into those who use ADAS features and those who do not.

Frequency, voice calls	Category		**Sum**
	Without ADAS	With ADAS	
Never	17.89	6.11	**24**
Rarely	23.85	8.15	**32**
Occasionally	23.10	7.90	**31**
Regularly	14.16	4.84	**19**
Sum	**79**	**27**	**106**

Table 7.2: The calculation of the expected values $E(X)$.

Frequency, voice calls	Category		**Sum**
	Without ADAS	With ADAS	
Never	0.9459	2.7675	**3.7134**
Rarely	0.1940	0.5676	**0.7616**
Occasionally	0.1916	0.5605	**0.7521**
Regularly	1.2223	3.5765	**4.7988**
Sum	**2.5538**	**7.4721**	**10.0259**

Table 7.3: The calculation of the chi-squares χ^2.

7.2 Analysis of the system usability scores

The SUS will help us determine whether the system has generally been improved between the two high-fidelity prototype iterations. There were some indication with the control questions that the attentiveness has improved in the latter test. The SUS, however, will give an indication if the usability has improved as well.

A SUS score for each test subject is calculated as described in Section 2.4.2. Tables 7.4 and 7.5 show the computed scores for the first and second high-fidelity prototype iterations, respectively.

Subject	SUS score
1	85.0%
2	70.0%
3	72.5%
4	67.5%
5	52.5%
6	45.0%
Mean	65.4 %

Table 7.4: The SUS scores from the test subjects of the first high-fidelity prototype iteration.

Subject	SUS score
1	30.0%
2	62.5%
3	65.0%
4	70.0%
5	35.0%
6	27.5%
7	62.5%
Mean	50.4 %

Table 7.5: The SUS scores from the test subjects of the second high-fidelity prototype iteration.

The lower score on the second iteration indicates that the usability has decreased in this iteration. The factors that most probably have had an impact on this result will be brought up next in the discussions. Looking at the SUS scores, the mean score between all test subjects for prototype test 1 was 65.4%, with the highest, median, and lowest scores at 85.0%, 68.8% and 45.0%, respectively. For prototype test 2, the mean score between all test subjects was 50.4%, with the highest, median, and lowest scores at 70.0%, 62.5% and 27.5%, respectively.

8

Discussion

During the project, we have gotten feedback regarding STs during semi-autonomous and manual driving throughout several of the phases. We began by collecting initial feedback using a survey from a wide target group, namely all drivers of cars and trucks, leading us to distribute our survey as wide as possible. We have also done three user tests with a low-fidelity prototype and two iterations of a high-fidelity prototype. In this chapter, we will discuss the feedback we have gotten, in addition to the data that we have collected, to see what conclusions can be made. We will also go into our process and discuss what could have been done differently, which might have yielded other results. Then we will discuss what generalisations can be made to our work, in regard to whether it can be adapted for higher levels of automation. Lastly, we will discuss some key points for what future work could have been done on the concept and on the prototype.

8.1 Findings

During the beginning of the project, it became more and more obvious that text messaging was one of the most dangerous tasks to engage in during driving, with several guidelines conflicting with the actions required to send a text message. There are most likely a substantial amount of key presses required, as well as having to constantly read and correct the written text. The reason behind why we chose to continue work on concepts for text writing are partly because of the project limitations, of not using voice control, and partly because it wouldn't have been a particularly interesting project only looking at concepts for the alternative communication forms, such as voice calls. Because of this, we had to disregard to the guidelines regarding text messaging, and try to comply with other guidelines instead. Also, before the project, we decided on the assumption of this concept working in a couple of years of time from the time of doing this project, when ADAS systems might have improved.

The survey was the first indicator of what goals different kinds of drivers have with in-vehicle entertainment. Since we targeted all types of drivers, we collected feedback from anyone who had a driver's license. Looking at the demographics, it can be seen that roughly $\frac{1}{3}$ of the drivers were Swedish, $\frac{1}{3}$ American, and $\frac{1}{3}$ from one of the 17 other foreign countries, which made the data fairly unbiased on what country the driver is from, at least between the Swedish and American sectors. We also had a fairly distributed age groups and driving experiences. However, we didn't get as equally distributed genders, with $5\frac{1}{2}$ times more males responding than females. Most of the responses also came from no automation drivers, giving a slight bias towards manual driving. We solved this by splitting up the responses by the presence of ADAS in their main motor vehicle of transport, and comparing ST independently between these divided groups.

Most driver's, regardless of presence of ADAS, do not engage in any other ST other than voice calls and text messaging, except for a handful of drivers. Moreover, the engagement in text messaging was also too low, in order to see any significant difference between ADAS and non-ADAS drivers. Nevertheless, we could see some difference in the frequency and comfort of engagement in voice calls between these categories of drivers, indicating that the presence of ADAS have an impact on the driver's activity. We also found that daily driver's are also much more prone to engage in voice calls than occasional drivers. Given this insight, we had reason to believe that text messaging might be a use case for drivers as well, given that it is more accessible than the current solutions, and that it may be designed towards intermediate users who are comfortable with the driving environment.

We brought these insights with us when creating our concept, and ended up with the system of the trackpads and the HUD, which we later did our user tests on. The initial feedback from the low-fidelity prototype was that users thought that the trackpads might be a good idea, but were more sceptical towards Circular T9 and favoured the Scribble method more. The reason why we didn't used the Scribble idea for the high-fidelity prototype was partly a technical challenge of adapting the technology to our trackpad layout, and partly because Circular T9 felt more in line with the trackpad interactions, that were appreciated by the test subjects.

The high-fidelity user tests yielded more data on the safety and usability of our system than the low-fidelity prototype did. The initial response for the first prototype iteration was that the overall experience felt good to use, although the functionality was restricted to only play music and write a preset message. The main complaint was that Circular T9 did not give enough feedback from both the HUD and the trackpads. This was also the predominant complaint of the second prototype iteration, and ultimately brought down the usability of our system, which can be seen by looking at the SUS scores for each iteration. The reason the score has gone down in the second iteration, is most probably because of the fact that we made added an editing mode in the second iteration. While being an important addition to the usability of the system, it also made it more difficult to write messages now, since mistakes could be done and were needed to be corrected. In combination with insufficient input feedback, the input method rather becomes more cumbersome to use.

Although users were generally dissatisfied with the insufficient feedback from the Circular T9 writing method, many of the said that it could probably be fixed by finding ways of making them both feel and see where they are pressing their fingers. The former could be solved with more precise haptic feedback or possible using other types of material than glass, that would allow to have distinct borders between different touch sensitive areas. The latter was partly fixed in the prototype by having the buttons light up in the HUD after having pressed the corresponding button on the trackpad, but could be made more like a mouse pointer, where the user first “hover” the buttons by using touch, and then “click” by applying additional pressure.

For the safety aspect of the system, we have the answers from the control questions asked during the simulations, which was used to calculate a “attentiveness” score for each test subject. It can be seen in the results that test subjects seem to be more attentive in the second high-fidelity prototype user test than the first. One reason for this may be the different tasks given to the test subjects between the different tests, with the second test only had writing messages as a task. But since the test subjects gave more critical feedback towards the second iteration than the first, it is more likely that it only was by chance that the second group of drivers were more attentive in general. A more rigorous safety measure would have to be used to be able to determine the safety of using the system, and Circular T9 in particular. There have been studies that have shown that T9 may have higher cognitive load for regular users, but may be a faster input method than QWERTY for an expert user [1]. The reason for the higher cognitive load is that T9 on older mobile phones required constant verification to see that the correct word was written. Our system would then have to rely on a good prediction system in order to minimise the number of corrections needed. One emerging technology today is machine learning and artificial intelligence, and it could potentially be used to give the best suggestion given a certain context of the written message.

8.2 Work process

The design process we have had, with the project divided up into distinct phases (literature research, user research, ideation, and prototype-evaluate iterations), has allowed us to work at different levels of abstractions, and made it manageable to choose and work on the most promising ideas from the beginning. Without proper literature research, we would not be able to specify what factors might affect driving performance, and how to construct relevant survey questions. The user research is needed to determine the goals the users have with an in-vehicle entertainment and communication system, to give an indication of where to start. A good ideation phase is essential to any design project, and the Jones’ model we have followed have worked well for that phase of the project. Lastly, we have also been able to iteratively improve our concept, at different fidelities of prototypes and with user tests of different purposes.

Although the survey did help us understand some of the drivers’ needs, it didn’t give us all the information we needed. Since this is a highly subjective matter, that is what the goals of the driver has, it would perhaps be more fitting to have focus groups with some drivers, where a more in depth discussion would be possible. The survey was great for finding broader trends, such as the engagement in certain tasks, but failed to answer why this behaviour was present. Consequently, we had to extrapolate some of the goals with our own understandings and insights.

Our initial goal was to work on several different types of applications for the system that we designed. However, we might have gotten more relevant results if we had instead focused on trying out different input methods, since that seems to be one of the most difficult challenges to solve with in-vehicle communication. Having different input methods to compare might have given us more insights into which factors contributes the most to the mental workload of writing a message while driving. We have found, from our user tests, that affordances of buttons play a large role in the attentiveness and comfort of using an input interface. We didn't, however, get much insight in whether composing a message in itself might be enough to disrupt the attention of the driver, let alone by using Circular T9.

