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The effects of secondary tasks in semi-automated vehicles

A Laboratory user-study regarding driver response time to get back into the loop

Master of Science Thesis in Industrial and Materials Science, IMSX30

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CHALMERS UNIVERSITY OF TECHNOLOGY
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Cover: Driver's view in the simulation car.
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Abstract

Every year, over 1.3 million people die in the traffic. It is estimated that over 90% of these accidents are caused by human errors. Semi-automated cars looks to be the solution to lower these deaths.

The goal of this master thesis work has been to look at how to make an autonomous car more attractive, specifically what would be required for a driver to conduct work in these upcoming cars. It is theorised that, if work could be safely conducted in a semi-autonomous vehicle, the increased price tag would be justified by the added value of using time for work that was previously wasted. This study tested two different ways of conducting work in the car with a passive task serving as a base line. A simulation was conducted with 15 participants to try out the three different car setups. The different setups were, a heads-up display for working tasks, a cell phone for working tasks, and a relaxation task as a base line. During each task a take-over request was presented and the response time for the take-over was gathered.

After the results had been analysed it was discovered that the heads-up display showed the best result with a statistical significance compared to the cell phone task. It is theorised that the main reasoning for these results were that the system shutdown the display when the take-over request started, as well as the incentives gaze towards the road centre. This result suggests that it is not only possible to conduct work in a car, but if done right, it might even improve the cognitive recall time which could improve the re-take control of the car. Therefore, it is recommended to conduct further research within the area of using the car system to conduct work in autonomous vehicles.

Keywords: Effect, Secondary task, Semi-autonomous vehicle, Take-over time, Active task, Passive task

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Jonas Sundmark & Erik Wassén, Gothenburg, June 2019

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Abbreviation and definition of terms

HAD - Highly advanced driving

SA - Situation awareness

AV - Autonomous vehicle

ST - Secondary task

HUD - Heads-up display

HMI - Human-machine interaction

TOR - Take-over request

VLT - Visible light transmission

SAE - Society of Automotive Engineers

Back-in-loop - Is about the reduced ability of an operator to take back the control of the system during automation failure

1

Introduction

1.1 Stating the problem

One fact that many people do not know about is the number of deaths occurring in the traffic each year. Since traffic is such an integrated part of our society, it is difficult to see it as something dangerous, but the matter of fact is that well over 1.3 million people die in traffic each year on this planet [1], figure 1.1. Beyond that, up to an additional 50 million people get injured or disabled each year from traffic accidents. This makes traffic injuries the leading cause of death for people between the age of 5 and 24, and overall number eight for all age groups. While this statistic is not evenly distributed between different countries, still about 70 thousand people dies in Europe annually from traffic injuries.

Figure 1.1: Depicting the chaotic nature of traffic around the globe [1]

According to the U.S organisation NHTSA [8], 94% of all traffic accidents are caused by human errors directly or indirectly. Therefore, the common thought on how to lower the accidents is to lower the impact of the human factor, and this is where ADAS comes in. ADAS stands for Advanced driver-assistance system, and is the collection name for all the systems that activity tries to help the driver avoid an accident from happening. It is generally believed that, with more ADAS functions installed and used, more lives can be saved. Therefore, the goal of ADAS is clearly to save more lives, something that one of the makers, Autoliv Inc also works toward. That said, it is believed that a point will be reached where only adding more supportive systems to a human driver will not be enough, since it is still the human that makes decisions and performs based on the individual's own ability and current well-being. Hence, the potential for fully autonomous vehicles surpasses the human's ability to drive and keep constant focus on the surrounding. But the road to the fully autonomous vehicles is long and will take time, and before that partial autonomous vehicles will be on the road. These partial autonomous vehicles will most likely do some driving by itself, but will not have the ability to work in all conditions. This means that the human driver would need to be ready to take over the wheels when the car demands so. This level is also called SAE level 3, the Society of Automobile Engineers has defined the different SAE levels [4].

However, it is implied that with less need of focus on the road, inevitably the driver will instead of monitoring the car, start engaging in other tasks, so called secondary tasks. This poses a question; how can one make sure that it is safe to take over the wheels from the car while have being engaged in a secondary task not related to driving and thus been out of-the-loop?

1.2 Purpose

The purpose of this project is to study the area of SAE Level 3 and more specifically, through the incentives of performing secondary tasks as an effect of increased automation, find out how secondary tasks can be performed without reducing traffic safety. To understand what requirements and supportive functions that needs to be provided by the human-machine system, a broad field study of the subject must be conducted. Interesting areas to be studied includes cognitive and physical ergonomics, aspects of safety and the effects caused by automation. This will create the fundamental knowledge needed to be able to design a system with human-machine interaction in focus that helps support the driver in the situations to come. This knowledge will practically be put to use in a development process to develop an improved conceptual design of the HMI. The focus will be put on bringing the driver back into the loop as efficiently as possible, and at the same time, have a system that adds enough value for the user to actually wanting to use it. The developed concept will then be used to test the hypothesis being, if this developed system can help to improve the act of getting back into the loop. The test will be a simulation with participants in a car with the chosen concept installed and tested versus a baseline. The outcome of this simulation will then be used to try to answer the final hypothesis regarding secondary tasks in SAE level 3 cars.

1.3 Research Questions

- ***Should it be allowed for secondary tasks to be performed by the driver?*** This first question aims to justify the continuation of the project, and serves as a gate that needs to be passed for the project to continue in the planned path. If it is discovered that no secondary tasks should be allowed to carry out while SAE level 3 is engaged, then there would be no need to develop a system to help the driver with these tasks.

- ***How would safety be affected by different secondary tasks compared to passive monitoring tasks?*** One vital understanding is to understand the difference between passive monitoring, with active secondary tasks from a safety perspective.

- ***According to current research, what are the biggest challenges in order to allow for secondary tasks to safely be conducted?*** By understanding the biggest challenges and problems, it will be easier to focus on what adds value to the current state of the art.

- ***How could a conceptual HMI system look like, based on the found guide lines to support ST and back-to-loop?*** This is a vital input to determine what to be tested in the simulation phase.

1.4 Goals

The goal of this report is to answer the research questions and more specifically to increase the usability of the ADAS system and improve upon the current human-machine interaction that exist in the car cockpit. Therefore, three specific goals have been stated and follows:

- Create a compilation of guidelines based on the current work and research.
- Develop a concept system that support the driver's needs to perform secondary tasks.
- Use this concept to test the hypothesis in a car simulation with participants.
- Analyse the outcome from the simulation and answer the research questions.

1.5 Delimitations

- The first delimitation of this project was to only focus on SAE level 3, and exclude SAE level 2 and 4. The reason being that SAE level 2 is already in use, and SAE level 4 do not face the same problems as SAE level 3 with regards to taking over the vehicle.
- The project will also only focus on the driver in the car, and more specifically the human-machine interaction between the driver and the car. This means

that a boundary is set to only include the inside of the car, even though information about the surrounding will be used, no research regarding this information will be further explored.

- As SAE level 3 is not commercially available as of now, and many specifications are bound to change by the time it gets available, rules and regulations being one of them. Therefore, the current rules and regulations will be taken more lightly. This means that a possible concept that would not been approved with today's rules, will not be discarded since these rules are subject to change by the time SAE level 3 will be commercially available.

1.6 Autoliv

Autoliv Sverige AB, the outsourcer of this project, is a part of the global group, Autoliv Inc. Autoliv Inc [2] is the largest supplier of automobile safety in the world with an estimated total market share of 38% and have in total 67000 employers in 27 countries. Summary of Autoliv around the globe can be found in figure 1.2. Autoliv does not only produces seat belts and air bags, but also steering wheels and electronics for passive safety. Autoliv's mission is to keep their leading position on the market both now and for future cars and be well integrated with autonomous driving.

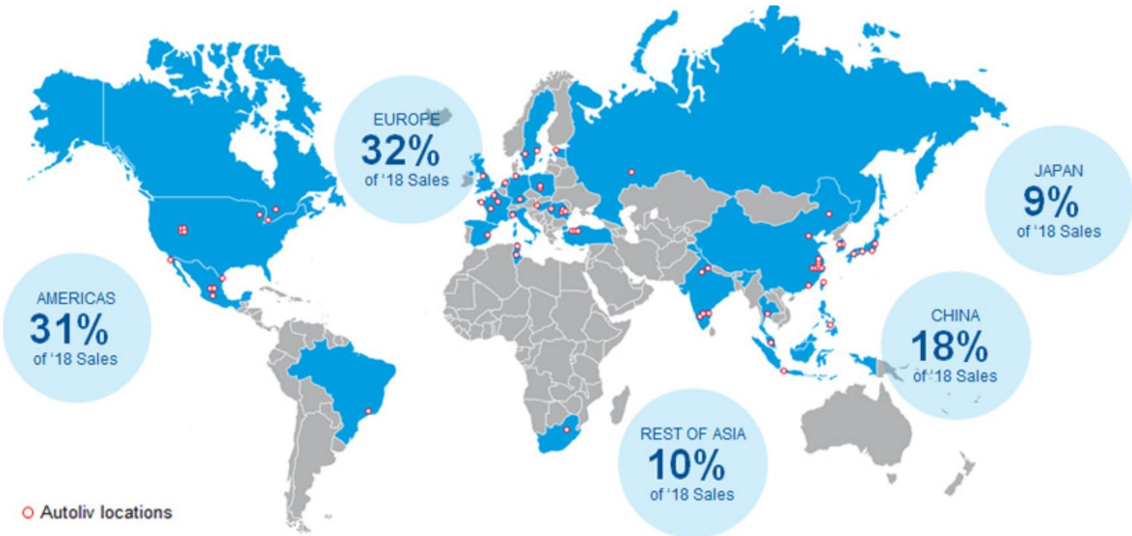


Figure 1.2: Autoliv Group around the globe, [2]

2
Theoretical Framework

The following chapter looks to alleviate the understanding of the theories and topics included in this report, and this by describing the basics as well as the most important aspects of them.

2.1 Cognitive theories

In order to achieve the goal of creating an HMI-system that can minimise the time to bring back the driver back-in-loop with highest possible quality, this includes being aware of the situation and having the ability to act safely, one must understand some basic knowledge and theories about the functions of the human cognition. Recognising the strengths, weaknesses and finding out where support by the system is needed makes cognitive ergonomics a central part in this thesis work. The chapter will describe the following areas, namely HMI (human-machine interaction), vigilance, the information process model, situation awareness and back-in-loop.

2.1.1 Human-machine interaction

The concept Human-Machine interaction focusing on, as its name states how the interactions between the human and the machine, within a set environment are conducted to reach the system goal. [3] Back in time, the machines were not necessarily made to fit the needs of the user but rather to successfully execute the system goal. This way of developing machines has however changed and nowadays, a lot of emphasise is also put into improving the use experience which is making the system process not only more satisfying to use, but also safer and more efficient.

The Human-Machine interaction model visualised in figure 2.1 describes the typical information and interaction flow in between the user and the machine which are communicate through the interface. The user can input desired data via the provided machine controls which in turn gets processed by the machine and finally presented through the interface. The machine output gets interpret by the human which makes actions accordingly. The choice of actions and the quality of executing them basis on several aspects, both personal ones such as previous experience and the individual's health and well-being, but also depends on the machine's ability to support the user in the specific situation. [3]

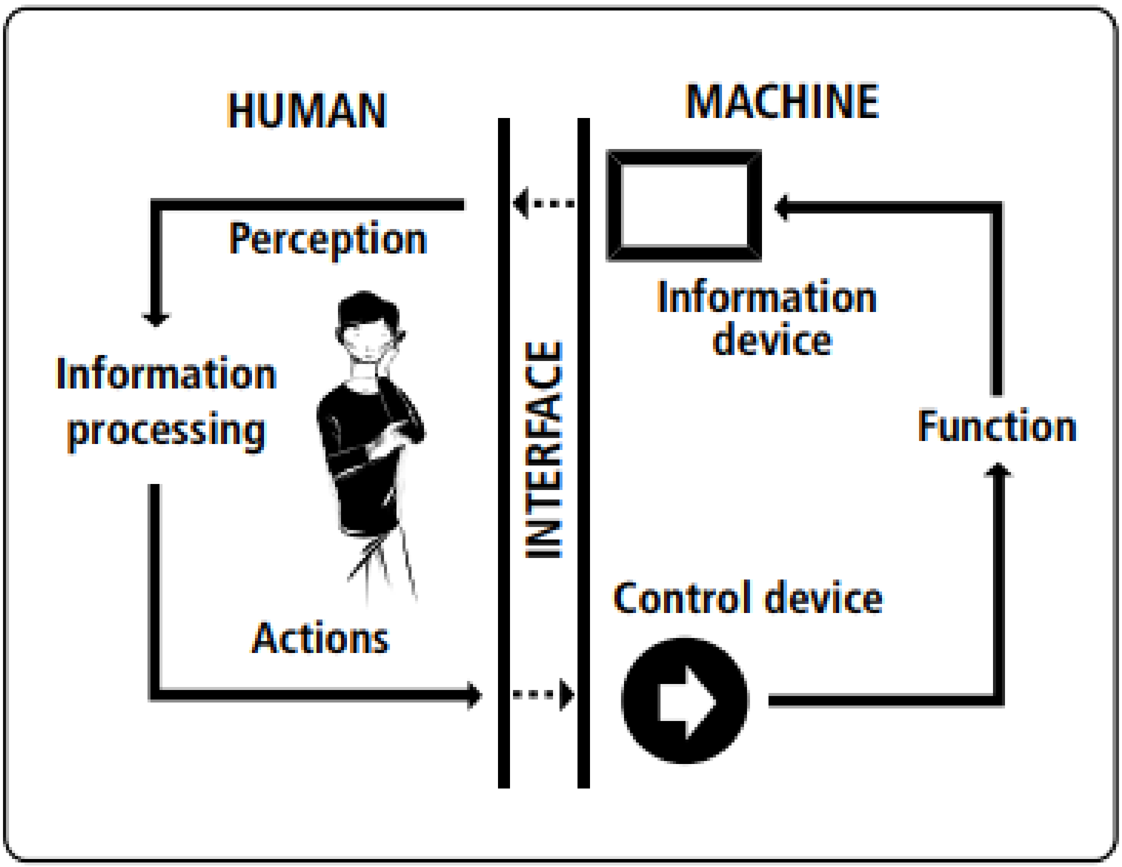


Figure 2.1: The picture illustrates the HMI model. [3]