Another reason for how the test subjects perceived the usability of our system, was the simulation setup that we had. The setup we performed our tests on, didn't reflect an authentic driving environment, according to the feedback from the test subjects. Since it would be difficult and unethical to test out a prototype like ours in the real world, the next best thing would have been some form of driving simulation. We did consider to use a simulator called *OpenDS* during the testing phase of the project. However, there were limitations to this software, as it wasn't sophisticated enough to accurately depict a congested environment. The decision was then made to instead use real footage taken from a car driving in a city, as we believed that would give more conviction of reality than what the simulation would have provided. As we have learned, the measures of safety of the HMI is highly sensitive to the authenticity of the driving environment, as the less believable the simulation is, the less "effort" or attention is given to the driving tasks.

8.3 Generalisations

The methods we have used for testing out our prototype could have been done with other types of input interfaces, as well as at other levels of automation. The Scribble input method, as mentioned earlier in the report, could have been tested in addition to Circular T9. However, the trackpad concept allows for a much more versatile range of input methods, opening up for new ideas in the future. Since input is interpreted by software, tweaks can be made to a hypothetical implementation of the prototype, even after it has been deployed into a motor vehicle product.

The user tests we did was adapted to a SAE Level 2 car, but it could as well be adapted for manual driving by using a sophisticated driving simulator. This may also affect the attentiveness of the drivers, as well as the performance of completing the tasks. The same could be done for higher levels of automation, where only some parts of the driving are fully autonomous, but other parts may still need the driver. This could also affect the information architecture of the HUD.

Lastly, other technologies that at the present are not developed enough to use in a driving environment, may be used in the future. Examples of this is voice dictation, which have been a requested feature from the user tests. This was intentionally disregarded from our design from the beginning, just because of this reason.

8.4 Future work

The most pressing issue with our design is insufficient feedback with the current input interface. This is due to the smart phones we used, which only has a quantised measurement of touch; either the user is touching the screen or the user is not touching the screen. This made it impossible to implement a concept which allows for the user to hover over buttons, much like a mouse would on a desktop computer. By using a continuous measurement of the force applied to the screen, much like what is present in the 2016 and 2017 MacBook Pro models, this behaviour could have been mimicked, in conjunction with haptic feedback and proper visual feedback in the HUD. Since this was part of the concept from the beginning, this would be an obvious addition to the prototype.

Working on different applications than just text messaging is also something which would have been interesting to continue to work on. A condensed application for social media, which allows for simple emoji responses (similar to what is done by Facebook) and short replies to other people posts, would have been an interesting design challenge using the interactions of the trackpad. The same goes for web surfing, which may be even more difficult to adapt for an in-vehicle environment, since it might require both trackpads to be used at the same time.

One other important thing, which were excluded from the prototype, are notifications, how they should be presented to the driver and in what situations. We discussed this briefly in Section 2.3.3. Doing further work with different use cases, where notifications might be appropriate and beneficial to the driver, would also pose as an interesting design challenge.

9
Conclusion

This project has set out to investigate how to improve the in-vehicle interactions with and engagement in entertainment and communication tasks, for semi-autonomous motor vehicles. The research questions that we wanted to answer are targeted towards city driving and STs, and how an HMI in this context can be used to increase the comfort and efficiency for the driver.

Research question 1 stated "*What safe interactions exist for using in-vehicle interfaces for digital communication, while driving in congested traffic environments?*". The results we got are not substantial enough to prove that our system is safe enough to use while driving in cities. While the interactions for controlling the music are similar to how it is controlled using physical buttons, we haven't tested it with enough persons or made rigorous measurements in order to support that claim. Additionally, the simulation environment used does not fully represent a real driving setting, which makes it more difficult to relate the results to a real driving environment. However, the system we have designed has followed the NHTSA guidelines for in-vehicle equipment as closely as feasible, in relation to the project's goals. The interactions within the system is a good start for further investigation, and will benefit from more development time and more rigorous safety testing.

To give some examples, the NHTSA guidelines recommend to have only one hand operating with an input interface at a time, which our concept is complying to. Additionally, our system do not show more than 30 alphanumeric characters of text, when in the text message app, and this could easily be used in other text-entry contexts. Furthermore, with the NHTSA guidelines stating that no task should be required to be completed in one continuous sequence, our system is compatible with the interruptibility nature of congested driving environments, with the standby button available at all times. However, some guidelines, such as no more than 6 button presses for a single task or specifically engaging in visual-manual text writing, were disregarded in order to make the project interesting.

Research question 2 was divided into two parts, where the first part stated "*How can current HMIs for digital communication (infotainment systems) be improved, such that it does not divert the driver's attention in congested traffic environments?*". The way we have solved that is to bring the interactions to the steering wheel, and the display of information up into the line of sight from the driver towards the road. In addition, our idea with the T9 input method, in conjunction with visual and haptic feedback, has the potential to break the driver's dependency of looking down, by learning where the different buttons are positioned.

The second part of research question 2 stated "*How can current HMIs for digital communication (infotainment systems) be improved, such that it lends itself as an efficient tool for the driver, without sacrificing comfort and safety?*". The trackpad idea we developed for the project has been shown to have several opportunities to be adapted to the users' needs. While the SUS scoring data has shown that the usability of the system is not what it should be, the direct feedback from the test subjects has shown that with additional development, it might be a viable input method. The lack of usability was largely due to insufficient input feedback from the system; many subjects also said that it might have been much easier to use if these issues were addressed.

The system that we have designed has sparked some interesting ideas for novel interactions to use for an in-vehicle HMI. While the high-fidelity prototype haven't met up with the standards of our concept, it has given some insight of how it might feel to use a similar system. We hope that this project will be, at the very least, a catalyst for future projects to come.

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A

Hierarchical Task Analysis of Volvo XC60 Infotainment System

In order to get a direction in the design of our infotainment system, we analysed the infotainment system of a Volvo XC60. We performed an HTA, which outlines the different steps to take in order to complete a given task. Some of the tasks could be completed using the steering wheel controls, while others could only be completed by using the touch display of the infotainment system. In this Appendix, we will present the HTA for completing for common tasks, namely reading and writing text messages, and making and receiving phone calls. Each task is initiated by a *plan 0*, which describes what the task is about.

In order to send a text message (plan 0), you have to:

1. Decide who you want to text.
2. Use the infotainment system:
   - 2.1. Swipe to the left from the home page.
   - 2.2. Press the 'Messages' app.
   - 2.3. Identify the contact in the 'Conversations' list.
   - 2.4. Press the contact.
   - 2.5. Start a new conversation:
     - 2.5.1. Press the plus button.
     - 2.5.2. Write the name of the person using QWERTY.
     - 2.5.3. Write the name of the person using Scribble.
     - 2.5.4. Write the name of the person using voice dictation.
   - 2.6. Write the message:
     - 2.6.1. Use QWERTY-keyboard.
     - 2.6.2. Use Scribble.
     - 2.6.3. Use voice dictation.

plan 0: Do 1 - 2.
plan 2: Do 2.1 - 2.2 - (2.3 - 2.4 or 2.5) - 2.6.
plan 2.5 Do 2.5.1 - (2.5.2 or 2.5.3 or 2.5.4).
plan 2.6 Do (2.6.1 or 2.6.2 or 2.6.3).

In order to read a text message (plan 0), you have to:

1. Use the infotainment system:
    - 1.1. React to the notifications:
        - 1.1.1. Drag down the notification page from the top.
        - 1.1.2. Press the ‘Read out’ button.
        - 1.1.3. Press the contact name.
        - 1.1.4. Read the message.
    - 1.2. Go to the applications page:
        - 1.2.1. Swipe to the left from the home page.
        - 1.2.2. Press the ‘Messages’ app.
        - 1.2.3. Identify the contact in the ‘Conversations’ list.
        - 1.2.4. Press the contact.
        - 1.2.5. Read the message.
        - 1.2.6. Press the ‘Read out’ button.

plan 0: Do 1.

plan 1: Do (1.1 or 1.2).

plan 1.1: If the notification got hidden, do 1.1.1 - (1.1.2 or 1.1.3 - 1.1.4 or 1.1.3 - 1.1.2). If the notification is still visible at the top of the screen, do (1.1.2 or 1.1.3).

plan 1.2: Do 1.2.1 - 1.2.2 - 1.2.3 - 1.2.4 - (1.2.5 or 1.2.6).

In order to make a phone call (plan 0), you have to:

1. Decide who you want to call.
2. Use the infotainment system:
    - 2.1. Call a contact:
        - 2.1.1. Press the ‘Phone’ icon.
        - 2.1.2. Press the ‘Contacts’ icon.
        - 2.1.3. Navigate to the ‘Contacts’ tab by pressing the text.
        - 2.1.4. Navigate to the ‘Recent’ tab by pressing the text.
        - 2.1.5. Navigate to the ‘Favorites’ tab by pressing the text.
        - 2.1.6. Find the contact by scrolling the list of contacts.
        - 2.1.7. Initiate the call by pressing the contact.
    - 2.2. Call a number:
        - 2.2.1. Press the ‘Keypad’ icon.
        - 2.2.2. Write the first digits of the number.

2.2.3. Press the corresponding contact in the suggestion list.
2.2.4. Write the rest of the digits.
2.2.5. Press ‘Call’.

3. Use voice control:
   3.1. Press ‘Voice’ button on steering wheel.
   3.2. Say ‘Call <person’s name>’.
   3.3. Say ‘Yes’.
4. Use the dashboard:
   4.1. Press ‘Quick Menu’ button on the steering wheel.
   4.2. Navigate to the ‘Phone’ page using left/right buttons on steering wheel.
   4.3. Find contact or number in list by using up/down buttons on steering wheel.
   4.4. Call contact or number by pressing the middle button on the steering wheel.

plan 0: Do 1 - (2 or 3 or 4).
plan 2: Do 2.1 or 2.2.
plan 2.1: Do 2.1.1 - 2.1.2 - (2.1.3 or 2.1.4 or 2.1.5) - 2.1.6 - 2.1.7.
plan 2.2: Do 2.2.1 - 2.2.2 - (2.2.3 or 2.2.4 - 2.2.5).
plan 3: Do 3.1 - 3.2. If the system recognised the person’s name correctly, do 3.3. Otherwise, repeat 3.1 - 3.2.
plan 4: Do 4.1 - 4.2 - 4.3 - 4.4.

In order to answer an incoming call (plan 0), you have to:

1. Identify who is calling:
   1.1. Look at the infotainment system.
   1.2. Look at the dashboard.
2. Answer the call:
   2.1. Press ‘Answer’ on the infotainment system.
   2.2. Press left and middle buttons, in that order.

plan 0: Do 1 - 2.
plan 1: Do (1.1 or 1.2).
plan 2: Do (2.1 or 2.2).

B

Survey

In this appendix, we will present the questions of the survey that was sent out to motor vehicle drivers around the world, as well as present some additional, interesting results, but was not relevant enough for further studies.

B.1 Questions

In the following sub-sections of this section, the questionnaire sections have been sectioned. Each questionnaire section has a corresponding number, which relate to how they originally appeared, as can be seen in Figure 5.1. Some sections were left out, namely the ones which only had questions about highway driving in it, since they were not relevant to our research.

A question written in bold style indicates that it is mandatory, i. e. an answer must be given, while a question written in italics is optional. Some question may also have some additional explanation written below it, in a smaller font. Question answer options listed with bullet points were presented with radio buttons, i. e. only one answer must be given, while options with dashes indicate that multiple answers are accepted. Question answer options written as "Other ..." or "Answer ...", indicate that it is an open-ended answer, meaning that the respondents can fill in custom text as an answer.

Some questions have RANGE written under them, with some values after. These questions indicate that for each question answer option, zero or more range values need to be selected. In the survey, these questions were laid out as a matrix, with the vertical axis showing the question answer options, and the horizontal axis showing the range values. Similarly as mentioned earlier, question answer options with a bullet can only be chosen with one range value, and options with a dash can have multiple range values.

B.1.1 Driving habits (1)

We are conducting this survey as part of a research project of driving habits in motor vehicles with advanced driver assistance. We hope you can spare 5-7 minutes by answering some questions. Your answers will be part of an exciting project meant to benefit future motor vehicles!

Note: This survey assumes you have a driver's license. All personal information is confidential and not to be distributed!

B.1.2 Background (2)

In this section you answer general questions about yourself.

1. **What is your gender?**
    - Male
    - Female
    - Other
    - Rather not say
2. **What country are you from?**
    - Afghanistan
    - Akrotiri
    - Albania
    - ... [*all other countries in the world*]
3. **How long have you had a driver's license?**
    - Less than 2 years
    - 2 to 5 years
    - 6 to 9 years
    - 10 to 19 years
    - 20+ years

B.1.3 General driving habits (3)

This section contains questions about your every day driving habits.

1. **How often do you drive?**
    - Daily
    - Once of a few times a week
    - Once or a few times a month
    - Once or a few times a year
    - Never (or rarely)
2. **How long are your average driving sessions?**

- Less than 30 minutes
- 30 - 59 minutes
- 1 - 3 hours
- 4+ hours

3. **What are you primary reasons for driving?**
   Choose one or two options.
   - To get to and from work
   - As a part of my job
   - To perform small errands now and then
   - It's more convenient compared to other options (bicycle, public transport etc.)
   - I have no other means of transportation
   - I don't drive or I drive very rarely
   - Other ...
4. *If you answered 'as a part of my job' on the previous question, what type of vehicle do you drive for the job?*
   - Car
   - Truck
   - Other ...
5. **What environments do you drive in mainly?**
   - Highways, country roads and/or rural environments
   - Cities
   - Both of the above
   - None

B.1.4 Advanced driver assistance (4, 7)

In this section, we ask you questions about your familiarity with motor vehicles with advanced driver assistance. A motor vehicle with advanced driver assistance have systems that automatically allows the vehicle to keep a fixed distance to the motor vehicle in front by adjusting the speed and/or systems for staying in the middle of the lane.

1. **Have you ever driven a motor vehicle with advanced driver assistance enabled?**
   - Yes

- No

2. **Do you own or primarily drive a motor vehicle with advanced driver assistance from any of these brands?**

    - I don't own or drive a motor vehicle with driver assistance
    - Acura
    - Audi
    - BMW
    - Buick
    - Cadillac
    - Chevrolet
    - Chrysler
    - Daimler
    - Dodge
    - Fiat
    - Ford
    - GMC
    - Honda
    - Hyundai
    - Infiniti
    - Jeep
    - Kia
    - Lexus
    - Lincoln
    - Mazda
    - Mercedes-Benz
    - Nissan
    - Peugeot
    - Tesla
    - Toyota
    - Volkswagen
    - Volvo
    - Other ...

B.1.5 Performing non-driving tasks while driving (5)

Here we ask questions regarding what non-driving tasks are being performed while driving in your usual driving environment (either highways or city driving), as well as how often you perform them and how comfortable you are with them.

1. **How much do you perform any of these tasks while driving in your usual driving environment?**

   Tasks can be performed on a mobile phone or on built-in interfaces in the motor vehicle (infotainment system, buttons on the steering wheel, etc.).

   RANGE: Never, Rarely, Occasionally, Regularly

   - Social media (e.g. Facebook, Instagram)
   - Direct messages (e.g. SMS, Whatsapp, Messenger)
   - Voice calls
   - Email
   - Browse the web
   - Games
   - News, blogs or forums
   - Videos or movies

2. *How comfortable are you performing these tasks while driving in your usual driving environment?*

   If you never perform a specific task, then don't choose any alternative for that task.

   RANGE: Not at all, A little, Very, Completely

   - Social media (e.g. Facebook, Instagram)
   - Direct messages (e.g. SMS, Whatsapp, Messenger)
   - Voice calls
   - Email
   - Browse the web
   - Games
   - News, blogs or forums
   - Videos or movies

3. *Do you perform any other tasks while driving in your usual driving environment?*

   Describe the tasks, how you perform them, and how comfortable you feel performing them.

   Answer ...

4. *What tasks would you engage in more, if the motor vehicle took responsibility of applying gas and brakes, as well as steering, while driving?*

   Assume you still have to keep track of the road and be aware if the motor vehicle can no longer drive.

   Answer ...

5. *In what ways do you perform these tasks while driving in your usual driving environment?*

   For instance, do you call someone by selecting a person with a touch screen or using numbers to give a command to call a person? If you do not perform a specific task, then do not select an option.

   Range: Speech, Touch, Buttons or dials, Other

   – Social media (e.g. Facebook, Instagram)
   – Direct messages (e.g. SMS, Whatsapp, Messenger)
   – Voice calls
   – Email
   – Browse the web
   – Games
   – News, blogs or forums
   – Videos or movies

6. *If you chose 'Other' for any of the tasks above, what type of interface do you use to complete those tasks?*

   Answer ...

7. *What would you change in order to make you more comfortable performing tasks while driving, which you normally would not perform?*

   Assume you still have to keep track of the road and be aware if the motor vehicle can no longer drive.

   Answer ...

B.1.6 Performing non-driving tasks while driving with active driver assistance (6)

Here we ask questions regarding what non-driving tasks are being performed while driving in your usual driving environment (either highways or city driving) with driver assistance active, as well as how often you perform them and how comfortable you are with them.

1. **How much do you perform any of these tasks while driving in your usual driving environment and when driver assistance is active?**

   Tasks can be performed on a mobile phone or on built-in interfaces in the motor vehicle (infotainment system, buttons on the steering wheel, etc.).

   Range: Never, Rarely, Occasionally, Regularly

   - Social media (e.g. Facebook, Instagram)
   - Direct messages (e.g. SMS, Whatsapp, Messenger)
   - Voice calls
   - Email

- Browse the web
- Games
- News, blogs or forums
- Videos or movies

2. *How comfortable are you performing these tasks while driving in your usual driving environment and when driver assistance is active?*

   If you never perform a specific task, then don't choose any alternative for that task.

   RANGE: Not at all, A little, Very, Completely

   - Social media (e.g. Facebook, Instagram)
   - Direct messages (e.g. SMS, Whatsapp, Messenger)
   - Voice calls
   - Email
   - Browse the web
   - Games
   - News, blogs or forums
   - Videos or movies

3. *Do you perform any other tasks while driving and when driver assistance is active?*

   Describe the tasks, how you perform them, and how comfortable you feel performing them.

   Answer ...

4. *In what ways do you perform these tasks while driving in your usual driving environment?*

   For instance, do you call someone by selecting a person with a touch screen or using numbers to give a command to call a person? If you do not perform a specific task, then do not select an option.