2.1.2 Information process model

The information process model describes the steps of how humans manage and act upon stimuli. [3] The process which is presented in figure 2.2 also includes the surrounding factors that affects the individual's reasoning, decision making and resulting performance. This could be factors such as previous experience and the individual's condition. The process starts with stimuli being picked-up by our senses, the eyes, ears, the nose etc. The body singles out unnecessary information based on given attention and perception. As the information is being processed, both the short and long-term memory are activated, both are needed in order to understand the situation. The short-term memory enables information to be contained and thought of, while the long-term one, which expresses as experience unravels the missing pieces of the pattern in the seemingly most logical way. This process also decides the response outcome, and in turn the response execution. [3]

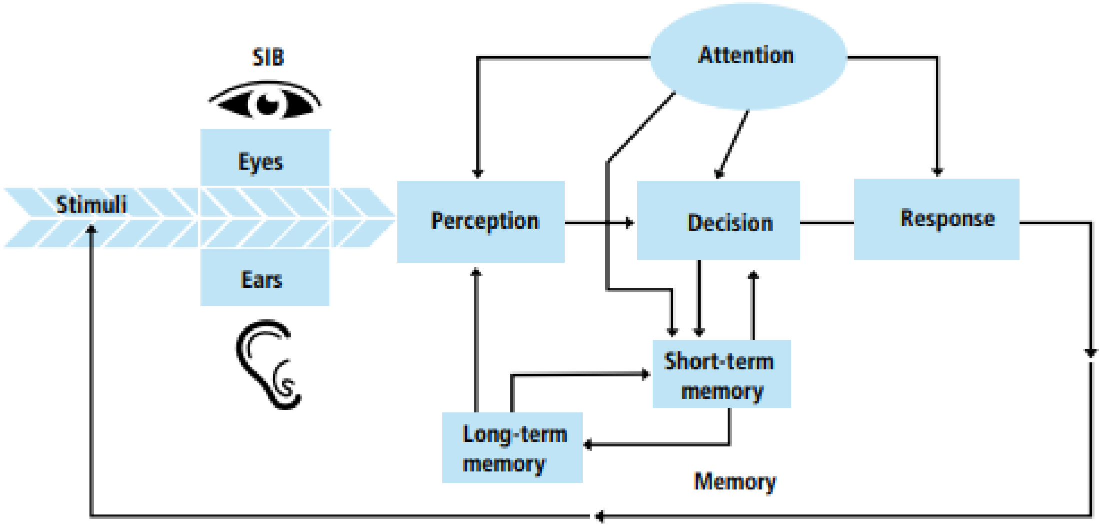


Figure 2.2: The picture illustrates the information process model. [3]

Important to highlight is the number of steps of the model that are affected by attention resources. This shows how essential it is to manage the limited attention in the correct way. Attention allows us to shut out noise in order to focus on the task at hand. More complex activities require more attention resources and vice verse. Attention can become affected by both the individual's condition, such as tiredness, stress, happiness or sadness, and by external factors such as given time resources and climate settings. Low level of attention can affect the ability of recognise patterns and delaying the thinking process, but also the quality of performance. The ability to divide attention, which means the ability to conduct multiple activities simultaneously is something that can be trained. However, the consensus regarding the capability to multitask is depending on previous experience, the complexity of both tasks, and what modalities that are most present during both tasks.

2.1.3 Vigilance

Vigilance is a term to describe the ability to maintain a high level of attention and alertness over a prolonged time. [3] The need of vigilance become especially apparent during monitoring tasks where an individual is being exposed to, little to no new impression for a longer duration of time and thus losing performance quality when suddenly one need to act. The reasons for such an occurring are often a result due to cognitive fatigue, boredom or sleepiness. The poor ability of monitoring is further discussed in article [9] with the focused on how one should engage the driving during autonomous driving.

Article [10] showed evidence that ST can support in maintaining vigilance if the system is designed properly by bringing the driver's gaze toward the road centre. Studies about secondary tasks and driving is not a new occurrence. Article [11] investigated how a secondary task such as voice interaction affected the act of driving.

The result presented a significantly increased performance factor compared to being passive.

In the article [12] the authors talk about how the lack of vigilance, of drowsiness affects the time to get back into the loop and. In their findings they prefer active tasks over monitor tasks, and they found that it takes twelve seconds to get back into the loop. Furthermore, in the web article, "Driver Fatigue and Road Accidents" [13] it is described how fatigue and drowsiness affects road safety.

2.1.4 Situation Awareness

Situation awareness is about understanding the elements being presented so that a holistic view of the present, its upcoming changes and even predicting the future, as consequences of one's actions can be created. Knowing how to use the information and what is important at a current stage leads to the ability to prioritise actions and making the correct decision, all to achieve the system objectives and goals. Elements represent all the information that is available for an individual to properly conduct a specific task or work. Hence, the elements are domain specific. For instance, comparing an automobile driver's information needs with the ones of a pilot of an aircraft's, it fast becomes clear that difference sets of information are required to achieve SA. [14]

Endsley talks about the 3 levels of situation awareness (SA), namely Perception, Comprehension and projection. The levels are inter-twined, where the higher levels are build-up by the information presented on the lower ones. The following paragraphs will describe the three levels in the context of an automobile driver.

The three levels of SA
Level 1 called *Perception* refers to how the elements are delivered and perceived by the senses of the driver. A driver receives input from both internal and external factors, which is realise through both auditory, visually and tactile signals. From the instrument panel, information such as speed, time and fuel levels be extracted, and information about the surroundings such as terrain and weather conditions is of equal importance.

While level 1 perceives information, level 2 *Comprehension* works to evaluate that information, what it means, how it should be used and prioritised based on the current context and condition. By understanding the information, a driver can assess the situation to make the right decisions. This enables the driver to selectively block out unnecessary information for the task at hand, which lowers the mental workload that otherwise would be required, and offered one to allocate the attention resources where it is needed. In the context of a driver who is approaching a STOP-sign. The driver would after recognising it, adjust the speed to suit the expected stop. If there are other cars around, or if the road conditions are poor, this must also be taken into consideration when reducing the speed.

The third and final level is called *Projection* and is about having the ability to use the information and knowledge gained from the two previous levels to predict the future. Being able to understand and project the consequences of certain activity support the choosing of the action to be made. However, having this ability requires well developed mental models. Mental models can be described as our way of reasoning or thinking process. Its goal is to reduce the cognitive workload of a task and making the work easier. With increasing experience and education within a field of work result in better and more efficient mental models for that specific area. This is a reason why experts can realise and understand things faster but with less effort compared to a novice that would do the same kind of task, recognition and reconstruction of patters goes much quicker. For instance, a rally driver will not only perform the action of steering the car better than the everyday car user, but also better understand the outcome caused by the slightest adjustment made.

Endsley emphasises the need of displaying the right level 1 information, and how the lack of it correlated to human errors. It is difficult to finding them all and know how it should be presented in the optimal way. It was found that in 1996, 76% of the SA error by pilots were due to the lack of the correct information. [14]

In article [15] the influence of age regarding take-over vehicle control for HAD was supposed to be studies. However, that was not the most interesting of findings, but rather the effect of traffic density on the take-over response time. High density traffic compared to low density traffic found to increase the response time due to the increased stimuli from the surrounding.

In order to minimise the reduced situation awareness caused by conducting secondary tasks, article [16] studied the effect of using a heads-up display along with interaction buttons on the steering wheel. The result indicated that the used HMI-system design could possibly increase both situation awareness and driving safety.

2.1.5 Automation theories

The article [17] the fundamentals about automation is described. As technology advances, more can be used to support the human in achieving their system goal, but also replacing them if needed. Automation can be described as when work previously conducted by man, now is being executed by a machine. Automation aims to make the work more efficient by having the ability to managing higher workloads, increased precision and quality. It is important to know that just be replacing a human with a machine not necessarily leads to less overall work, but it is rather taken shape as new tasks such as supervision of the machine and maintenance. Thus, more automation does not directly lower the risk of human errors, but rather transitions it to take place in a new form or entity.

The same article describes the different levels of automation. This being the four categories, Information acquisition, Information analysis, Decision and action selection and action implementation. The two first mentioned aims to support the user with cognitive tasks, present the right information and suggest upon how to use that particular information. The third category aims to execute physical task such as autonomous driving. However, the level of automation within each of the categories can vary. This means that a machine can have a high level of decision support but remain a lower level of execution. [17]

Going from manual to a more autonomous environment, there are also several factors that needs to be taken into consideration to ensure a successful transition. The most noticeable problems are regarding *Out-of-the-loop, Loss of skills and Inappropriate trust*, which is explained in detail in article [17]. Out-of-loop is about the reduced ability of an operator to take back the control of the system during automation failure. This is a result of a reduced overall understanding of the more automated system which the man has become a lesser part of. During low automation, the operator is controlling the majority of the actions and knows the consequences of them. As the machine works more independently and displays little amount of the actual process, the operator's tasks become more of a supervisor's. By eliminating the manual working procedure the sets of needed perceived information changes in turn. With less knowledge about the process details eventually leads to loss of skill. Inappropriate trust is another problem with automation. Having too much trust could result in exceeding the automation limits and reaching a point where the machine no longer can handle the situation. Having too much belief in what the system is capable of could lead to accidents. However, if too little trust is put into the system's capabilities, implemented functions will end up being not utilised leading to loss of value. Thus, it is important for the designer to make it clear what and when a system can and cannot function. Being able to convert that knowledge to the user is vital.

In the article [18] it is described how the gaze affects getting back into the loop. The findings in this article talks about that scenarios encouraging driver gaze towards road centre are likely to bring driver back into the loop more efficiently. It is recommended to place information interfaces towards the road centre. In the report [19], it is tested whether the duration of the autonomous ride affected the gaze and the take-over performance for the driver. They did this by measuring the gaze behaviour after five minutes of autonomous driving as well as after 20 minutes of autonomous driver. They concluded that the duration did not affect the take-over performance, but a bit slower reaction were shown by the drivers in the study.

It is described in the article [20] that drivers take longer to resume control of the car if they are engaged in secondary tasks prior to the take-over request, something that also was found in the article [21]. They also touch upon the big variance in time for a take-over from different reports written in the field.

The article [22] examines how trust of automation affects take-over time, and that when trust increases so does the take-over time. It is also stressed that manual control of the car is only one aspect of a take-over, and that the quality of the take-over is just as important. In the article [23], it is described how drivers are more likely to stay in a slow-moving lane and keep automation online than switch lane by manual driving. They also saw that drivers in an automated vehicle becomes more involved with in-vehicle tasks.

2.2 SAE levels

Talking about autonomous vehicles, there is today a framework called J3016 "Levels of Driving Automation" which consists out of six levels of automation, ranging from no (level 0) to fully autonomous driving (level 5). Visualisation of the framework can be seen in 2.3 and described in [4]. The framework was developed by SAE international and is now considered to be the standard and recommended practice for manufacturers within the automation industry. The levels are represented by the columns which gives answers to the stated questions serving as the rows. More so, the chart is divided into two sections and also with colours. The upper half focusing on the human in the driver's seat's responsibilities and expectations, whereas the bottom half describes the driver support features and automated driving features provided by the system.

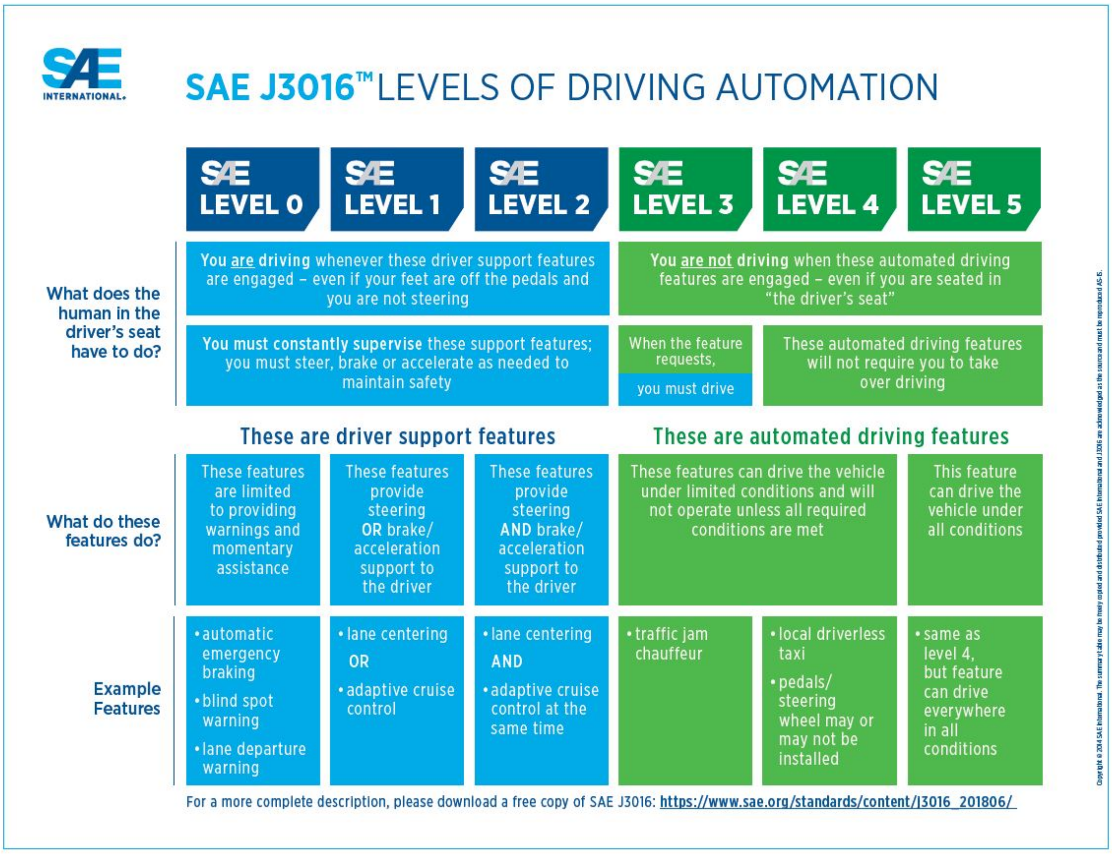


Figure 2.3: Definitions of the different SAE levels from Society of Automobile Engineers. [4]

The lower levels of automation, namely level 0 to level 2 are colour coded with blue and with the consensus that the driver is always enacting in driving with complete responsibility, even though some or all supportive functions are activated and used. This means that full control of the car must always be present to maintain safety. The bottom half of the same levels displays features and functions that are included in the different levels. Level 3, 4 and 5 are highlighted in green colour and speaks for the self-driving levels. For these levels the framework states that when automated driving is engaged, the driver is not driving. What differentiate level 3 the most with the two upper levels are that when the system request, one must take over the control back from the car and start driving again. This mostly refers to an unplanned take-over due to the increased system limitations. Level 4 and 5 defined to never require an over take. However, during both SAE level 3 and 4 the autonomous features are condition depended which means that only if all of the system requirements for each of the levels are met, will allow for AD. When a system reaches the SAE Level 5 then the automation will be able to operate under all conditions.

The most distinctive difference between the bottom and the top three levels of automation is about how the technologies are utilised in the system. Either with the system goal of only aid the driver toward a safer ride, or, offering complete or occasionally autonomous driving when the prerequisites are being met, also switching the role of the driver.

2.3 ADAS

Advanced driving assistance system (ADAS) is the brain of the car which offers active and supportive driving features to support the driver in the act of driving, and this to increase the car and road safety.

ADAS helps to reduce the accidents previously caused by distracted or tiered drivers (among others) by offering features such as emergency brake assist, lane keep assistant and drive monitoring systems to name a few [24] & [25]. The system includes both active and supportive features which in turn both passively keeps an eye on the surroundings and informs the driver about the situation, and also intervene if needed. The *drive monitoring system* observes the driver and can detect driver' behaviour such as drowsiness and the level of attention, by measuring eye behaviour and head position. The application can in turn and if needed, take action and bring back the driver to a more alert state [25].

Even though ADAS is where all the data is processed, the system needs sensors to gather the input to create an image of its surrounding environment. This is achieved by a variety of technologies, namely cameras, Radar, Lidar and ultrasound, each working at a certain distance that together are creates a holistic view of the ruling conditions. Information is also communicated using satellite and between other ADAS, so called vehicle to vehicle (V2V). This creates a smart and efficient network that constantly can send and receive information about other cars as well as about the infrastructure. [24]

A continued development of ADAS features are being conducted by companies such as Veoneer and Zenuity for the system to be adapted toward a SAE level 3 and 4 autonomous environments. For instance, "Deep learning" is currently being worked on which is a machine learning application that is supposed to make the system smarter by being more aware, precise and able to predict the action of other cars. In addition, *Deep learning* is supposed to better conduct multitasking which all in all offers both a more effective and efficient ADAS to account for an evolving autonomous environment. [26]

3

Pre-Study

The goal of the pre-study phase was to generate design guidelines which would enhances the HMI to better bring back the driver back-in-loop and serve as input for the concept development process.

3.1 Methods in Pre-Study

The methods used to gain relevant knowledge and data consisted of analysing previous reports and articles, held interviews and a conducted benchmark. Furthermore, methods such as use case and system theory were used to map out as well as break down the important aspects and factors to the task at hand.

3.1.1 Literature study

The literature study can include articles, journals, book and magazines. The most common way to do a literature study is to start by searching online, this is usually done by accessing different online libraries or databases. When using online databases, the most common way to find the right information is with the use of keywords related to the field and limiters such as year of publication. One has to keep in mind that when using keywords there is always a trade-off between using many specific words, resulting in fewer but possible more relevant search results, and using fewer words which results in more hits. To deal with this trade off it is recommended to start with a wide search and narrow it down along the way. [5]

3.1.2 Technical Benchmark

Conducting a benchmark is an essential part for any product development project [5]. It has the goal to inspire and expand a company's knowledge about new trends, competitors and their products' level of performance. It can help finding out the industry standard of what is expected today, revealing potential market opportunities to create a niche product, or enter areas that have yet been utilised. Furthermore, to also explore other businesses and trying to understand how they are using certain technologies.

3.1.3 System Theory

The system theory defines and creates a holistic view of a system. By breaking it down and visualise all the actors and entities that are included in the system, emphasising their relationship to each other and where in the system they are, simplifies the overall understanding of the system, and can create clarity for even the most complex systems. The system theory has defined system boundaries which distinguish the internal and the external environment from each other. What defines the two environments are the system's ability to control them. The external environment can affect the system, but the system cannot in turn not control it, and thus needs to be accounted for when developing e.g. a new product. The internal environment however, with all its elements, is a part of the system of which it has some control over. Furthermore, a system's size is defined by where the boundaries are set up. For a larger more complex system it can be easier to divide it into smaller and more manageable sub-systems. This and more about system theories can be found in article [27].

3.1.4 Use Case

Use cases are created to help explore the situation from the user's perspective [28]. It is done by focusing on a specific event or situation, then go through each step in this event in chronologically order. Before the process is started there is a couple of posts that needs to be described to ease the finding of a particular user case and set the stage and aim of the user case. The following is recommended to set up before the start of the case:

- Use case name
- Use case number
- Actor of the user case
- Context of the user case
- Abstract
- Goal
- Pre-condition

The example use case shows the initiating trigger, which starts the process, being the actor (the elevator user) wanting to change floor. Following, is the eight-step process that describes all the sub-tasks and actions needed in order to fulfil the use case goal. The ending of the use case is called Termination which in this case refers to the user exiting the elevator at the requested floor. The "Exception(S)" is concerning potential problems or use errors that might occur which would hinder a successful delivery of the end goal. It is however a vital part of the method in order to become aware of them.

3.1.5 Qualitative interviews

Qualitative interviews are a tool used for gathering more in-depth knowledge from customers or other stakeholder, and in this project primarily used for gathering information from experts in the field [29]. There are different structures to be used, namely structured, semi-structured and opened interviews. The different types all have their respective pros and cons, and which one that suits the best depends on the goal of the interview. Structured interviews are better used when trying to compare answers between interviews, while opened interviews are more suitable when searching for information that cannot easily be quantified. Semi structured interviews rely on open ended questions prepared in advanced.

3.1.6 KJ-Analysis

A KJ-analysis, also known by the name Affinity diagram, is a method developed in the 1960's by the Jiro Kawakita as one of the seven management and planning tools [30]. The tool is often used when dealing with large number of ideas or in this case different ideas and guidelines collected by the authors. The goal of using this method is to make sense and manage a large amount of information to be organised in different categories. To conduct an Affinity diagram, one firstly need to write down the information that is supposed to be included. This is followed up by putting the written notes on a wall or alike. Once all notes are on the wall, one can start to group them based on which notes that looks similar to each other at the moment. These groups are then analysed which can allow the participants to gain new insight into how different information can be viewed. Several iterations of this Affinity diagram can be conducted to generate new groups based on new aspects or thoughts, broadening the perspective even more.

3.2 Application of methods in Pre-Study

The pre-study was conducted under nine weeks with the objective to create a foundation of knowledge to be able of answering the research questions, make the right decision and in turn reach the project goal. The pre-study phase focused on gaining information about the areas of cognitive and physical ergonomics, the current state of autonomous driving, as well as reading field studies about commonly conducted activities during commuting. Discovering problems, needs and expert's thoughts about self-driving are all important aspects to investigate.

3.2.1 Literature study

The literature study was mainly conducted by the use of Chalmers online library. For the articles that were not accessible from Chalmers online library, Google scholar was generally found to fill in the missing articles. However, some articles, found as references in certain literature were never to be found in any of the two libraries. To discover different articles, keywords relevant to certain topics were used. Examples of these keywords are as follows: "Secondary task", "take-over time", "autonomous driving" and "situation awareness". The findings of this literature study were collected into the guidelines to be used as a validating document to compare different concepts and ease the creation of concepts in the later stages.

3.2.2 Technical Benchmark

A technical Benchmark was conducted with the focus on a variety of brands, namely, Tesla, Volvo, Toyota and BMW. These brands do all strive to advance into self-driving market and have been known for being in the forefront when it comes to autonomous driving. Looking toward these car manufacturers were thought to create a good baseline of what brands are working towards today.

The car brands' websites were used to collect easy to grab information, this included watching videos reviews about brands and models made by external critics, watching videos produced by the brand themselves, and also reading about different models and brands. Emails were also sent out to these companies with the goal of getting more in-depth information about their perspective on the future of autonomous driving. Unfortunately, these emails were rarely answered, and did not yield any significant information due to confidentiality reasons. Different car dealers were also visited to get first hand impressions on different car models' interior design. This gave the opportunity to sit in an actual car and get a better feel for it, and particularly looking at factors such as size and placement of displays, distances to interactive screens or number of physical versus digitised buttons and functions there were.

3.2.3 System theory

The system theory constructed included three areas, namely Cockpit, Internal Environment and External Environment, and where the last one mentioned consist of two minor areas, called Planning and Near Monitoring, see figure 3.1. The Cockpit is the area where the focus of improving was laid, and it is defined by to what the user has a direct contact with and can control the outcome, and sources that delivers information to make actions properly. This is the core of the system theory and all other areas are build-up out of this area. There are seven defined elements in the cockpit, including the driver, the tools provided by the car interior, the new secondary task and information from the outside view. The arrows show how information is directed, and a central part is that the driver is the key component. If a line contains two arrows means that information is traded back and forth, whereas a single arrow line indicates a one-way distribution of data.

The second area is the internal environment which is constructed by the car in whole, including the ADAS-system as well as sensors and cameras working to gather and process information from the surrounding. The internal environment, in-which the cockpit is included, it is defined by the ability of the driver to affect it. For instance by turning the steering wheel to change the direction of the car, or by accelerating or braking to manipulate the speed. The main connection between the first two areas that are relevant for the discussion about autonomous driving, are all the outcomes processed by the ADAS that gets presented for the driver by the several elements in the cockpit.

The last area is the external environment, this area includes factors that affect the internal environment, and primarily the performance of ADAS, and in turn the ability to use the self-driving features. The external environment was divided into two sub-areas as earlier stated. "Planning" are factors that are viewed to send a constant stream of information to the car in order for it to plan and guide the driver about the ruling conditions and how the drive will turn out to be. Near monitoring are entities that affects ADAS during the drive in the present moment. This is information gathered through the likes of sensors and cameras where if anomalies are detected, need to act accordingly. Weather, GPS-signal, surrounding traffic and road conditions are some of the factors contained in the external environment.

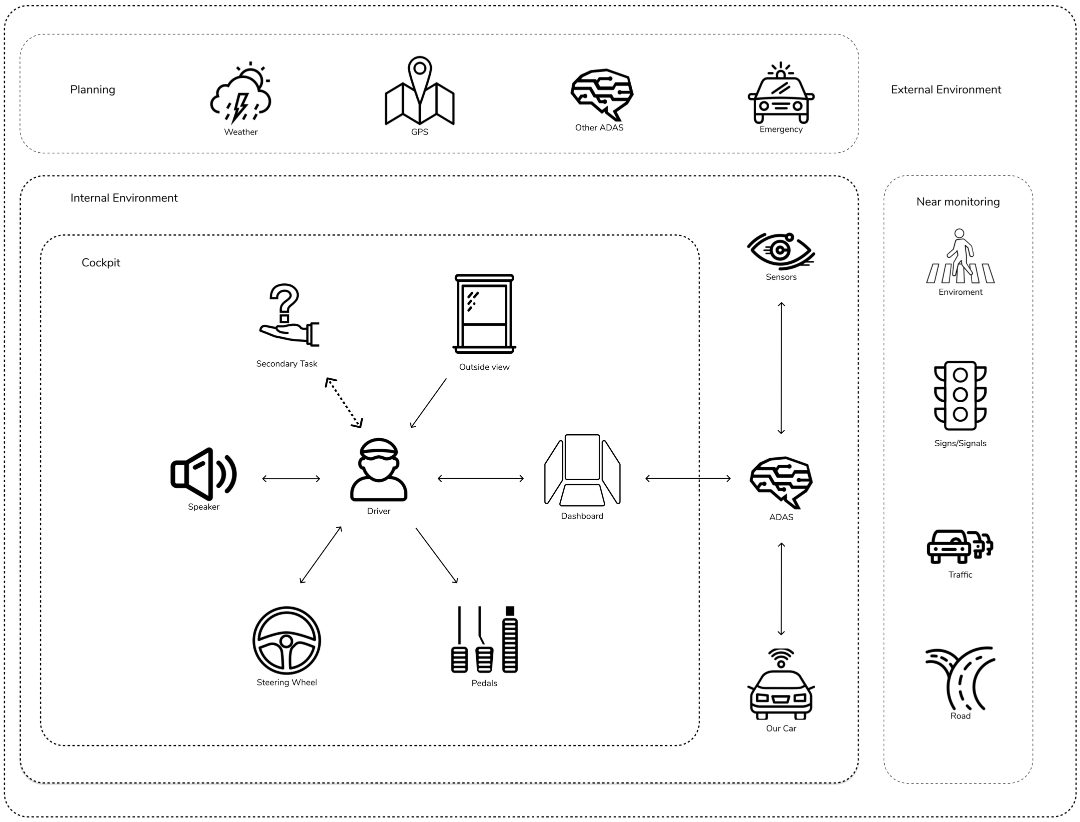


Figure 3.1: The system theory displays the three system areas and the relation between the included elements

3.2.4 Use cases

In order to map the activities for some of the core tasks that follows with autonomous driving, five use cases were created. These were the first iteration of use cases which were constructed in chronological order. The use cases include the following scenarios, "Starting SAE Level 3", "Secondary task- Work" & "Secondary task- Relax", "Unplanned take-over" and "Planned take-over". Use case number four "Unplanned take-over" can be seen in figure 3.2 and serve as an example of the general use case layout. The remaining four can be found in Appendix A. These describes the conditions and the thought-out way of how the car and the driver, through certain actions and interaction can engage/disengage in autonomous driving, perform secondary tasks and be supported back-in-loop when needed.

Use case name:	Unplanned take-over
Use case number:	4
Actor:	Driver
Context:	In the car
Abstract: Unplanned situation arises that forces driver to quickly take back control.	
Goal: Driver manually drives the car & is aware of new circumstances.	
Pre condition: External event* changes prerequisites for SAE 3 to SAE level 2 or lower - Heavy fog - Freezing rain, GPS signal lost * ADAS cannot drive safely, within 5 seconds	
Normal course: *Initialisation (triggers):* - External event trigger sensors *Process:* 1. **Emergency alert** for driver. 2. **Request imminent** take over 3. Driver takes over motor control 4. **Inform and make** driver aware of situation (Post take-over) *Termination* - Driver manually drives and is **aware of situation**	
Alternative course: ADAS does not connect with driver and instead park on the side of the road.	
Post condition: SAE level 3 has been disengaged and driver steers the vehicle and being aware of why.	
Exception(s): - Technical failure prevents signals/take over - Driver does not notice signals - Driver does not understand the urgency of the situation (type of alert) - Driver do not know how to approve request - Driver does not take over control within time frame - Driver do not want to engage in SAE level 2 or lower - Driver does not understand given information (SA)	

Figure 3.2: Use case number 4 describes the process of retaking control of the vehicle during an unplanned event.