   RANGE: Speech, Touch, Buttons or dials, Other

   - Social media (e.g. Facebook, Instagram)
   - Direct messages (e.g. SMS, Whatsapp, Messenger)
   - Voice calls
   - Email
   - Browse the web
   - Games
   - News, blogs or forums
   - Videos or movies

5. *If you chose 'Other' for any of the tasks above, what type of interface do you use to complete those tasks?*

   Answer ...

6. *What would you change in order to make you more comfortable performing tasks while driving, which you normally would not perform?*
   Assume you still have to keep track of the road and be aware if the motor vehicle can no longer drive.

   Answer ...

B.1.7 City driving - performing non-driving tasks (9)

Here we ask questions regarding what non-driving tasks, i.e. tasks other than those directly related to driving, are being performed while driving in cities, as well as how often you perform them and how comfortable you are with them.

1. **How much do you perform any of these tasks during city driving?**
   Tasks can be performed on a mobile phone or built-in interfaces in the motor vehicle (infotainment system, buttons on the steering wheel, etc.).

   Range: Never, Rarely, Occasionally, Regularly

   - Social media (e.g. Facebook, Instagram)
   - Direct messages (e.g. SMS, Whatsapp, Messenger)
   - Voice calls
   - Email
   - Browse the web
   - Games
   - News, blogs or forums
   - Videos or movies

2. *How comfortable are you performing these tasks during city driving?*
   If you never perform a specific task, then don't choose any alternative for that task.

   Range: Not at all, A little, Very, Completely

   - Social media (e.g. Facebook, Instagram)
   - Direct messages (e.g. SMS, Whatsapp, Messenger)
   - Voice calls
   - Email
   - Browse the web
   - Games
   - News, blogs or forums
   - Videos or movies

3. *Do you perform any other tasks during city driving?*
   Describe the tasks, how you perform them, and how comfortable you feel performing them.

   Answer ...

4. *What tasks would you engage in more, if the motor vehicle took responsibility of applying gas and brakes, while driving in cities?*
   Assume you still have to keep track of the traffic and be aware if the motor vehicle can no longer drive.

   Answer ...

B.1.8 Task interaction (10, 13)

In what way do you interact with an interface to complete a task.

1. *In what ways do you perform these tasks while driving?*
   For instance, do you call someone by selecting a person with a touch screen or using numbers to give a command to call a person? If you do not perform a specific task, then do not select an option.

   RANGE: Speech, Touch, Buttons or dials, Other

   - Social media (e.g. Facebook, Instagram)
   - Direct messages (e.g. SMS, Whatsapp, Messenger)
   - Voice calls
   - Email
   - Browse the web
   - Games
   - News, blogs or forums
   - Videos or movies

2. *If you chose 'Other' for any of the tasks above, what type of interface do you use to complete those tasks?*

   Answer ...

3. *What would you change in order to make you more comfortable performing tasks while driving, which you normally would not perform?*
   Assume you still have to keep track of the road and be aware if the motor vehicle can no longer drive.

   Answer ...

B.1.9 City driving - performing non-driving tasks with active driver assistance (12)

Here we ask question regarding what non-driving tasks are being performed while driving in cities, with driver assistance active, as well as how often you perform them and how comfortable you are with them.

1. **How much do you perform any of these tasks during city driving and when driver assistance is active?**

Tasks can be performed on a mobile phone or built-in interfaces in the motor vehicle (infotainment system, buttons on the steering wheel, etc.).

RANGE: Never, Rarely, Occasionally, Regularly

- Social media (e.g. Facebook, Instagram)
- Direct messages (e.g. SMS, Whatsapp, Messenger)
- Voice calls
- Email
- Browse the web
- Games
- News, blogs or forums
- Videos or movies

2. *How comfortable are you performing these tasks during city driving and when driver assistance is active?*

   If you never perform a specific task, then don't choose any alternative for that task.

   RANGE: Not at all, A little, Very, Completely

   - Social media (e.g. Facebook, Instagram)
   - Direct messages (e.g. SMS, Whatsapp, Messenger)
   - Voice calls
   - Email
   - Browse the web
   - Games
   - News, blogs or forums
   - Videos or movies

3. *Do you perform any other tasks while driving in cities and when driver assistance is active?*

   Describe these tasks below, how to perform these tasks and how comfortable you feel.

   Answer ...

B.1.10 Expectations with driver assistance (14)

Here we ask you what your expectations with motor vehicles with driver assistance.

1. *What do you know about the current state of motor vehicles with driver assistance, how well they perform and what their capabilities are, etc?*

   Please elaborate.

   Answer ...

B.1.11 Experience with driver assistance (15, 16)

In this section, we will ask you questions about the driver assistance systems you are using. Abbreviations:

CC Cruise Control, keeps a constant speed of the vehicle automatically

ACC Adaptive Cruise Control, advanced cruise control which automatically keeps distance to the vehicle in front by adjusting the speed

LC Lane Centering, steers and keeps the vehicle in the middle of the lane automatically

1. **How often do you use these systems while driving in your usual driving environment?**

   Range: Never, Rarely, Occasionally, Reguarly

   - CC
   - ACC
   - LC

2. **How much do you trust these systems while driving in your usual driving environment?**

   Range: Not at all, A little, A lot, Completley

   - CC
   - ACC
   - LC

3. *Are there any other driver assistance systems which you have used? In that case, what are your experiences with them?*

   Answer ...

B.1.12 Followup Questions (17)

1. *Do you have any other thoughts or comments?*

   Answer ...

2. **Do you want to participate in future surveys?**

   - Yes
   - No

3. **Do you want to participate in future user tests?**

   - Yes

- No

4. *If you answered yes on any of the previous questions, how can we contact you?*
   Please specify your email and/or phone number.

   Answer ...

B.2 Additional results

Table B.1 shows the division of nationalities of the respondents of the "Other" sector in Figure 6.1a. Figure B.1 shows a similar comparison between different categories of drivers for text messaging as in Figure 6.2.

Nationality	**Number of responses**
Afghanistan	1
Algeria	1
Australia	2
Austria	2
Denmark	2
Finland	1
France	1
Germany	3
Heard Island and McDonald Islands	1
Netherlands	2
New Zealand	2
Norway	1
Pakistan	1
Poland	1
Switzerland	1

Table B.1: The number of responses from the different nationalities in the "Other" sector of Figure 6.1a.

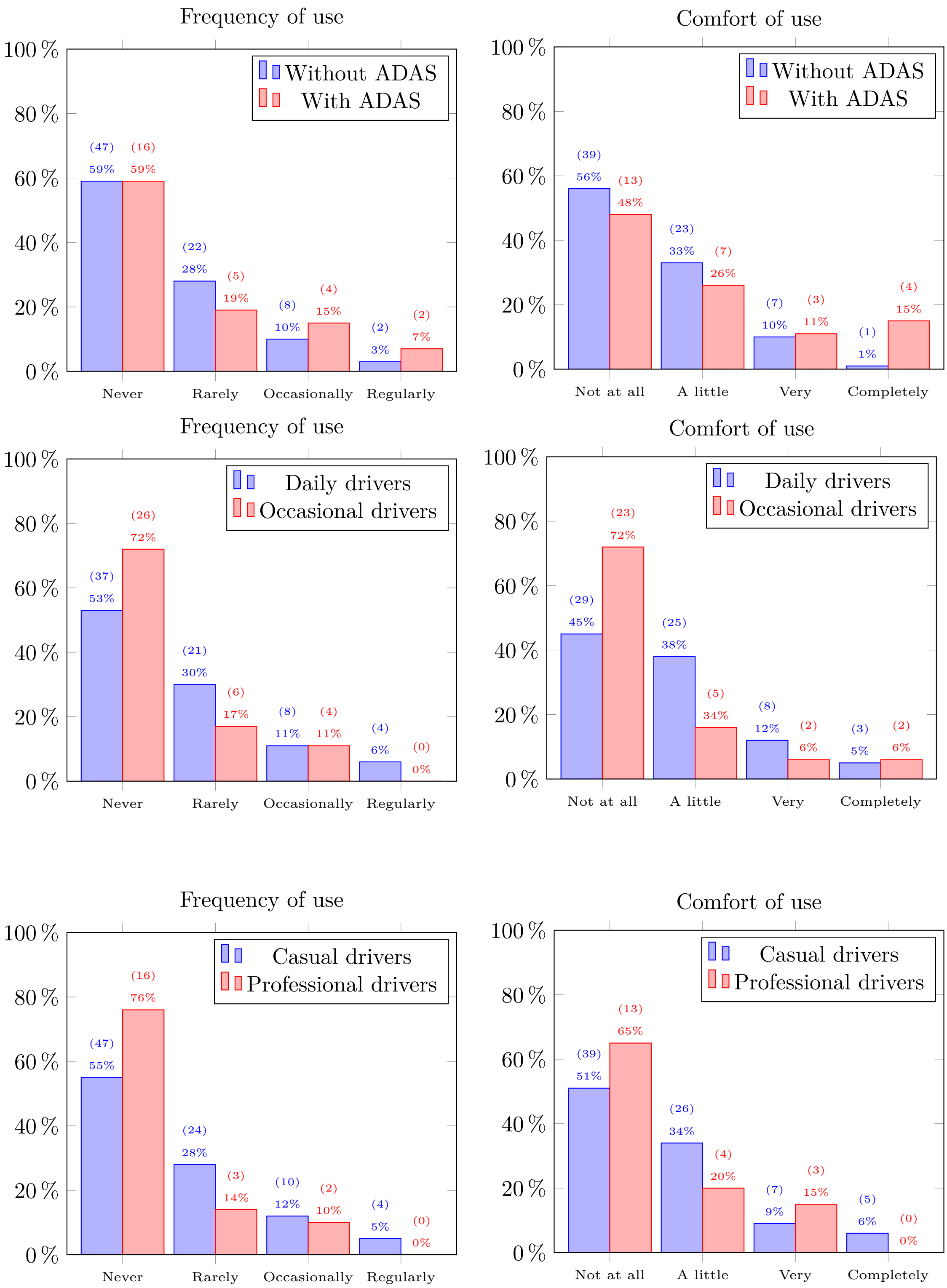

Figure B.1: The respondents' frequency and comfort of text messaging, comparing between different categories of drivers.