As shown, two different take-over sequences were made with the reason to break down and see how they would differentiate from each other. A planned take-over could be that the car is about to enter an area where autonomous driving is yet to be allowed. The ADAS-system knows this and thus notifies the driver well ahead of time about the upcoming retake phase. An unplanned take-over however, is more problematic due to its unpredictability. The correlating use case 3.2 describes one potential reason, that being poor weather conditions which could affect the sensors to a point where ADAS cannot drive safely anymore. A scenario where the car cannot perform properly and if the driver is out of the loop could be dangerous. Seen as the more critical one out of the two for SAE level 3 autonomous driving, moving forward, the focus was put solely onto the unplanned take-over task where a more detailed, second version was created, see figure 3.3. A second iteration of use case concerning secondary task interaction was also created, namely "System interaction" see fig 3.4. This was done due to the similar actions that would be required to conduct any secondary task, thus a more generalised and in turn versatile use case would serve better.

<table>
<tr><td>Use case name:</td><td>Unplanned Take-over</td></tr>
<tr><td>Use case number:</td><td>2</td></tr>
<tr><td>Actor:</td><td>Driver</td></tr>
<tr><td>Context:</td><td>In the car</td></tr>
<tr><td colspan="2">Abstract: Unplanned situation arises that forces driver to quickly take back control.</td></tr>
<tr><td colspan="2">Goal: Driver manually drives the car & is aware of new circumstances.</td></tr>
<tr><td colspan="2">Pre condition: External event* changes prerequisites for SAE 3 to SAE level 2 or lower
- Heavy fog
- Freezing rain, GPS signal lost
* ADAS cannot drive safely, within 5 seconds</td></tr>
<tr><td colspan="2">Normal course:
Initialisation (triggers):
- External event trigger sensors
Process:
1. Emergency alert for driver.
a. Sound + possible vibration (unplanned)
2. Request imminent take over
a. On work screen
i. Voice
ii. Icon
iii. Text
3. Present traffic information (as close while not blocking view. (Fade?))
a. Speed
b. Radar oversight & GPS (minimap)
4. Guide gaze toward road center
a. Change visual view
i. AR (higher level of SA)
ii. LED
iii. Colour
5. Manoeuvre advice
a. AR (level 3)
b. Voice
c. Text
d. Picture
6. Driver takes over motor control
7. Inform and make driver aware of situation (Post take-over)
a. Audible
b. HUD in manual mode
i. text
ii. icons
Termination
- Driver manually drives and is aware of situation</td></tr>
<tr><td colspan="2">Alternative course: ADAS does not connect with driver and instead park on the side of the road.</td></tr>
<tr><td colspan="2">Post condition: SAE level 3 has been disengaged and driver steers the vehicle and being aware of why.</td></tr>
<tr><td colspan="2">Exception(s):
- Technical failure prevents signals/take over
- Driver does not notice signals
- Driver does not understand the urgency of the situation (type of alert)
- Driver do not know how to approve request
- Driver does not take over control within time frame
- Driver do not want to engage in SAE level 2 or lower
- Driver does not understand given information (SA)</td></tr>
</table>

Figure 3.3: The second iteration of use case describing a detailed unplanned take-over process.

Use case name:	System Interaction
Use case number:	1
Actor:	Driver
Context:	In the car
Abstract: Driver wants to conduct work during ongoing SAE level 3	
Goal: Successfully conducting work tasks safely	
Pre condition: SAE level 3 engaged	
Normal course: *Initialisation (triggers):* - ADAS signals readiness for conducting ST *Process:* 1. Driver **request** work mode (uses apps) 2. ADAS **acknowledge** request 3. ADAS engage work mode (does something happen?) 4. Driver **uses displays, navigation and input functions** to work a. Most important information closest to the driver b. Ability to find "secondary" information if desired 5. Driver **exit** work mode 6. ADAS **updates** the driver with **information** about the current traffic situationen. a. Other screen than ST screen *Termination* - ADAS disengaged work mode	
Alternative course: - Depending on work task different screens and functions can be used. - Earlier stopped work mode due to system request take over.	
Post condition: Work conducted by driver who gets freed up time	
Exception(s): - Technical failures - Driver do not understand how to use the work related functions. - Driver do not understood the current traffic situation information	

Figure 3.4: The new use case describes the general HMI-process during autonomous driving.

3.2.5 Qualitative Interviews

Qualitative interviews were conducted with the goal of having in-depth discussions with experts in the field to broaden the knowledge about autonomous driving in whole. To find suitable people to interview, research about interesting experts in the area of the western parts of Sweden. In total, over 15 experts were reached out to, but since many experts declined the interview due to confidentiality reasons, five interviews were conducted.
The interviews were all recorded for the ability to listen to them again at a later time if needed. The structure of these interviews was made to follow the semi-structured path.

3.2.6 KJ-Analysis

At this stage, many ideas and guidelines had already been collected and summarised various online documents, but the information in its entirety, lacked proper sorting nor fully checked for duplicates. Hence, all the ideas and guidelines that had been extracted from the interviews and the articles, were written down onto post-it notes. Several duplicates were detected and removed, also, ideas that were similar were merged together to simplify the outcome. Once the number of ideas were finalised, the grouping of the ideas was done 3.5.

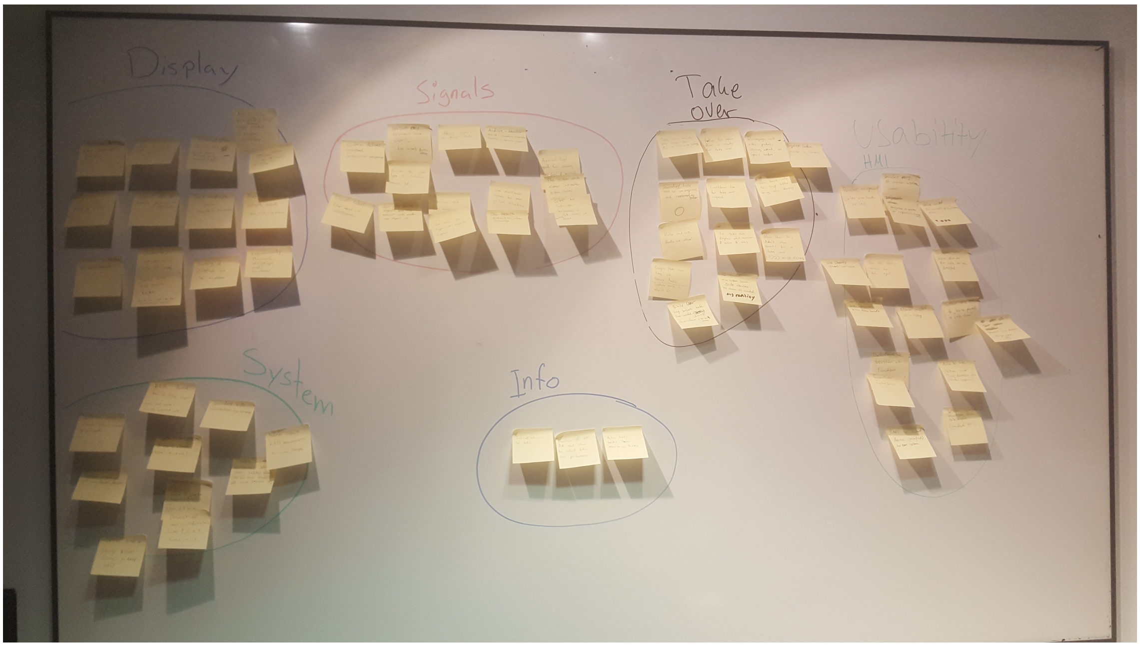


Figure 3.5: The first iteration of KJ-analysis.

A second iteration was conducted to explore new ways of grouping the ideas. It was decided that the second iteration of the KJ-analysis worked better than the first one due clearer headings, see the second iteration in figure 3.6. Therefore, this became the output which was to be used as input for the creation of the digitised design guidelines.

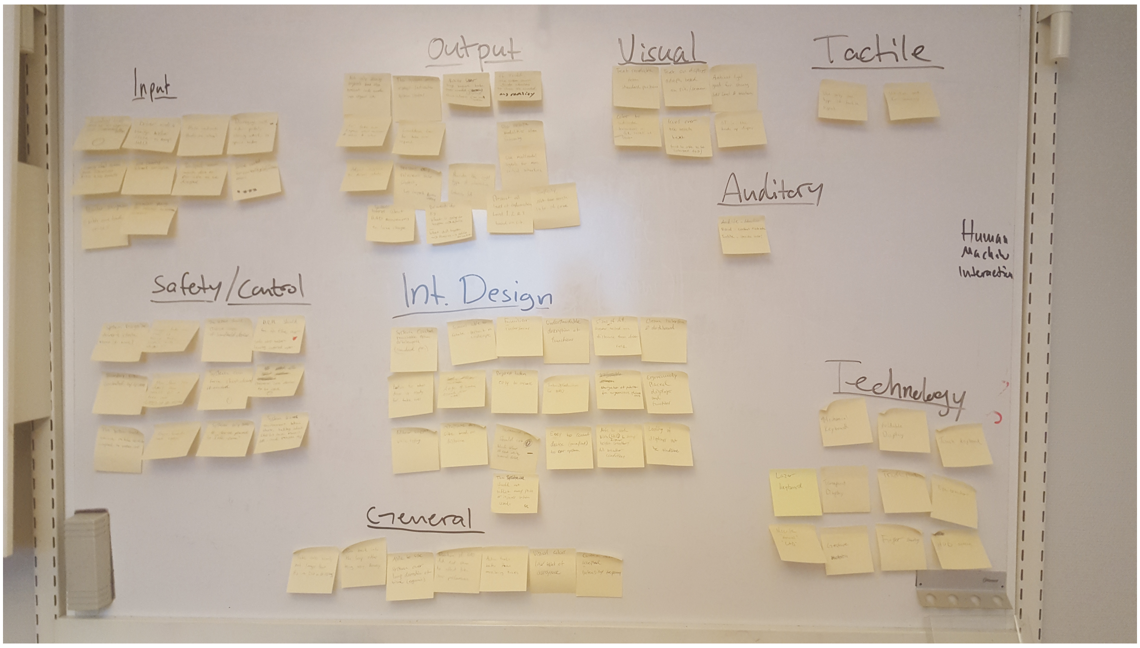


Figure 3.6: The picture displays the seconds iteration of KJ-analysis.

3.3 Findings

The key findings regarding HMI improvements collected from the application phase was put together into the design guidelines. The interviews, customer segment, and state of the art were also summarised which created a holistic view about potential challenges and opportunities concerning the area of autonomous driving.

3.3.1 Design guidelines

The goal was to create a document that clearly describes all information gathered in the pre-study phase and which information that will be used in order to create the concepts. This was done via the use of the output from the KJ-analysis. A list was created with each guideline getting its own number, and a group to be long to. The guidelines were separated into wishes and requirements from the importance of said guideline. The design guidelines can be seen in figure 3.7 and 3.8. The key take points from this document was to incentives the driver to gaze towards the road centre, hands on steering wheel and to terminate the ST when a take-over request (TOR) is initiated.

Subject	Design Guideline (5-95 percentile)	Requirements
System Output	**Information** 1. Present enough information for the driver to understand given situation (past, present, predicted) 2. Guide driver attention during take over 3. For take-over, explain what manoeuvre is needed 4. For take-over, explain when it is due 5. For take-over, explain why it is needed 6. Present all type of information level (1,2,3) 7. ST good in windshield 8. Incentivise driver gaze towards road centre 9. System explain reason for allowed ST at certain time 10. Don't give driver too much information at once **Signals** 11. Adaptable signal to driver state 12. Adapt signal to situation criticality 13. More multimodal signals create higher attention, adapt to criticality **Tactile** 14. Vibration signals good in steering wheel 15. Only one vibrations signal in system 16. Vibrations good for warnings **Visual** 17. Colour indicate system changes (ADAS) 18. Light indicate system changes (ADAS) 19. Use icons, for fast interpretation 20. Colours produce low level annoyance 21. Visual good for content rich information **Audible** 22. Audible good for catching attention	**Information** 1. System in control of ST, can shut down if needed 2. System can reject ST if not appropriate 3. Always indicate system status 4. Give clear system status report 5. Text readable from standard position
System Input	**ST Interaction** 23. Driver needs to request to start ST* 24. Minimize hand usage away from steering wheel* 25. Pointer navigation with one hand or less* 26. Device easy to connect to system* 27. Steering wheel interaction good with two hands 28. Steering wheel interaction creates good motor readiness **Take over interaction** 29. Driver signal ready for take over 30. Disengage AD with either pedal, steering wheel, or assigned input	

Figure 3.7: The picture displays the first part of the design guideline.

Interior Design

General

31. Familiar interface beneficial
32. (Clear description of functions)
33. Aesthetically pleasing for user

Ergonomics

6. Driver able to use system without getting injured
7. Using the screens should not inflict exhausting
8. Displays placed ergonomically
9. System control reachable from standard position

Display

34. Allow for multiple apps to be displayed at the same time.
35. Works with different lighting settings
36. Display should not block view of road in manual mode
37. Angle of display adjustable
38. Screen size based on position
39. Landscape and portrait mode of screen both desired

Ergonomics

40. Clean interface and dashboard
41. Ergonomically support writing tasks

Safety/ control

General

42. Update driver of situation every x sec
43. Update driver of AD manoeuvre
44. Prevent loose devices to be used
45. System recognize driver state
46. Driver to update system of his/her state every x sec

General info.

General

47. TOR aiming to not be longer than 8 sec
48. Incentivise driver to engage in active tasks rather than passive tasks
49. Tutorial of HAD beneficial to driver
50. MRM recommended to be in car
51. Take over time longer in heavy traffic, system adapt for this
52. Low risk for potential misuse.

General

10. TOR should not be more than 30 sec

Figure 3.8: The picture displays the last part of the design guideline.

3.3.2 Qualitative Interviews

The interviews highlighted several important areas and factors to consider in order to realise a safe implementation of autonomous driving. For instance, areas concerning the general confusion of the SAE definition, the difficulty of creating a HMI-system suitable for everyone and how regulation, laws and infrastructure must adapt to support a safe autonomous traffic are some of what was brought up. The following paragraphs will include the most important and interesting findings.

The interviews showed that the well-known and standardised SAE levels that were described in chapter 2.2 lacked clarity and the simplicity to be understood in the same way among all people. Two common thoughts were that the SAE levels were too vaguely described and too technical, but also difficult to understand what capabilities a level 3 car really has.
All in all, this creates confusion to the extent where some organisations and com-

panies views SAE level 3 similar to how other parties' views SAE level 4. It was further emphasised in one interview that a country such as Germany has forbidden the ability to proclaim a SAE level 4 capability, and that in order to minimise the risk of misunderstanding some car manufacturers have internally removed the SAE levels.

The next topic, which was the most debated problem throughout almost all of the interviews, was about the difficulties or the inability of ensuring a safe transition between the car being in control and the driver, for all individuals and their actions, in all scenarios. The fundamental reason to the problem is that every individual is different and thus a generic interface would be able to support the entirety of the population. Factors such as age, physical inabilities or even culture could have an impact. More so, being stressed, tiered, bored, drunk, hangover or sick, which are less obvious conditions could affect the way of how an individual would react to a take-over request. Further problems regarding how proper situation awareness could be provided, and which the three levels the would be of most needs at certain situations.

Another topic that was frequently brought up was regarding responsibility. A question stated was about how one could ensure that drivers takes responsibility to act in the right way when needed, or even if it would be ethically to put it on them. Understanding a system is not always easy and it takes time. Making clear of who is in control, the car or the driver, in all situations was regarded as key. Discussions regarding the need of proper education were held. An idea was to limit the use of the self-driving function to the ones with a certificate. Responsibility was also found to be important when talking about insurance and whom would be stand charged in the case of an accident, the driver or the car manufacturer? Further question regarding of how to find out which of the two that actually was driving was brought up. Partly, as a result to this, car manufacturers decided to not engage in making semi-autonomous car, and rather wait until full automation is possible. Thus, the responsibility factor onto the driver would be eliminated.

A representative from the same company stated the question why one ever would like to remove one of the most essential parts of the traffic safety, this being the driver itself, in a, according to him, the under qualified SAE level 3 system. Whereas in a SAE level 4 car the driver would not be included as a part of such a system. His perspective does not see the need of SAE level 3 when there are still room for improvements regarding SAE level 2. To him, the SAE level 3 would not improve the overall traffic safety but rather increase cost and value adding.

Summarising the interviews, some uniform actions or measures were highlighted as required or as support to precociously work and prepare toward an autonomous future. It is assumed that manual drive will remain the primarily way of travelling for a long time to come. This means that the traffic will eventually consist out of both manual and automated driving. This was seen as dangerous and thus the need for dedicated roads to each of the two ways of travelling. More were emphasised regarding certifications where a basic training following advanced training to increase the understandings of the driver seems highly needed.

3.3.3 State of the art

Even though the future looks to include fully autonomous vehicles, it is still some time until it will become a reality. The reason is not purely a result due to the lack of optimised technologies but also because of undeveloped laws, regulations and questions about how insurance deals should be constructed. This is further talked about in the extensive project report co-funded by the European Union [31]. That said, already today can self-driving cars be found in some places as part of projects to learn more about the field in general. However, these cars are all supervised by a safety engineer that can retake the control of the vehicle when needed. In Europe there are now an ongoing research project called L3Pilot [32]. The goal with this project is to answer key question regarding automated driving before market introduction. The project includes multiple parties of the automobile industry where OEMs like Toyota, BMW and Volvo, suppliers and research institutes that all plays part in the project to learn. The project has entered its final stage which is road testing. Thus, 1000 drivers distributed among 100 cars are now deployed and are driving across ten European countries such as Sweden, Austria, Germany, Finland and the Netherlands to name a few.

3.3.4 Customer segment and activities

With an increasing number of cars that have ADAS and drivers that are willing to use the implemented features are contributing to a safer traffic environment. It is still unknown when SAE level 3 will reach the mass market. The reason for the long waiting is not solely because of underdeveloped technologies but according to Litman [33] rather due to the predicted high cost of cars capably of SAE level 3.

Hence the question, what can justify the cost and who finds value in it? What could justify the cost more than just an increased safety, which according to Patel [34] is not a strong selling point, could be the opportunity to conduct secondary tasks during autonomous driving. For instance, engaging in work tasks. Commuting is often a result caused be the demand of people to get back and forth from work. The time spent travelling is often seen as unproductive due to the inability to perform useful tasks [35]. The role of a driver today does not include the possibility to enacting in ST because of the driver's constant need of driving which requires the driver's full attention. However, going by bus or train makes the individual a passenger which gives the option to be productive. That said, there are several aspects that have been seen affecting both the likelihood of engagement in ST, what ST but also how many to be engaged with. Two major factors are the amount of privacy and space given to the passenger. With an increasing level of both factors have been seen to incentives more activities and work-related tasks. Lower levels show to lower the amount of enacted activities which also seems to be more of leisure tasks. [35]. In an article from year 2010, activities of commuters travelling by train, buss and tram were studied. The result showed that people generally tended to entertain themselves with music, games and reading. The percentage of people performing work related tasks was observed to be generally low, but higher when travelling by train.

4

Concept Development

The goal of the concept development phase was to come up with a concept that could be tested with participants in a simulation. This includes the methods that were used, how these methods were applied, and lastly the outcome from this phase.

4.1 Methods in Concept development

Following the concluded pre-study phase and make use of the gathered knowledge, starts the development process. Since developing a new concept or product is a complicated task, especially out of nothing, a structured and well proven methodology was used. In figure 4.1 Ulrich and Eppinger have displayed a visualisation of how they see this methodology [5].

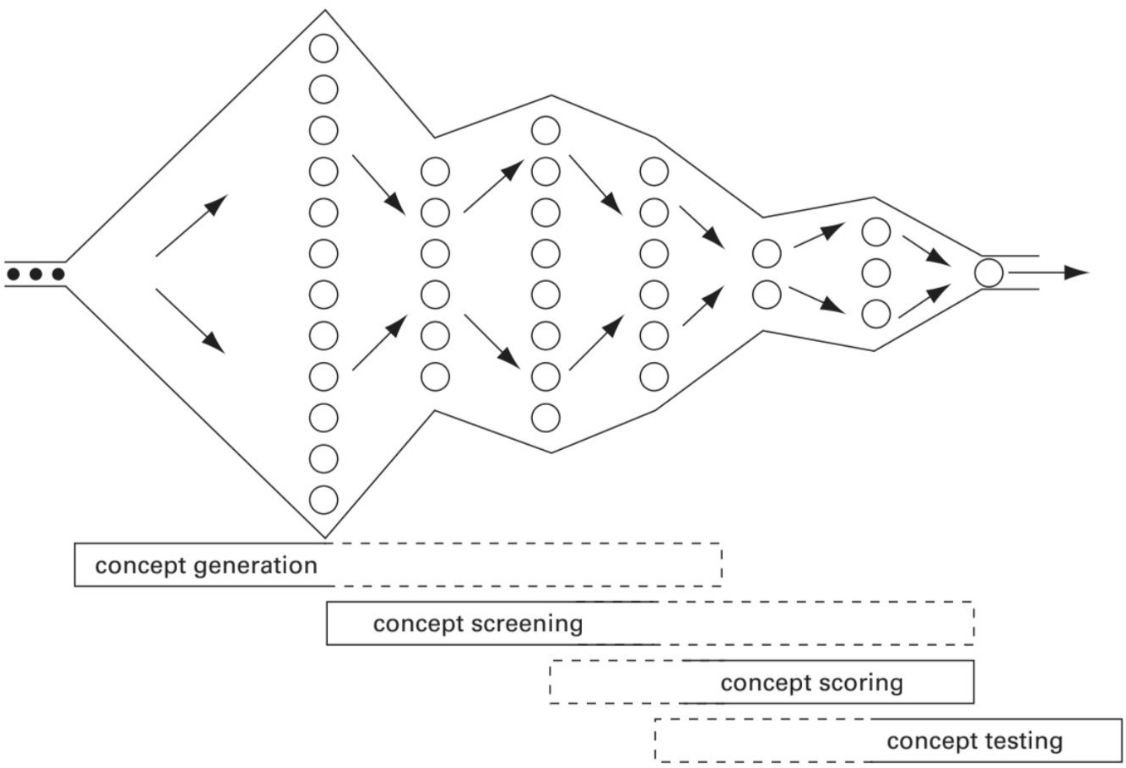


Figure 4.1: Product development methodology including the four major phases. [5]

4.1.1 Function-Means-Tree

To better set up what the concept shall achieve, the function-means-tree tool was used. This tools aims to help the participants to break down one big function into several smaller ones, make them more manageable and easier to grasp, and help coming up with new ways to satisfy the function needs. To start the function-means-tree one must first define the main function that the product or service wishes to satisfy. The next step is to break down that function in a hierarchical order and specify which means that could satisfy that particular function. Following, one look at each means that was created, and then try to come up with functions that satisfy each means. At this point one can repeat the first step, and continue on by creating means for functions and functions for means until the right level of details are reached for the purpose of the project. It is important to keep note of which each mean that is answering for a function, and in turn, which function that is answering to that mean. A visualization of a function-mean-tree can be seen in figure 4.2 [6]

Drawing the method will then create a tree shape like structure that expands out from the first function to all the means on the last level. When drawing it, one does often put the main function at the top and expanding downwards, like a tree upside down, this is because the main functions are the highest level in the hierarchy.

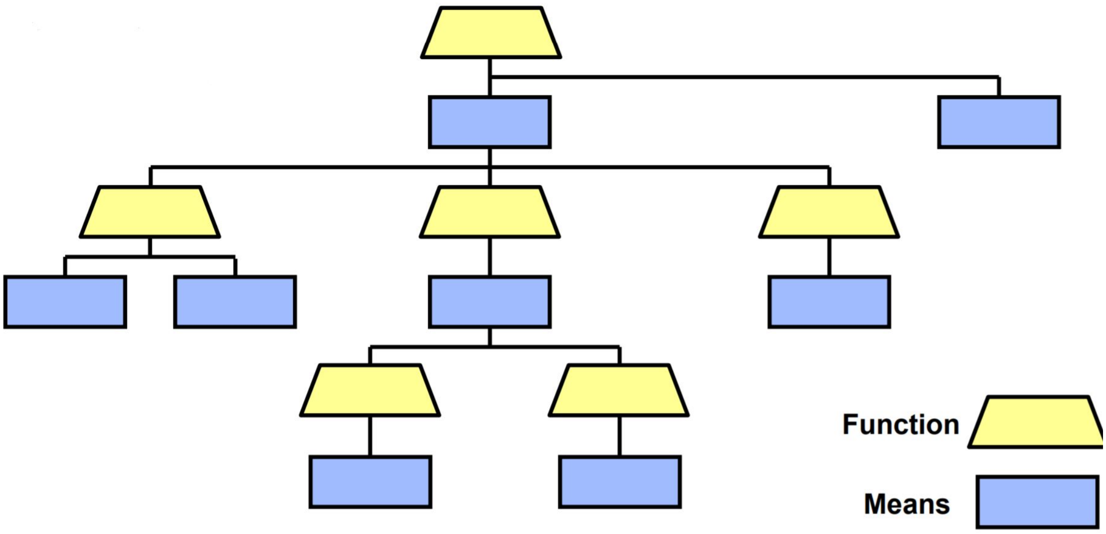


Figure 4.2: Visualisation of Function Means Tree [6]

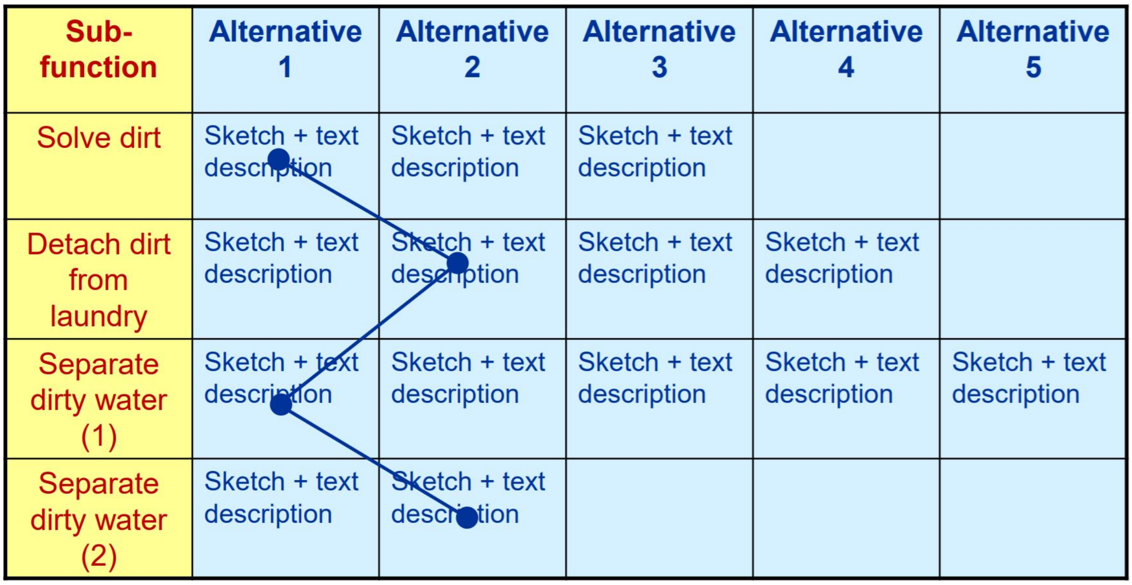
4.1.2 Brainstorming

Brainstorming method is a common tool to help foster creativity and tackle problems with new ideas [5]. Since a few of the other methods chosen require creativity, the brainstorming method also played a vital part in complementing these methods serving as input data. These are methods such as the function-means-tree and the morphological matrix.

4.1.3 Morphological Matrix

When a function-means-tree is completed the next common step is to do the morphological matrix. The morphological matrix takes the functions and means from the function-means-tree and put them in a matrix. The idea behind this is to try to explore as much as possible and have a more structured approach to generating new concepts.[6]

The goal is then to select one of the means for a sub function, and then continue down until one mean has been selected for each function. The aim when selecting these means is to create synergies between them to make overall stronger concepts. It is also important to keep the creativity flowing, even if a concept looks silly on first sight it can spark for new ideas that can hold more value. Therefore, the output from this method is not only a number of concepts, but also an increased level of creativity which can be difficult to achieve otherwise.