B.3 Additional chi-squared tests

This section will describe the additional chi-squared tests made on other pairs of categories. The frequency or the comfort of engagement in either text messaging or voice calls, was used as the first axis of a category type, while the presence of ADAS, frequency of driving, or driving as a profession was used as the second axis of a category types. The first axis has four combinations, and second one has three, giving us twelve different comparisons to make, of which the first was presented in Section 7.1. An overview of the null hypothesises that were rejected are shown in Table B.2. As a reminder, ν denotes the degrees of freedom, α denotes the significance threshold, and the P-value denotes the computed probability of the null hypothesis being valid, calculated from ν and χ^2.

Category pair	Null hypothesis rejected?
Frequency, text messaging / ADAS - no ADAS	No
Frequency, text messaging / Daily - Occasional	No
Frequency, text messaging / Professional - Casual	No
Frequency, voice calls / ADAS - no ADAS	**Yes**
Frequency, voice calls / Daily - Occasional	**Yes**
Frequency, voice calls / Professional - Casual	No
Comfort, text messaging / ADAS - no ADAS	No
Comfort, text messaging / Daily - Occasional	No
Comfort, text messaging / Professional - Casual	No
Comfort, voice calls / ADAS - no ADAS	**Yes**
Comfort, voice calls / Daily - Occasional	**Yes**
Comfort, voice calls / Professional - Casual	No

Table B.2: The null hypothesises that were rejected.

Data points x

Frequency, text messaging		Category		**Sum**
Value	Description	Without ADAS	With ADAS	
0	Never	47	16	**63**
1	Rarely	22	5	**27**
2	Occasionally	8	4	**12**
3	Regularly	2	2	**4**
	Sum	**79**	**27**	**106**
	Weighted mean	0.56	0.70	0.59

Expected values $E(X)$

Frequency, text messaging	Category		**Sum**
	Without ADAS	With ADAS	
Never	46.95	16.05	**63**
Rarely	20.12	6.88	**27**
Occasionally	8.94	3.06	**12**
Regularly	2.98	1.02	**4**
Sum	**79**	**27**	**106**

Chi-squares χ^2

Frequency, text messaging	Category		**Sum**
	Without ADAS	With ADAS	
Never	0.0000	0.0001	**0.0002**
Rarely	0.1751	0.5125	**0.6876**
Occasionally	0.0995	0.2912	**0.3907**
Regularly	0.3229	0.9448	**1.2677**
Sum	**0.5976**	**1.7486**	**2.3462**

Hypothesis testing

Alternative hypothesis	People who drive with ADAS, engage in text messaging more frequently than people driving without ADAS.
ν	3
χ^2	2.35
α	5.00%
P-value	50.37%
Reject null hypothesis	**No**

Table B.3: The calculation of the chi-squares χ^2 of the frequency of engaging in text messaging, comparing between car drivers with and without ADAS.

Data points x

Frequency, text messaging		Category		**Sum**
Value	Description	Daily	Occasional	
0	Never	37	26	**63**
1	Rarely	21	6	**27**
2	Occasionally	8	4	**12**
3	Regularly	4	0	**4**
	Sum	**70**	**36**	**106**
	Weighted mean	0.70	0.39	0.59

Expected values $E(X)$

Frequency, text messaging	Category		**Sum**
	Daily	Occasional	
Never	41.60	21.40	**63**
Rarely	17.83	9.17	**27**
Occasionally	7.92	4.08	**12**
Regularly	2.64	1.36	**4**
Sum	**70**	**36**	**106**

Chi-squares χ^2

Frequency, text messaging	Category		**Sum**
	Daily	Occasional	
Never	0.5094	0.9906	**1.5000**
Rarely	0.5635	1.0957	**1.6593**
Occasionally	0.0007	0.0014	**0.0021**
Regularly	0.6987	1.3585	**2.0571**
Sum	**1.7723**	**3.4462**	**5.2185**

Hypothesis testing

Alternative hypothesis	People who drive daily, engage in text messaging more frequently than people driving occasionally.
ν	3
χ^2	5.22
α	5.00%
P-value	15.65%
Reject null hypothesis	**No**

Table B.4: The calculation of the chi-squares χ^2 of the frequency of engaging in text messaging, comparing between daily and occasional car drivers.

Data points x

Frequency, text messaging		Category		Sum
Value	Description	Professional	Casual	
0	Never	16	47	**63**
1	Rarely	3	24	**27**
2	Occasionally	2	10	**12**
3	Regularly	0	4	**4**
	Sum	**21**	**85**	**106**
	Weighted mean	0.33	0.66	0.59

Expected values $E(X)$

Frequency, text messaging	Category		Sum
	Professional	Casual	
Never	12.48	50.52	**63**
Rarely	5.35	21.65	**27**
Occasionally	2.38	9.62	**12**
Regularly	0.79	3.21	**4**
Sum	**21**	**85**	**106**

Chi-squares χ^2

Frequency, text messaging	Category		Sum
	Professional	Casual	
Never	0.9921	0.2451	**1.2372**
Rarely	1.0316	0.2549	**1.2865**
Occasionally	0.0599	0.0148	**0.0747**
Regularly	0.7925	0.1958	**0.9882**
Sum	**2.8760**	**0.7106**	**3.5866**

Hypothesis testing

Alternative hypothesis	People who drive professionally, engage in text messaging more frequently than people driving casually.
ν	3
χ^2	3.59
α	5.00%
P-value	30.97%
Reject null hypothesis	**No**

Table B.5: The calculation of the chi-squares χ^2 of the frequency of engaging in text messaging, comparing between professional and casual car drivers.

Data points x

Frequency, voice calls		Category		Sum
Value	Description	Without ADAS	With ADAS	
0	Never	22	2	**24**
1	Rarely	26	6	**32**
2	Occasionally	21	10	**31**
3	Regularly	10	9	**19**
	Sum	**79**	**27**	**106**
	Weighted mean	1.24	1.96	1.42

Expected values $E(X)$

Frequency, voice calls	Category		Sum
	Without ADAS	With ADAS	
Never	17.89	6.11	**24**
Rarely	23.85	8.15	**32**
Occasionally	23.10	7.90	**31**
Regularly	14.16	4.84	**19**
Sum	**79**	**27**	**106**

Chi-squares χ^2

Frequency, voice calls	Category		Sum
	Without ADAS	With ADAS	
Never	0.9459	2.7675	**3.7134**
Rarely	0.1940	0.5676	**0.7616**
Occasionally	0.1916	0.5605	**0.7521**
Regularly	1.2223	3.5765	**4.7988**
Sum	**2.5538**	**7.4721**	**10.0259**

Hypothesis testing

Alternative hypothesis	People who drive with ADAS, engage in voice calls more frequently than people driving without ADAS.
ν	3
χ^2	10.03
α	5.00%
P-value	1.83%
Reject null hypothesis	**Yes**

Table B.6: The calculation of the chi-squares χ^2 of the frequency of engaging in voice calls, comparing between car drivers with and without ADAS.

Data points x

Frequency, voice calls		Category		Sum
Value	Description	Daily	Occasional	
0	Never	9	15	**24**
1	Rarely	23	9	**32**
2	Occasionally	20	11	**31**
3	Regularly	18	1	**19**
	Sum	**70**	**36**	**106**
	Weighted mean	1.67	0.94	1.42

Expected values $E(X)$

Frequency, voice calls	Category		Sum
	Daily	Occasional	
Never	15.85	8.15	**24**
Rarely	21.13	10.87	**32**
Occasionally	20.47	10.53	**31**
Regularly	12.55	6.45	**19**
Sum	**70**	**36**	**106**

Chi-squares χ^2

Frequency, voice calls	Category		Sum
	Daily	Occasional	
Never	2.9598	5.7551	**8.7149**
Rarely	0.1651	0.3210	**0.4862**
Occasionally	0.0109	0.0211	**0.0320**
Regularly	2.3697	4.6078	**6.9775**
Sum	**5.5055**	**10.7051**	**16.2106**

Hypothesis testing

Alternative hypothesis	People who drive daily, engage in voice calls more frequently than people driving occasionally.
ν	3
χ^2	16.21
α	0.50%
P-value	0.10%
Reject null hypothesis	**Yes**

Table B.7: The calculation of the chi-squares χ^2 of the frequency of engaging in voice calls, comparing between daily and occasional car drivers.

Data points x

Frequency, voice calls		Category		**Sum**
Value	Description	Professional	Casual	
0	Never	3	21	**24**
1	Rarely	8	24	**32**
2	Occasionally	5	26	**31**
3	Regularly	5	14	**19**
	Sum	**21**	**85**	**106**
	Weighted mean	1.57	1.39	1.42

Expected values $E(X)$

Frequency, voice calls	Category		**Sum**
	Professional	Casual	
Never	4.75	19.25	**24**
Rarely	6.34	25.66	**32**
Occasionally	6.14	24.86	**31**
Regularly	3.76	15.24	**19**
Sum	**21**	**85**	**106**

Chi-squares χ^2

Frequency, voice calls	Category		**Sum**
	Professional	Casual	
Never	0.6476	0.1600	**0.8076**
Rarely	0.4349	0.1074	**0.5423**
Occasionally	0.2122	0.0524	**0.2646**
Regularly	0.4058	0.1002	**0.5060**
Sum	**1.7004**	**0.4201**	**2.1204**

Hypothesis testing

Alternative hypothesis	People who drive professionally, engage in voice calls more frequently than people driving casually.
ν	3
χ^2	2.12
α	5.00%
P-value	54.78%
Reject null hypothesis	**No**

Table B.8: The calculation of the chi-squares χ^2 of the frequency of engaging in voice calls, comparing between professional and casual car drivers.

Data points x

Comfort, text messaging		Category		Sum
Value	Description	Without ADAS	With ADAS	
0	Not at all	39	13	**52**
1	A little	23	7	**30**
2	Very	7	3	**10**
3	Completely	1	4	**5**
	Sum	**70**	**27**	**97**
	Weighted mean	0.57	0.93	0.67

Expected values $E(X)$

Comfort, text messaging	Category		Sum
	Without ADAS	With ADAS	
Not at all	37.53	14.47	**52**
A little	21.65	8.35	**30**
Very	7.22	2.78	**10**
Completely	3.61	1.39	**5**
Sum	**70**	**27**	**97**

Chi-squares χ^2

Comfort, text messaging	Category		Sum
	Without ADAS	With ADAS	
Not at all	0.0579	0.1502	**0.2081**
A little	0.0842	0.2184	**0.3027**
Very	0.0065	0.0168	**0.0233**
Completely	1.8854	4.8880	**6.7734**
Sum	**2.0340**	**5.2735**	**7.3075**

Hypothesis testing

Alternative hypothesis	People who drive with ADAS, are more comfortable with text messaging than people driving without ADAS.
ν	3
χ^2	7.31
α	5.00%
P-value	6.27%
Reject null hypothesis	**No**

Table B.9: The calculation of the chi-squares χ^2 of the comfort of engaging in text messaging, comparing between car drivers with and without ADAS.

Data points x

Comfort, text messaging		Category		**Sum**
Value	Description	Daily	Occasionally	
0	Not at all	29	23	**52**
1	A little	25	5	**30**
2	Very	8	2	**10**
3	Completely	3	2	**5**
	Sum	**65**	**32**	**97**
	Weighted mean	0.77	0.47	0.67

Expected values $E(X)$

Comfort, text messaging	Category		**Sum**
	Daily	Occasional	
Not at all	34.85	17.15	**52**
A little	20.10	9.90	**30**
Very	6.70	3.30	**10**
Completely	3.35	1.65	**5**
Sum	**65**	**32**	**97**

Chi-squares χ^2

Comfort, text messaging	Category		**Sum**
	Daily	Occasional	
Not at all	0.9806	1.9918	**2.9723**
A little	1.1928	2.4229	**3.6158**
Very	0.2518	0.5115	**0.7633**
Completely	0.0367	0.0745	**0.1112**
Sum	**2.4619**	**5.0007**	**7.4626**

Hypothesis testing

Alternative hypothesis	People who drive daily, are more comfortable with text messaging than people driving occasionally.
ν	3
χ^2	7.46
α	5.00%
P-value	5.85%
Reject null hypothesis	**No**

Table B.10: The calculation of the chi-squares χ^2 of the comfort of engaging in text messaging, comparing between daily and occasional car drivers.

Data points x

Comfort, text messaging		Category		**Sum**
Value	Description	Professional	Casual	
0	Not at all	13	39	**52**
1	A little	4	26	**30**
2	Very	3	7	**10**
3	Completely	0	5	**5**
	Sum	**20**	**77**	**97**
	Weighted mean	0.50	0.71	0.67

Expected values $E(X)$

Comfort, text messaging	Category		**Sum**
	Professional	Casual	
Not at all	10.72	41.28	**52**
A little	6.19	23.81	**30**
Very	2.06	7.94	**10**
Completely	1.03	3.97	**5**
Sum	**20**	**77**	**97**

Chi-squares χ^2

Comfort, text messaging	Category		**Sum**
	Professional	Casual	
Not at all	0.4841	0.1258	**0.6099**
A little	0.7722	0.2006	**0.9728**
Very	0.4269	0.1109	**0.5377**
Completely	1.0309	0.2678	**1.2987**
Sum	**2.7142**	**0.7050**	**3.4191**

Hypothesis testing

Alternative hypothesis	People who drive professionally, are more comfortable with text messaging than people driving casually.
ν	3
χ^2	3.42
α	5.00%
P-value	33.14%
Reject null hypothesis	**No**

Table B.11: The calculation of the chi-squares χ^2 of the comfort of engaging in text messaging, comparing between professional and casual car drivers.

Data points x

Comfort, voice calls		Category		Sum
Value	Description	Without ADAS	With ADAS	
0	Not at all	18	4	**22**
1	A little	22	3	**25**
2	Very	17	4	**21**
3	Completely	16	16	**32**
	Sum	**73**	**27**	**100**
	Weighted mean	1.42	2.19	1.63

Expected values $E(X)$

Comfort, voice calls	Category		Sum
	Without ADAS	With ADAS	
Not at all	16.06	5.94	**22**
A little	18.25	6.75	**25**
Very	15.33	5.67	**21**
Completely	23.36	8.64	**32**
Sum	**73**	**27**	**100**

Chi-squares χ^2

Comfort, voice calls	Category		Sum
	Without ADAS	With ADAS	
Not at all	0.2343	0.6336	**0.8679**
A little	0.7705	2.0833	**2.8539**
Very	0.1819	0.4919	**0.6738**
Completely	2.3189	6.2696	**8.5885**
Sum	**3.5057**	**9.4784**	**12.9842**

Hypothesis testing

Alternative hypothesis	People who drive with ADAS, are more comfortable with voice calls than people driving without ADAS.
ν	3
χ^2	12.98
α	0.50%
P-value	0.47%
Reject null hypothesis	**Yes**

Table B.12: The calculation of the chi-squares χ^2 of the comfort of engaging in voice calls, comparing between car drivers with and without ADAS.

Data points x

Comfort, voice calls		Category		**Sum**
Value	Description	Daily	Occasionally	
0	Not at all	9	13	**22**
1	A little	16	9	**25**
2	Very	13	8	**21**
3	Completely	28	4	**32**
	Sum	**66**	**34**	**100**
	Weighted mean	1.91	1.09	1.63

Expected values $E(X)$

Comfort, voice calls	Category		**Sum**
	Daily	Occasional	
Not at all	14.52	7.48	**22**
A little	16.50	8.50	**25**
Very	13.86	7.14	**21**
Completely	21.12	10.88	**32**
Sum	**66**	**34**	**100**

Chi-squares χ^2

Comfort, voice calls	Category		**Sum**
	Daily	Occasional	
Not at all	2.0985	4.0736	**6.1721**
A little	0.0152	0.0294	**0.0446**
Very	0.0534	0.1036	**0.1569**
Completely	2.2412	4.3506	**6.5918**
Sum	**4.4082**	**8.5572**	**12.9654**

Hypothesis testing

Alternative hypothesis	People who drive daily, are more comfortable with voice calls than people driving occasionally.
ν	3
χ^2	12.97
α	0.50%
P-value	0.47%
Reject null hypothesis	**Yes**

Table B.13: The calculation of the chi-squares χ^2 of the comfort of engaging in voice calls, comparing between daily and occasional car drivers.

Data points x

Comfort, voice calls		Category		**Sum**
Value	Description	Professional	Casual	
0	Not at all	4	18	**22**
1	A little	4	21	**25**
2	Very	6	15	**21**
3	Completely	7	25	**32**
	Sum	**21**	**79**	**100**
	Weighted mean	1.76	1.59	1.63

Expected values $E(X)$

Comfort, voice calls	Category		**Sum**
	Professional	Casual	
Not at all	4.62	17.38	**22**
A little	5.25	19.75	**25**
Very	4.41	16.59	**21**
Completely	6.72	25.28	**32**
Sum	**21**	**79**	**100**

Chi-squares χ^2

Comfort, voice calls	Category		**Sum**
	Professional	Casual	
Not at all	0.0832	0.0221	**0.1053**
A little	0.2976	0.0791	**0.3767**
Very	0.5733	0.1524	**0.7257**
Completely	0.0117	0.0031	**0.0148**
Sum	**0.9658**	**0.2567**	**1.2225**

Hypothesis testing

Alternative hypothesis	People who drive professionally, are more comfortable with voice calls than people driving casually.
ν	3
χ^2	1.22
α	5.00%
P-value	74.76%
Reject null hypothesis	**No**

Table B.14: The calculation of the chi-squares χ^2 of the comfort of engaging in voice calls, comparing between professional and casual car drivers.