Sub-function	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
Solve dirt	Sketch + text description	Sketch + text description	Sketch + text description		
Detach dirt from laundry	Sketch + text description	Sketch + text description	Sketch + text description	Sketch + text description	
Separate dirty water (1)	Sketch + text description	Sketch + text description	Sketch + text description	Sketch + text description	Sketch + text description
Separate dirty water (2)	Sketch + text description	Sketch + text description			

Figure 4.3: Visualisation of Morphological Matrix [6], here it can be seen how a concept is generated from the combination of alternative 1 and 2

4.1.4 Elimination Matrix

It is favourable to generate many new concepts and ideas early in the concept development phase. This will of course make the output from these phases being quite large, one downside of generating many concepts are that they all require some attention and time, and if there are too many of them it will be a time consuming task to properly evaluate and select a winner right from the get go. This is where the elimination matrix come in. The main goal of the elimination matrix is to primarily eliminate ideas or concepts that have been generated. [7]

Elimination matrix for:

Elimination criteria::
(+) Yes
(-) No
(?) More info required
(!) Check product specification

Decision:
(+) Go further with solution
(-) Eliminate solution
(?) Seek more information
(!) Check product specification

Solution	Solves main problem	Fulfils all requirements	Realisable	Within cost constraints	Safe and ergonomic	Suits the company	Adequate information	Comments	Decision
1	+	+	+	+	+	+	+		
2	+	-	+	+	-	?	?		+
3	+	+	?	?	+	+	+		-
4									?
5									
6									
7									

Figure 4.4: Example of the Elimination matrix by Pahl and Beitz [7]

The elimination matrix only looks at the basic requirements that are set up and eliminates concepts from that basis. If a concept fails to fulfil any of the requirements set up, it will be eliminated. Due to the elimination matrix only looking at basic requirements and not trying to rank each concept, this tool can manage a greater number of concepts without taking up an excessive amount of time.

4.1.5 Pugh Matrix

Once the elimination matrix has eliminated the first round of concepts and reduced the number of concepts to about a dozen, it is reasonable to start with the Pugh matrix. The Pugh matrix method was developed by Stuart Pugh in the late 1980s and is a method that operates in a general high level of abstraction [5]. The Pugh Matrix often has five to ten different dimensions that each concept is scored upon. Compare to the elimination matrix, the Pugh matrix scores each concept in comparison with one of the concepts that is selected to be the reference point. To simplify this comparison between concepts, each concept can only score either a minus, suggesting the concept is worse than the reference concept on said dimension, a zero, suggesting that the concept is equal to the reference concept in said dimension, or a plus, suggesting the concept is better than the reference concept in said dimension. After all of the concepts have been scored on all dimensions, the total score is summarised with the total number of minuses, zeros, and pluses that then get transformed into the rank of the concept, example in figure 4.5.

	Concepts						
Selection Criteria	**A Master Cylinder**	**B Rubber Brake**	**C Ratchet**	**D (Reference) Plunge Stop**	**E Swash Ring**	**F Lever Set**	**G Dial Screw**
Ease of handling	0	0	–	0	0	–	–
Ease of use	0	–	–	0	0	+	0
Readability of settings	0	0	+	0	+	0	+
Dose metering accuracy	0	0	0	0	–	0	0
Durability	0	0	0	0	0	+	0
Ease of manufacture	+	–	–	0	0	–	0
Portability	+	+	0	0	+	0	0
Sum +'s	2	1	1	0	2	2	1
Sum 0's	5	4	3	7	4	3	5
Sum –'s	0	2	3	0	1	2	1
Net Score	2	–1	–2	0	1	0	0
Rank	1	6	7	3	2	3	3
Continue?	Yes	No	No	Combine	Yes	Combine	Revise

Figure 4.5: Example of Pugh Matrix from Ulrich and Eppinger [5]

The rank of a given concept is to be seen as a recommendation about how good the concept rank up, meaning that a concept with a lower rank can be kept if there is an easy argument for this. This is due to the high abstraction level and the simplicity of dimensions, that being said, if it is difficult to argue for a low ranked concept it is recommended to eliminate it. Another approach to lower ranked concepts is to try to morph a few of them together to cover for the weaknesses each one has, and to compliment for the strengths of each other. This way of eliminating is preferable due to stronger concepts are created but at the cost of time that is needed to figure out how to merge the concepts.

Depending on how much information has been received from this process, it is both possible to move on after the first iteration, or do an additional one. To launch the second iteration is recommended to switch to another reference concept to get a clearer picture of how the concepts perform.

4.1.6 Kesselring Matrix

The goal with the method is to narrow down the number of concepts into only one or two remaining ones, that being either through eliminating or merging the concepts together. The Kessering matrix is especially good at this since it both has more dimensions than the Pugh and each dimension also has a weighting system coupled with it, see figure 4.6 for an illustration of a Kesselring matrix. Having more dimensions and a weighting system increases the precision of the method, but does sacrifices time, and require a greater deal of knowledge about the subject area. Therefore, it is vital to only have a few concepts that will be evaluated, and that enough information was been gathered in beforehand so that educated ratings can be made. [5]

		Concept							
		A (Reference) Master Cylinder		DF Lever Stop		E Swash Ring		G+ Dial Screw+	
Selection Criteria	Weight	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Ease of handling	5%	**3**	0.15	3	0.15	4	0.2	4	0.2
Ease of use	15%	**3**	0.45	4	0.6	4	0.6	3	0.45
Readability of settings	10%	2	0.2	**3**	0.3	5	0.5	5	0.5
Dose metering accuracy	25%	**3**	0.75	3	0.75	2	0.5	3	0.75
Durability	15%	2	0.3	5	0.75	4	0.6	**3**	0.45
Ease of manufacture	20%	**3**	0.6	3	0.6	2	0.4	2	0.4
Portability	10%	**3**	0.3	3	0.3	3	0.3	3	0.3
	Total Score	2.75		3.45		3.10		3.05	
	Rank	4		1		2		3	
	Continue?	No		Develop		No		No	

Figure 4.6: Kesselring Matrix from Ulrich and Eppinger [5]

When constructing the Kessering Matrix one uses a similar set up as the Pugh Matrix but with a few differences. The first difference is that it is common to have the dimensions or criteria more detailed than before. It can be a difficult task to make the criteria be more detailed, but Ulrich and Eppinger [5] recommend using the function-means-tree as a way to do this. This is done by looking at the criteria in hand and then looking at the functions in the lower hierarchical level, as they all together sums up to the function in hand and each function being more detailed, see figure 4.7.

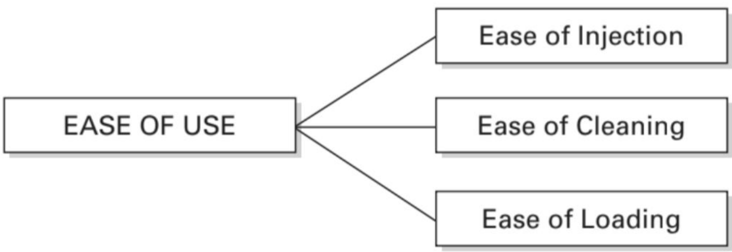


Figure 4.7: Example of making functions more detailed from Ulrich and Eppinger [5]

The second thing that differentiate the Pugh and the Kessering is the weighting system. This weighting system can be made in different ways, but the basic way of doing this is by rating each criteria between one and five on how important the criteria is for the final product. A rating of five means that the criteria is vital to the final product, while a rating of one means that the criteria is solely optional. This criteria rating will be referred as the weight of that criteria. The last difference is that instead if rating each concept with a minus, zero, or plus, each concept is rated in a scale from one to five. It is important to define in beforehand what a rating of five is, and what a rating of one is.

4.2 Application of methods in Concept Development

As the Pre-study phase ended with the creation of guidelines, the development process of realising a concept solution could start. The project goal was to develop a system that both incentives secondary task interaction and brings back the driver back-in-loop. Therefore, the concept generation was work based on these two perspectives individually, and later on merged together to fit one another. The final concept was then aimed to be used in testing with participants in a following simulation phase.

4.2.1 Function-means-tree

By breaking down the two main tasks "Back-in-loop" and "ST interaction" into lesser complex sub-task a better interpretation of what functions that are needed and in turn which means that are required to achieve them, a better grasp of the entire product system. Through several brainstorming sessions sub-functions and sub-solutions ideas were generated in parallel. Each function was taken out, one by one and worked with, first individually and then together to discuss and complement each other's ideas. The two function-mean-tree can be found in figure 4.8 and figure 4.9.

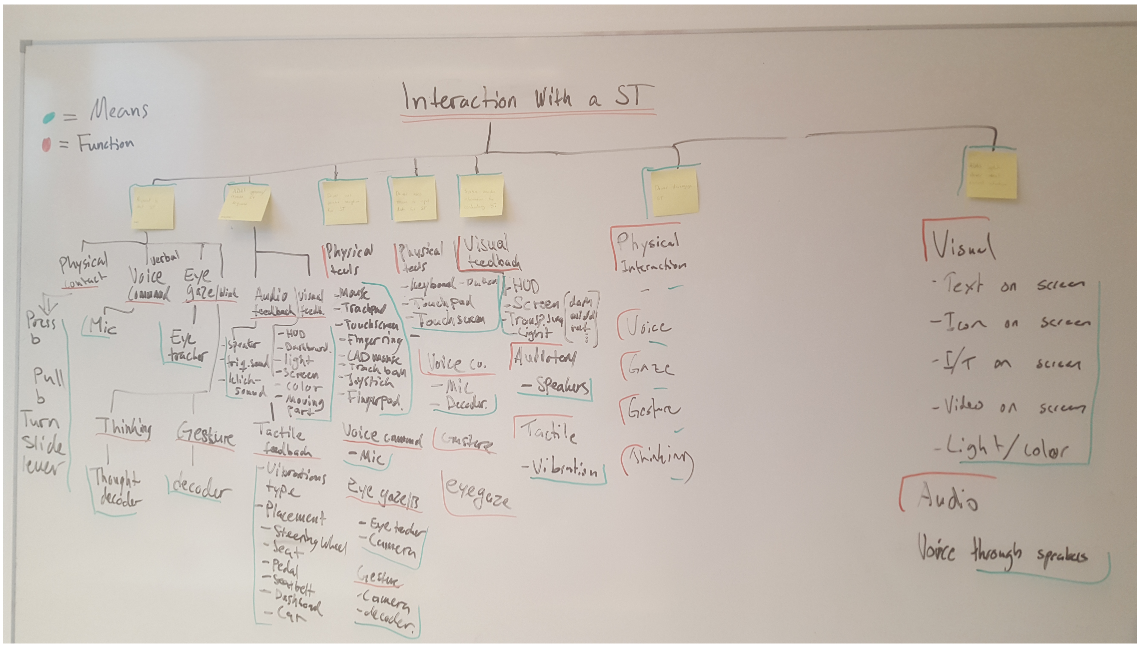


Figure 4.8: ST interaction Tree

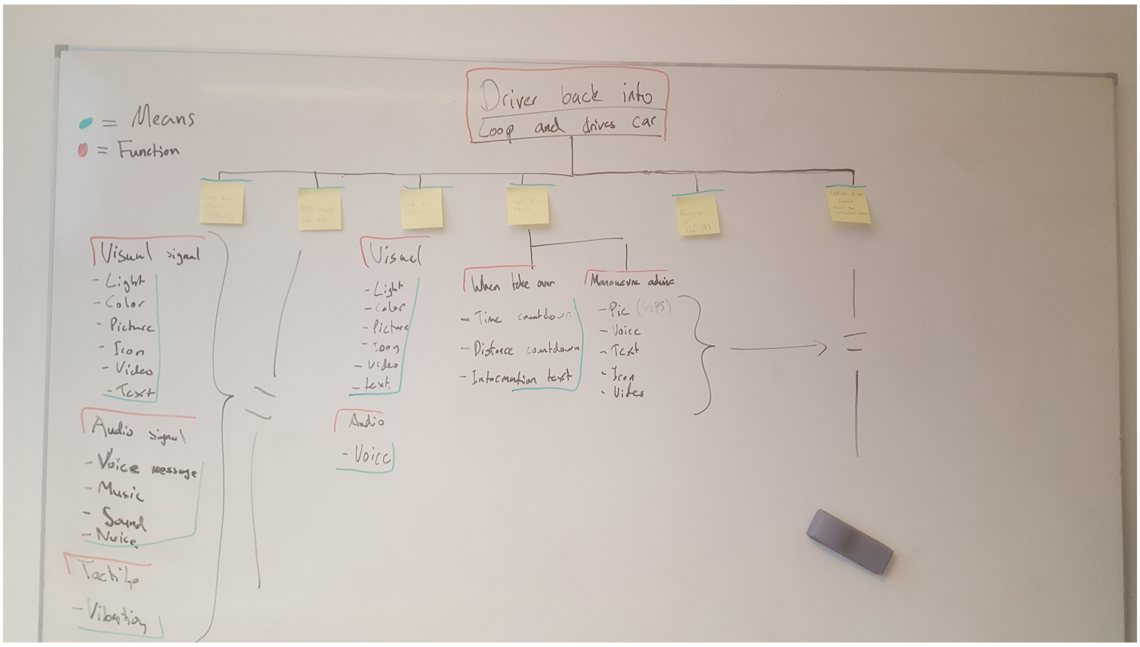


Figure 4.9: Back into the loop tree

The first one, the "Interaction with ST" consists of seven sub-tasks and describes the physical interplay between the driver and the car in order to conduct a secondary task. It starts off with the driver requesting a desire to start engaging in a ST, followed by a system response. Its decision depends on the ruling conditions and circumstances. The third and fourth phase focuses on the input controls of the system. The user must be able to navigate the pointer and constructing words. The fifth manage how the processed input should be presented. Various information has different level of importance based on the given situation. This decides where and in what way it should be delivered. The two remaining sub-tasks are input to disengage the ST and to update the driver about the current situation post ST. By making the engagement and disengagement of a ST to be a conscious act is thought to improve the level of SA. For the same reason an update of the traffic should be able to be accessed by the driver. The second function-mean-tree "Back-in-loop" was looking into how to create the alarm system. It consists of six stages including ways to catch and guide the driver's attention and make him or her aware of a situation as effective as possible.