C

User Roles

In this appendix, we will show thew remaining user roles introduced in Section 5.3. Several different user roles where constructed from different categories, such as professional and casual drivers, daily and casual drivers, and whether they use ADAS or not.

Median driving experience	20+ years
Median age	45 years
Genders	Almost all male
Demographics	Mostly US
Driving routines	Daily
Driving sessions	4+ hours

Since they are driving as part of their job, they would want the system to be as unobtrusive as possible, especially since they are driving trucks in city environment. The goal of using the system would be for occasional voice calls and rarely anything else.

Unobtrusive **Voice calls**

Figure C.1: A user role constructed for professional truckers not using ADAS. Symbols: [7].

Median driving experience	10-19 years
Median age	25-34 years
Genders	Almost all male
Demographics	Diverse, mostly Swedish
Driving routines	Daily
Driving sessions	Less than 30 minutes

As driving is part of the job, they will likely not want to be disturbed by unnecessary distractions, which is perhaps why they don't engage so much in secondary tasks. They are comfortable using voice calls and that would be their main goal with the system. They also engage in texting, albeit rarely, so a simple way to read and write could also be a goal.

Voice calls **Unobtrusive** **Simple texting**

Figure C.2: A user role constructed for professional car drivers not using ADAS. Symbols: [19].

Median driving experience	10-19 years
Median age	25-34 years
Genders	40% females, 60% males
Demographics	Mostly US
Driving routines	Daily
Driving sessions	Almost all less than 1 hour, some less than 30 minutes

They are comfortable with voice calls, although since they generally don't want to use phones while driving, they don't engage very much in secondary tasks involving the phone. The most prevalent way of task interaction is by using a touch screen, whether it is a mobile phone or more probably the infotainment system. A requirement for the system would be to ensure that other drivers' inattention wouldn't put them in danger. A goal for using the system would be to use it for simpler tasks, such as calling, as long as it is safer and more comfortable than using a phone.

Safety **No phones** **Voice calls**

Figure C.3: A user role constructed for daily casual car drivers not using ADAS. Symbols: [19].

Median driving experience	6-9 years
Median age	25-34 years
Genders	15% female, 85% male
Demographics	Mostly Sweden
Driving routines	Once or a few times a week
Driving sessions	Almost all less than 1 hour, some less than 30 minutes

Since they only drive occasionally, they're primary goal is not to engage so much in secondary tasks but to get to their destination. Their goal would be to not use the system very much.

Hide away

Figure C.4: A user role constructed for occasional casual car drivers not using ADAS. Symbols: [19].

Median driving experience	10-19 years
Median age	35-44 years
Genders	All male
Demographics	Few responses, 3 from Sweden, 2 from US
Driving routines	Daily
Driving sessions	Varying (less than 30 minutes to 4+ hours)

They care more about concentrating on the job rather than engage in secondary tasks, but is generally more open to trusting the system. Some would be more comfortable if some aspects of the care were improved, for instance the voice recognition. Goals of using the system would only be occasional voice calls.

Unobtrusive **Voice calls**

Figure C.5: A user role constructed for professional truckers and car drivers using ADAS. Symbols: [7].

D

Low-Fidelity Prototype User Test

The test subjects were asked to think out loud while they were performing the tasks given to them. The observation notes of how the test subjects performed during specific tasks, as well as the test subjects' commentaries translated to English, are presented below. The test operator's voice is shown in bold, while the test subjects' voices are shown in italics. All other notes are shown in regular style.

D.1 Subject 1

Tasks observation:

1. **Start the system.**

   Presses the on/off button, which is the right upper side button. Rotates the track pad.

2. **Go to the Messages app.**

   Rotates the track pad until they get to the app without much effort. Presses the middle button of the track pad.

3. **Pretend to write "Hello" (using T9).**

   Rotates the track pad until they get to the "GHI" sector. Presses two times. The operator explains that T9 is used, so it should predict the words. The subject finds it annoying. Manages to write the whole word. Inputs a space, which is the middle button.

4. **Go back to the main menu.**

   Presses the back button, which is the right lower side button.

5. **Turn off the system.**

   Presses the on/off button.

6. **Try out the standard controls.**

   Realises that the controls are for controlling the music.

7. **Increase the volume.**

   Increases the volume by rotating the track pad.

Feedback afterwards:

What was it that was cumbersome with T9?

I thought it was cumbersome before. It often chooses the wrong words, but you can write fast with it. When you drive a car, you have to look at the letters rather carefully.

Do you think it would have been easier to use the QWERTY layout instead?

Maybe, since you at least know which letter you have written. That was the thing about T9; you start writing a word, then you look at the road, and then you forgot what it was that you were supposed to write, when you had written a few words.

Do you think Scribble would have been a better alternative?

Yes, that would be much better, because that allows me to watch the road.

Did you understand the purpose of the main menu?

Yes.

Did you understand the purpose of the lights around the track pads?

No.

...

You could make the buttons more efficient by holding in a button on the track-pad to turn the system off, then you can get rid of the buttons around the track pad.

Are track pads a good idea compared to regular buttons?

Yes, it is, but you have to think about the different situations it is used in. If you have sticky fingers, which may be the case for some drivers, then regular would have been better.

D.2 Subject 2

Tasks observation:

1. **Start the system.**

   Presses the play button, which is the down button on the trackpad, but nothing happens. Presses the on/off button.

2. **Go to the Messages app.**

   Aha, the text messages app! It is over there! [to the far right in the HUD, without navigating there]

Presses the right button on the track pad, nothing happens. Presses the middle button on the track pad, nothing happens.

Do you remember the input methods?

No, what is that?

For instance, scroll by rotating, select by touching.

Scrolls to Mail, scrolls back to Social Media, then scrolls to Messages.

But there it is, the Messages app, you said it was over there? [to the left] *No right, that was the Mail app.*

...

There is no Messages app!

It is called Messages. [saying it in English this time]

Aha, well, I'll go back then.

Scrolls to the Messages app. Presses the middle button on the track pad.

3. **Pretend to write "Hello" (using T9).**

   Puts their finger on "GHI". Presses two times. The operator explains that it is using T9.

   I never used T9 before.

   The operator explains how T9 works.

   ...

   Puts their finger on "DEF" and presses one time. Puts their finger on "JKL".

   I'll wait a little.

   You don't have to wait.

   Manages to write the whole word. Presses the space button.

4. **Turn off the system.**

   Presses the on/off button.

5. **Increase the volume.**

   Presses the plus button, which is the up button on the left track pad.

   The music is on the right side, so logically the music controls should be on this side.

   Presses the mute button, which is the up button on the right track pad.

   No, that's the mute button.

   Presses the voice control button, which is the left lower side button. The operator explains the controls.

   Aha, but maybe I only have to rotate the track pad then?

   Rotates the right track pad.

   I see the blue light is filling up, so I know when the volume is at maximum.

Feedback afterwards:

Do you think it is cumbersome to use T9 while driving?

Yes, I would have had too much focus on writing a message.

Do you think it would have been easier to use the QWERTY layout instead?

Not really, it would have taken too much focus away as well. Do you have to write messages when driving? I can't drive and write at the same time, I could just as well have picked up my phone and used that to write on.

Do you think Scribble would have been a better alternative?

Yes, that would be much better, because that allows me to watch the road. I would have used this when driving.

Did you understand the purpose of the lights around the track pads?

No. But after you explained I now know that they are for indicating that the system is on.

Did you understand the standard controls when the system was inactive?

I think this button [the mute button] *is used for voice dictation, and this button* [the voice control button] *is used for reading up your messages.*

The operator explains the controls.

...

I have to turn off the system each time I want to turn on a new song, or increase the volume. You could be writing an SMS, and then a bad song is playing, then I don't want to turn off the system, just to change a song, and then go back.

...

Do you think pressing the right button on the right track pad would have been better for navigating the main menu rather than scrolling, like you thought first?

No, once I learnt that, I thought it worked well, like twisting the crown on a watch.

Do you think track pads are a more suitable alternative to touch screens in infotainment systems?

Yes, you'll at least have your hands on the wheel. But regular buttons would have worked as well.

D.3 Subject 3

Tasks observation:

1. **Start the system.**

   Presses the on/off button.

2. **Go to the Messages app.**

   Rotates the track pad until they get to the app without much effort. Presses the middle button of the track pad.

3. **Pretend to write "Hello" (using T9).**

   Scrolls the track pad until they get to the "GHI" sector. Presses two times. The operator explains that T9 is used, so it should predict the words. Scrolls back to "DEF". The operator explains that the sector will "light up" when their finger is touching the corresponding sector on the track pad. Presses "DEF", and "JKL".

   That is not "Hej" ["Hello" in Swedish]

   You were supposed to write "Hello" [in English]

   Manages to write the whole word. Presses the middle button to input a space.

4. **Go back to the main menu.**

   Presses the back button.

   I would have wanted something that was closer.

5. **Turn off the system.**

   Presses the on/off button.

6. **Increase the volume.**

   Holds in the mute button, and scrolls the track pad while still holding. The operator explains how to increase the volume. Scrolls the track pad.

Feedback afterwards:

Did you understand the standard controls when the system was inactive?