4.2.2 Morphological matrix

As the function-means-trees had been constructed two morphological matrices could be formed which can be seen in figure 4.10 and figure 4.11. The functions created the rows and the means became the sub-solutions. In total 30 concept compositions were generated, 20 from "ST interaction" and ten from "Back-in-loop". The 20 concepts from "ST Interaction" were in turn visualised by drawings, displaying the chosen sub-solutions that creates the overall system interface, including placement and how the interaction with them should be executed. Moving forward, these concepts are referred to as "design concepts".

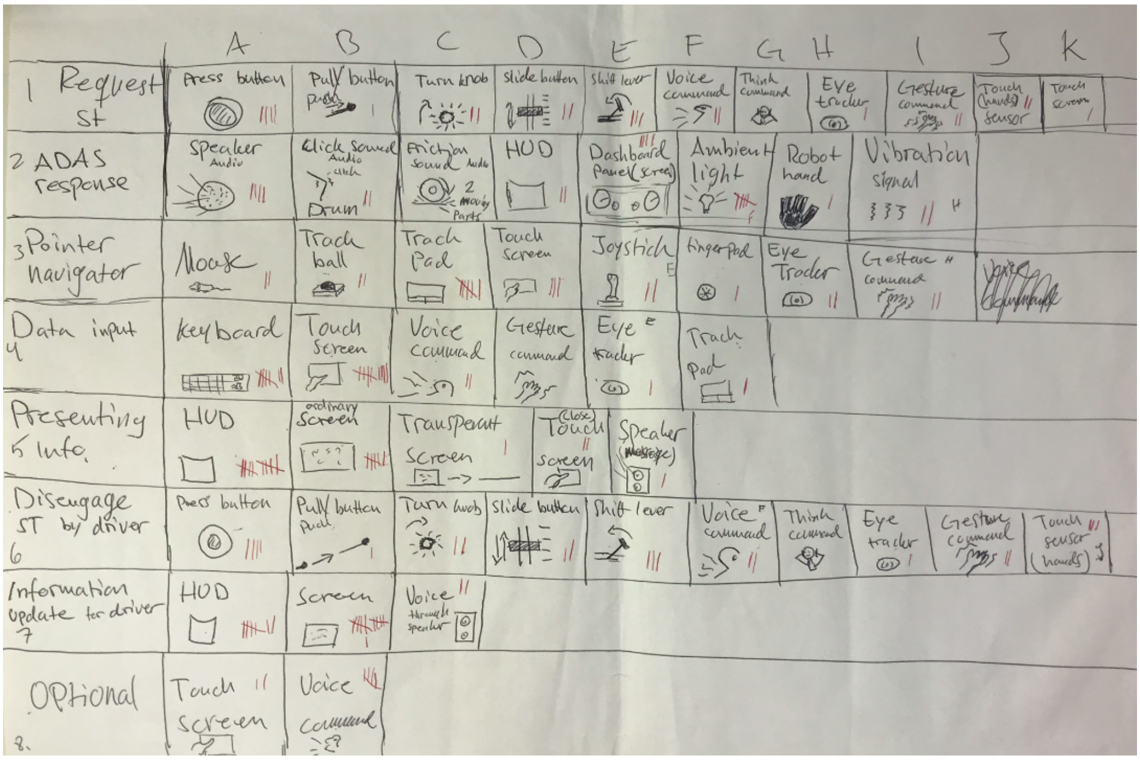


Figure 4.10: The morphological matrix representing ST interaction.

The ten concepts generated from "Back-in-loop" were found to be too abstract to be visualised in such a rigid form as the concepts from ST interaction. This is because,

an alarm system that is to be used in self-driving cars, needs to be able to deliver signals and information under various conditions and situations. A situation where a lot of noise is present, may require one way of catching and guiding attention of the driver, whereas other circumstances requires other system outputs accordingly. More often than not, for a system to properly perform it needs several signals and cues that complement each other. It was apparent that for each of the rows in the matrix, multiple sub-solutions would be needed.
The importance of a proper alarm system to bring back the driver back-in-loop was understood. However, further knowledge seeking within this area was not seen to advance the project closer to its goal, since the goal was to study the effects of a secondary task. It was rather used to provide a basic set of knowledge that could be included in all the ST concepts. Hence, the ten alarm concepts were put aside from being further developed.

Figure 4.11: The morphological matrix representing the back-in-loop.

By using the morphological matrix, the goal of creating a wide variety of concepts was achieved. The working process was structured and time efficient due to working in parallel with the function-means-tree which enables to elicit the task processes. However, the method was found to be easier to use when working with sub-solutions that individually could answer for a desired function, compared to what was described regarding the Alarm system which needed multiple ones simultaneously.

4.2.3 First screening

The construction of an elimination matrix started off the evaluation phase and the first screening of concepts. The 20 design concepts were assessed against four core requirements working as evaluation factors, see figure 4.12. These concerned the level of maturity regarding the technology needed for each concept, the complexity or ability for the concepts to be properly carried out within the project time frame, the system should not include any lose object, and the concepts must enhance the situation awareness of the driver. After completion, five concepts could be eliminated and eleven were given a pass. However, there were four concepts that showed uncertainties if they would increase the SA or not. Yet, a decision was made to bring these forward in the evaluation process where more information could be gathered and a better decision could be made. Hence, 15 concepts moved on to the second screening.

Elimination Matrix						Criteria fullfillment	
						(+) Yes	
						(-) No	
						(?) More info needed	
						(!) Check with specification	
						Decision	
						(+) Yes	
						(-) Remove	
						(?) More info needed	
						(!) Check with specification	
Number	Solution alternative	Concept using available technology	Concept must be able to be completed within the project timeframe	Cocnept must not include any lose objects	Concept will increase SA	Comment	Decision
1.	Chatful Lady	(-)	(+)	(+)	(-)	To complexed voice usage	(-)
2.	Mechaical Racer	(+)	(?)	(+)	(+)		(+)
3.	Joy Ride	(+)	(+)	(+)	(+)		(+)
4.	Feel Good	(+)	(+)	(+)	(+)		(+)
5.	Turned On	(+)	(+)	(+)	(?)	Not sure if increases SA	(?)
6.	Office Slider	(+)	(+)	(-)	(+)	Usage of a mouse leads to lose object	(-)
7.	Touchy Bwipo	(+)	(+)	(+)	(?)	Not sure if increases SA	(?)
8.	Three View	(+)	(+)	(+)	(+)		(+)
9.	Strong Boi	(-)	(-)	(+)	(+)	Gesture command too complex	(-)
10.	iBoy	(+)	(-)	(+)	(+)	Eye tracker becomes a too complexed solution	(-)
11.	Heads-Up	(+)	(+)	(+)	(+)		(+)
12.	A-Team	(+)	(+)	(?)	(+)	Mouse "semi loose"	(?)
13.	B-Star	(+)	(+)	(+)	(?)	Not sure if increases SA	(?)
14.	Ambient Screen	(+)	(+)	(+)	(+)		(+)
15.	J4	(+)	(+)	(+)	(+)		(+)
16.	S-S-P	(-)	(-)	(+)	(+)	Gesture command too complex	(-)
17.	Rize	(+)	(+)	(+)	(+)		(+)
18.	Slippery Zac	(+)	(+)	(+)	(+)		(+)
19.	Join Knob	(+)	(+)	(+)	(+)		(+)
20.	Braum	(+)	(+)	(+)	(+)		(+)

Figure 4.12: The elimination matrix that was carried out

4.2.4 Pugh matrix

The second screening of concepts was done by constructing a Pugh matrix. In this matrix, ten selection criteria were implemented. The criteria used can be interpret to be quite "wide" and could be split into multiple minor factors.
However, it was decided that at this stage, based on the current knowledge it would be "enough" to keep the demands and desires at a higher level, and when fewer concepts remained, early prototyping and simple testing could be conducted to answer for the current knowledge gaps. Two iteration of the Pugh matrix were conducted, see figure 4.13 and figure 4.14. The reference concept was changed in the second iteration to "Turned on". The reason for this specific change was due to that concept was one of the top performers in the first iteration, but also was the one that had the most differences with the first concept reference. This was seen as generating the most extensive comparison.

Pugh Matrix	Concepts														
Selection Criteria	(REF) Mech Racer	Joy Ride	Feel Good	Turned On	Touchy Bwipo	Three View	Heads - Up	A-Team	B-Star	Ambien t Screen	J4	Rize	Slippery Zac	Join Knob	Braum
Present Information	REFERENCE	(+)	0	(+)	(+)	(+)	0	(+)	0	(+)	(+)	(+)	(+)	(+)	(+)
Catch driver attention		(+)	(+)	(+)	(-)	0	(+)	(+)	0	(+)	(+)	0	(+)	(+)	(-)
Guide driver attention		0	0	0	0	0	0	0	(-)	(+)	0	0	(+)	0	(-)
Gaze towards road		0	(-)	(-)	(-)	0	0	0	(-)	0	0	0	0	0	(-)
Motor readiness		(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	0
ST interaction		(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Aesthetically pleasing		(-)	0	(-)	0	0	(-)	(-)	0	0	0	(-)	0	(-)	0
System Complexity		0	(+)	(+)	0	(-)	0	0	0	(-)	(-)	0	(-)	(-)	0
Ergonomically placed		(-)	0	0	0	(-)	(-)	0	(-)	(-)	(-)	0	(-)	(-)	0
Risk of misuse		(-)	0	(-)	0	0	0	(-)	0	0	0	0	0	0	0
Sum 0	REFERENCE	3	5	2	5	5	5	4	5	3	4	6	3	3	5
Sum (+)		3	3	4	2	2	2	3	1	4	3	2	4	3	2
Sum (-)		4	2	4	3	3	3	3	4	3	3	2	3	4	3
Total		−1	1	0	−1	−1	−1	0	−3	1	0	0	1	−1	−1
Rank		8	1	4	8	8	8	4	14	1	4	4	1	8	8

Figure 4.13: First iteration of Pugh matrix when Mech Racer being the reference concept.

Pugh Matrix	Concepts														
Selection Criteria	Mech Racer	Joy Ride	Feel Good	(REF) Turned On	Touchy Bwipo	Three View	Heads - Up	A-Team	B-Star	Ambient Screen	J4	Rize	Slippery Zac	Join Knob	Braum
Present Information (where)	(-)	(-)	(-)	REFERENCE	0	(+)	(-)	(-)	(-)	(+)	(+)	(-)	(-)	0	(-)
Catch driver attention understand acknowl. of ST	(-)	(+)	(+)		0	0	0	(+)	0	(+)	(+)	(+)	(+)	(+)	0
Guide driver attention ?	0	0	(+)		0	0	0	0	0	(+)	0	0	(+)	(+)	0
Gaze towards road	(+)	(+)	(-)		(-)	(+)	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	(-)
Motor readiness	(+)	(+)	(+)		(+)	0	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(-)	(+)
ST interaction	(-)	0	(+)		(+)	0	(+)	(+)	(-)	(+)	(+)	(+)	(+)	(+)	0
Aesthetically pleasing	(+)	(-)	(+)		(+)	(+)	0	(-)	(+)	(+)	(+)	(-)	(+)	(+)	(+)
System Complexity	(-)	(-)	0		0	(-)	0	(-)	(+)	(-)	(-)	(-)	(-)	(-)	(+)
Ergonomically placed	0	(-)	(-)		(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
Risk of misuse	0	0	0		0	0	0	(-)	0	0	0	0	0	0	0
Sum 0	3	3	2	REFERENCE	5	5	5	1	3	1	2	2	1	2	4
Sum (+)	3	3	5		3	3	3	4	2	7	6	4	6	5	3
Sum (-)	4	4	3		2	2	2	5	5	2	2	4	3	3	3
Total	−1	−1	2		1	1	1	−1	−3	5	4	0	3	2	0
Rank	11	11	4		6	6	6	11	14	1	2	9	3	4	9

Figure 4.14: Second iteration of Pugh matrix with Turned on being the reference concept.

By using the Pugh matrix method, four underperforming concepts and five top contenders were discovered, thus, the four underperforming concepts were eliminated. The remaining six concepts were rated as a middle tier. To progress in the right direction, the most apparent pros and cons for all of the concepts were summarised. This was done to map out which aspects that were dragging the concepts down, but also to find what was doing the opposite to make improvements to the concepts, see figure 4.15 below.

Concepts:	Mech Racer	Joy Ride	Feel Good	Turned On	Touchy Bwipo	Three View	Heads - Up	A-Team	B-Star	Ambient Screen	J4	Rize	Slippery Zac	Joy Knob	Braum
1st Pugh Rank:	REF	8	1	4	8	8	8	4	14	1	4	4	1	8	8
2nd Pugh Rank:	11	11	4	REF	6	6	6	11	14	1	2	9	3	4	9
Continue?	NO	NO	YES	YES	Merged with Feel good	YES	Merged with Rize	Merged with Rize	NO	YES	YES	YES	Merged with J4	Merged with Ambient Screen	NO

Figure 4.15: Summery of Pugh matrices

Once done, the focus was to remove drawbacks by merging concepts together. A few of the concepts that had a similar way of solving the main functions was successfully merged together. This resulted in a total of six remaining concepts, namely "Feel Good", "Turned On", "Three View", "Ambient Screen", "J4" and "Rize". Drawings on some of the merged concepts can be seen in appendix B.

4.2.5 Rapid Prototyping

The drawn concept sketches only created a basic feeling of how the set-up were to be, but left out impression of how the actual interaction would feel. Consequently, before the evaluation process could be continued answers to these knowledge gaps needed to be found. These were questions concerning placement of the intractable components and screen sizes to fit the distance to the driver, both ensuring the ability to interact with them and also so that they do not block road view more than necessary. Focus where also put to find out if simple heads-up displays could be created that were good enough to be used for simulation activities. If the result of the rapid prototyping showed too much difficulty in creating a HUD this would mean that concepts that relied too much on this technology would not be able to properly be realised as a prototype. In such a case these concepts would be eliminated due to the criteria "Concept must be able to be completed within the project time frame" used in the elimination matrix. Therefore, the concepts needed to be prototype and simply tested.

The prototyping took place at Autoliv Sverige's headquarters in Vårgårda where a prototype car rig of a Volvo S60 car could be accessed. By starting measuring the distance between the eye of an average sized driver in standard position to multiple designated positions of the interior in the car, indication of proper screen sizes could be decided. The measured distances and according screen sizes can be seen in figure 4.16. To create a better concept immersion, it was desired to use electric devices to answer for the required dimensions. Samsung Galaxy S6, Lenovo Tab 7 Essential and Samsung Galaxy Tab A6 were able to be used with sizes of 4,9", 7" and 10" respectively. The remaining ones were created out of cardboard material with sizes 13" and 18". As the screens of the concepts were created these were implemented inside the car. A Physical keyboard and track pad was scavenged from an old computer which were tried out in different locations to get a feeling of usability in correlation to ergonomics.