Yes, they control the music. I like the mute button, the scrolling works well for adjusting the volume, it's like an old iPod.

Did you understand the purpose of the main menu?

Yes, it is there for you to choose an app.

Do you think it is cumbersome to use T9 while driving?

It depends on how large screen you have. If it is on the windshield, I would have appreciated it more. I would rather have scrolled through the T9 sectors than selected them directly.

Do you think it would have been easier to use the QWERTY layout instead?

No, I think T9 is better. With QWERTY, you have to focus more on where your thumb is, less than what is required for T9, you would've probably lost more focus using QWERTY. T9 works well since you can write with one thumb on the right track pad, and correct mistakes with the other thumb on the left track pad.

Do you think Scribble would have been a better alternative?

Yes, this is also good. It feels better to write with my thumb rather than with my index finger. I would say either to go with Scribble or T9, but I would still have preferred to scroll through the different letter groups. I think it is easier and faster using T9.

Did you understand the purpose of the lights around the track pads?

They are for indicating that it is a track pad. It shows that you are using the track pad. If the lights are off, then the track pads are not active. If you press any button, they become active again.

The operator explains exactly how they work.

Was it something else that was confusing?

What does this button do? [the voice control button]

The operator explains.

Aha, I like this button! Otherwise it has been fairly self-explanatory. The only thing to mention is that the on/off button and the back button are easy to mix up.

The operator explains the difference.

Aha, so it works like a smart phone? But I'm still used to thinking that an on/off button is for turning it off completely.

Did the scolling work well, do you think?

I thought it worked well. I want to change my mind about T9, I think it is maybe better to have direct selection rather than scrolling through like I thought before. If you could see the letters on the track pad itself, it would have been easier. It is important to get response if you have pressed the right button or not.

...

Can you switch places of the track pads?

Yes.

E

High-Fidelity Prototype User Test 1

In this test, the subjects were also asked to think out loud while they were performing the tasks given to them, but they tended to focus more on the tasks this time, due to the simulation being more related to an actual driving environment. The tasks that were given include (not necessarily in the same order):

- Control the music:
  - turn on music,
  - decrease the volume,
  - go to the next song, and
  - pause the music.
- Use the infotainment system:
  - turn on the system,
  - explore and navigate the main menu, and
  - go to the Messages app.
- Write a message (“Hello ”, with a space at the end).
- Adjust the advanced driving assistance:
  - activate pilot assist, and
  - decrease distance to the car in front.

E.1 Subject 1

Tasks observation:

> Subject having a little problem getting out of the system, while they are in there.

E.2 Subject 2

Tasks observation:

The subject finds it easy to play music, with some prior inspection to the system. Other music related controls were handled without much effort. The subject thought it was good with feedback from the system (visual and vibration), and that it would become easier the more you become used to the system. They thought, however, that more feedback is needed for the T9 input.

Feedback afterwards:

I think it needs some more functionality. I think you also get used to the system the more you use it.

E.3 Subject 3

Tasks observation:

The subject found it confusing at first which controls each track pad was responsible for. They try to keep track of the traffic while they use the system. They thought there was a small learning curve, but you probably get used to it after a while.

The subject thought it was confusing with the Music app in the main menu, since the music controls were present in the standby mode. They managed to get to the Messages app, without much effort. They had less focus on the road, while they were standing still.

Feedback afterwards:

I think there is a mismatch between T9 and smartphone keyboards; you have to learn T9 all over again. But I still prefer the T9 layout over QWERTY. It also needs to have more feedback in the HUD, to be more aware of where you are pressing. It becomes easier as you use it more. I think I would have learned it after some amount of practice. The volume controls were a little ambiguous, but you get used to it after some time. I think T9 could be cumbersome to use without proper feedback.

E.4 Subject 4

Tasks observation:

The subject thought that the volume adjustment controls felt good. They were fairly focused on the road while using the music controls, only glancing down occasionally.

The subject found it easier to write with T9 while standing still at a crossroads than when driving.

Feedback afterwards:

Since there were not that much to do in the system, it was fairly simple to use. The size of the track pads was good. It was also good that it vibrated every time I pressed something. However, it was sometimes difficult to feel the different controls using only the finger, so I had to look down more often.

E.5 Subject 5

Tasks observation:

The subject found it difficult to take instructions while using the system, but otherwise it felt good to use. They tried to still remain focused on the road, while using the system.

The subject pressed the back button by mistake, while writing a message. They recognise the T9 layout, but it is to cumbersome to use, since you have to look down. They thought it would have been nice to know where the finger is at.

Feedback afterwards:

I tried to access the main menu, but I often missed the button. I wished to have feedback for when I pressed a button, and also have more feedback in the HUD. I also think the test did not represent a real driving setting; if I where to drive for real, I would have been more focused on the road.

E.6 Subject 6

Tasks observation:

The subject found the system to be unresponsive. They seemed to be comfortable with the different interactions, after some amount of practice.

Feedback afterwards:

I lost a lot of focus while writing with T9; when I was writing, I thought the letters on the HUD were too small. I think it is important to properly see what you write in the HUD. I would have wanted to scroll through the T9 sectors instead of stretching my thumb all the way to reach the furthest buttons. There has to be some feedback when pressing the buttons; it is important to feel when your finger "enter" a new button area, as you would feel with physical buttons. Haptic feedback might make this easier.

F

High-Fidelity Prototype Test 2

This test was almost identical to high-fidelity prototype test 1, except for the tasks that were given. We had the same simulation video and control questions as before, in order to compare if there were any difference in attentiveness. The tasks given to the test subjects were condensed to only writing messages, with our updated design of the prototype. The messages that they were asked to write were:

0. Testing
1. I drive safely
2. It is sunny today
3. Gothenburg is beautiful
4. The coffee tastes very good

The first message (message 0) was primarily used to teach the test subjects writing with our system, and was only used as a task for one of the test subject.

F.1 Subject 1

Tasks observation:

> The subject had trouble in the beginning with the scrolling.
>
> *This feels very dangerous.*
>
> The subject focuses on the road again after writing at a red light. They pressed the wrong buttons when writing message 4, and were confused of how to correct the mistake. They kept writing, regardless of the errors made before. At one point they pressed the back button instead of the backspace button, confusing one button with the other.

Feedback afterwards:

> *You have to look down a lot on the track pad, as you will not notice if you have pressed the right button or not. It took a lot of focus and was quite annoying. If you could feel the buttons, then it would have worked better. If you could hover your finger over the buttons, and see in the HUD which button your*

holding your finger at, then you would be able to look up more. Overall, the system was very easy to use. The menus themselves are very easy to navigate. It was only T9 that were cumbersome to use, because I want to look at the road and can't do that while typing. Controlling the music was very easy.

F.2 Subject 2

Tasks observation:

The subject found it very unnatural to write with their thumb. They don't like to lose focus while driving. They often confuse the back button with the backspace button. Manages to write message 1 without much effort. They seem to want to have focus on the traffic all the time. They feel more stressed when writing with the system. They managed to correct a mistake without much effort, and spot the speed sign, which no other test subject had done. They need some help with the spelling of the words.

Feedback afterwards:

I think it is easier to write with this system while driving, rather than using the smart phone, since the HUD is higher up so I don't have to look down. I only looked down because I hadn't become completely comfortable with the writing yet, but a felt that I learned where the buttons were the more I used it. I wished to have the letters on the HUD to follow my finger on the track pad. I would also prefer to have the backspace button in the writing mode instead, so I don't have to go back one step in the system to remove characters.

F.3 Subject 3

Tasks observation:

The subject found it cumbersome to remove characters when writing a message, since the backspace button is not in the same mode as T9.

Feedback afterwards:

I would like to have visual feedback in the HUD on where my finger is. Otherwise you lose to much focus by looking down.

F.4 Subject 4

Tasks observation:

This subject also found it cumbersome to remove characters when writing a message, since the backspace button is not in the same mode as T9.

Feedback afterwards:

> *I want feedback on where my finger is when writing in T9. Also, T9 is a bit of an adjustment to make, since I am comfortable using QWERTY already.*

F.5 Subject 5

Tasks observation:

> The subject found it difficult to write using T9.

Feedback afterwards:

> *I think it would have been easier to write if there were some feedback on what button I was holding my finger over.*

F.6 Subject 6

Tasks observation:

> The subject found that they didn't manage the driving as they would like when using the system. They felt that they didn't follow the motion of the traffic. They felt that if they could feel the steering wheel turn, then it would have made the driving experience better. They just followed the ride, and doesn't pay attention to what is happening in the traffic.

Feedback afterwards:

> *I wanted more visual feedback in the HUD, as well as having more feedback in the track pads, for instance with haptic feedback. Otherwise, I think T9 works relatively well.*

F.7 Subject 7

Tasks observation:

> The subject found it difficult to spell sometimes, relying on spell corrections instead of carefully writing the correct word from the beginning.

Feedback afterwards:

> *I had trouble with the spelling, the T9 prediction were not sufficient at times. There also need to be more feedback, to know what you have written. It was confusing with both a back button and a backspace button, as I sometimes was mistaking one for the other. I was looking to much on the steering wheel, instead of in the HUD. I do think, however, that the T9 idea is interesting. I was sceptical at first, but after using it, it felt fairly good. Maybe there could be some visual feedback on the track pads in which menu I'm in. Also, a better placement of the HUD might have made it better as well.*