Figure 4.16: Distance figure

Order number	Distance from driver position	Distance in cm	Screen size in inches (Field of view 20°/30°)
1.	Eye to SW	62	8,6 / 13
2.	Eye to dashboard	88	12,2 / 18,5
3.	Eye to windshield	88	12,2 / 18,5
4.	Eye to sunvisor	35	4,9 / 7,4
5.	Eye centre screen high	94	13 / 20
6.	Eye to centre console	86	12,2 / 18,5

Figure 4.17: Distance table

With the usage of a sun protection film, acrylic glass and a display to present information, a simple heads-up display was tested to be made. The first test was made without using any film, and this to see if a strong enough reflection could be projected. During dark conditions the visibility of the figure on the screen was decent but unreadable during brighter environments. The reflected image was also blurry which was more prominent when reading a text compared to watching a video. This thought to be caused by the same reflection index on both sides of the acrylic glass. To efficiently test and easily see the effects of adding sun protection films, three zones with different amount of films on an acrylic glass were made see figure 4.18. The tinted film had a visible light transmission (VLT) of 43% The first zone, staring from the left hand side did not include any film, on the second zone one layer of film was added and on the third zone a film was placed on each of the side on acrylic glass. The picture reveals the "double reflection" occurring if no film was used. Comparing zone two and three an important trade-off can be seen. The zone including the double layered film had clearer reflections, which enhances the usability in day light. However, the drawback was that the reduced transparency which directly affects the possibility for the driver to see the road behind the display. Thus, it was important to find out which level of VLT that was the most suitable to create a sufficient display quality while maintaining a certain level of see-through.

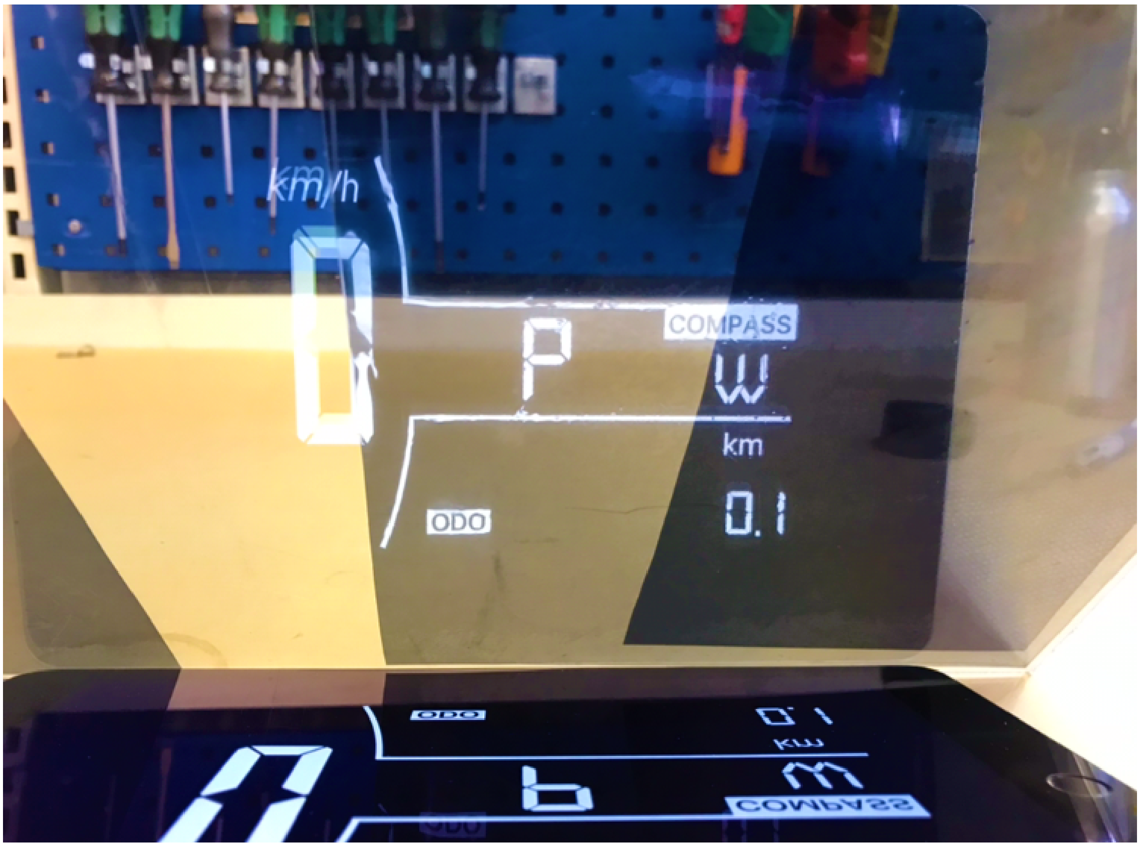


Figure 4.18: Displays the effect of using or not using sun protecting film when reflecting the image.

Next was to implement and test the HUD prototype's functionality inside the car. The film was applied directly onto the windshield and a Lenovo tablet was placed on top of the dashboard, behind the steering wheel. The result can be seen in figure 4.19 where a readable text seen from the driver's seat could be projected. However, two potential problems were discovered, firstly the curvature of the windshield made the reflection appear to be tilted or somewhat out of place, the second one being that if the image appears too close to the edges of the film could create an unsatisfying feeling of the screen being cramped together. Furthermore, the tablet that was used in this test was both visible and left unsecured.

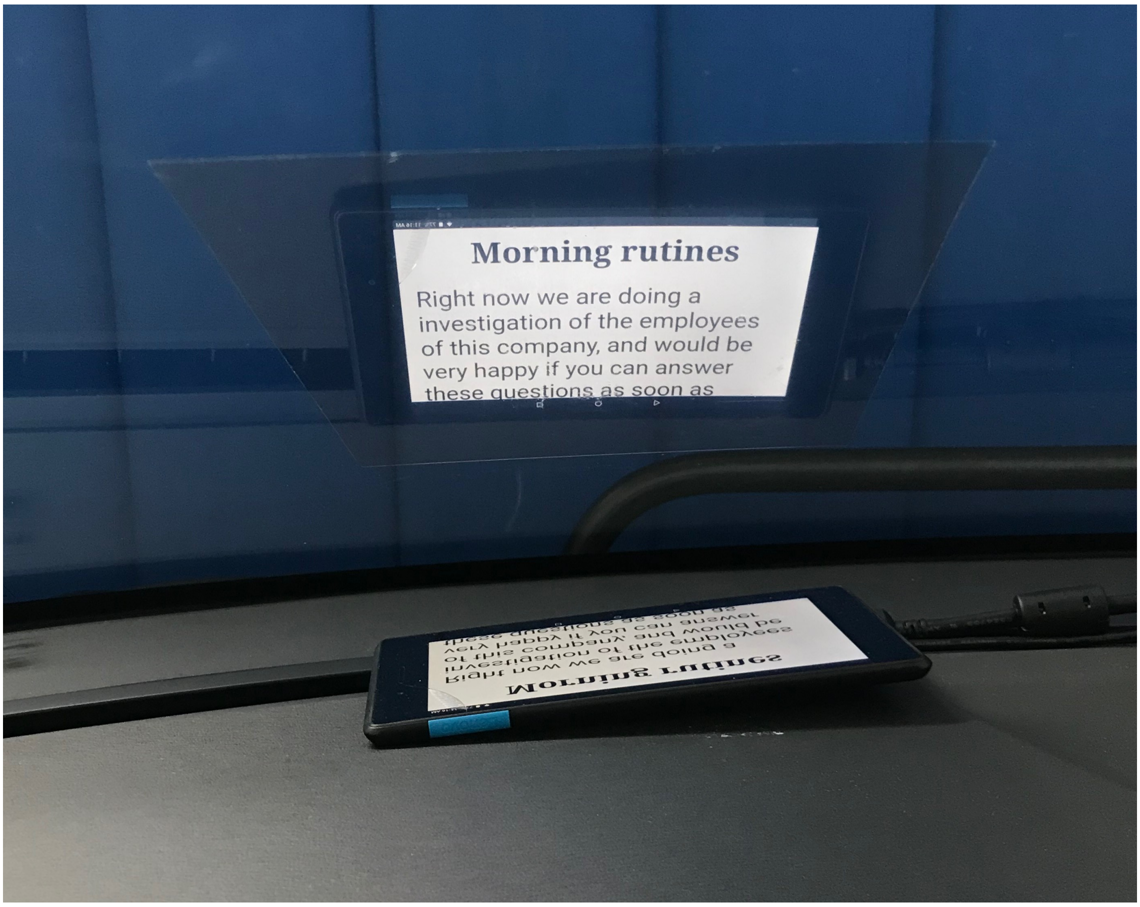


Figure 4.19: Trying to recreate a HUD experience using a tablet as light and display source.

4.2.6 Kesselring Matrix

As the previous knowledge gaps now had been answered the evaluation process and the narrowing down of the number of concepts could continue, and this by using a Kesselring matrix, the result of the two can be found in figure 4.20 and 4.21. The criteria used in this matrix were more detailed versions of the ones used in the Pugh matrix. This increased number of criteria from six to ten which led to a more complex but precise evaluation. For instance, the criteria "ST interaction" used in the Pugh matrix which refers to the system's input tools, were divided into three sub-categories, namely "navigation between ST applications", "Ability to input "shorter" amount of information" and "Ability to input "longer" amount of information". By dividing shorter and longer input requests made it possible to distinguish and compare concepts based on the duration of usage, where a solution could be sufficient under shorter periods whereas others strives in longer usage. Two iterations of the matrix were conducted, the first one called "Concept locked" and the second one "Concept unlocked".

		J4		Turned on		Rize		Feel Good		Ambient Screen		Three View	
Selection Criteria	Weight	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Present ST infromation	4	3	12	5	20	5	20	4	16	5	20	5	20
Navigation between ST applications	2	5	10	5	10	5	10	5	10	3	6	5	10
Ability to input "shorter" amount of information	3	5	15	3	9	5	15	5	15	5	15	3	9
Ability to input "longer" amount of information	2	4	8	3	6	4	8	4	8	4	8	2	4
Ergonomically placed input tasks	2	4	8	5	10	4	8	4	8	3	6	2	4
Ergonomically placed displays	3	4	12	5	15	5	15	4	12	4	12	5	15
ST to be able to be performed in different external conditions (Darkness, intensive light etc.)	4	3	12	4	16	3	12	4	16	3	12	3	12
Present ADAS infromation	5	4	20	3	15	4	20	4	20	3	15	4	20
Ability to guide the driver's attnention to where it's needed	4	4	16	3	12	3	12	3	12	4	16	5	20
Incentivise driver's gaze toward road center	5	3	15	5	25	5	25	2	10	5	25	4	20
Maximize the ability to view the road	4	4	16	1	4	4	16	5	20	4	16	4	16
The system's design to enhance motor readiness	3	4	12	1	3	3	9	3	9	4	12	3	9
The system uses multiple modalities	3	5	15	5	15	5	15	5	15	5	15	5	15
Aesthetically pleasing	2	4	8	2	4	2	4	3	6	4	8	4	8
System Complexity	2	3	6	4	8	3	6	4	8	3	6	2	4
Risk of Missuse	1	4	4	2	2	2	2	3	3	4	4	3	3
		189		174		197		188		196		189	
Procent of ideal:		77%		71%		80%		77%		80%		77%	
Rank:		3		6		1		3		1		3	

Figure 4.20: First iteration of Kesselring matrix with locked concepts.

The difference between the two were that in the first one, each display was tied to show a specific type of information, whereas in the unlocked version, it was not. Hence, information could be placed where it was the most suited, regards to incentives gaze toward road centre. The combination of evaluating both cases were seen as interesting and would prove that if the same concept became the top contender twice, a clear winner would have emerged.

		Three View		Ambient Screen		Feel Good		Rize		Turned on		J4	
Selection Criteria	Weight	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Navigation between ST applications	2	4	8	4	8	4	8	4	8	3	6	3	6
Ability to input "shorter" amount of information	4	3	12	4	16	4	16	4	16	3	12	4	16
Ability to input "longer" amount of information	3	2	6	3	9	3	9	4	12	3	9	3	9
Ergonomically placed displays	3	5	15	4	12	3	9	4	12	4	12	4	12
ST to be able to be performed in different external conditions (Darkness, intensive light etc.)	4	3	12	3	12	4	16	3	12	4	16	3	12
Ability to guide the driver's attnention to where it's needed	4	3	12	4	16	3	12	4	16	3	12	4	16
Incentivise driver's gaze toward road center	5	4	20	4	20	2	10	4	20	4	20	4	20
Maximize the ability to view the road	4	4	16	4	16	5	20	4	16	1	4	4	16
The system's design to enhance motor readiness	3	3	9	4	12	3	9	2	6	1	3	3	9
Aesthetically pleasing	2	4	8	4	8	3	6	2	4	3	6	4	8
System Complexity	2	4	8	3	6	4	8	4	8	4	8	3	6
Total score:		126		135		123		130		108		130	
Procent of ideal:		70,0%		75,0%		68,3%		72,2%		60,0%		72,2%	
Rank:		3		1		5		2		6		2	
Continue?		Merge with Rize		Develop		No		Develop		No		Merge with Ambient	

Figure 4.21: Second iteration of Kesselring matrix, this time with unlocked concepts.

The weighted score of each criterion, one to five, was determined by the knowledge gained from the pre-study phase. This was the understanding of what was found to be the most important aspects with concerns to attention, safety and usability. In this project a rating of five was generally seen as an ideal solution, whereas the rating of one would be a poor solution for that function.

The rating given to each of the criteria, for each of the concepts were colour coded, strong green indicates high scoring while yellow and red indicates mediocre or low scoring respectively. The concepts' total scoring in the first iteration revealed the concepts' many similarities by generating a close scoring. The second iteration also showed that most of the concepts had a close proximity rating. The concept "Turned On" generated lowest result in both of the occasions and therefore was removed first. Even though both "Rize" and "Ambient Screen" could be seen as winners in both of the iterations, but due to the competitive results among the rest further analysis of the matrices were needed.

The focus was then put on how well the concepts achieved and compared against the highest weighted criteria. If multiple concepts achieved the same total scoring, then the concept that scored best on highly weighted criteria would be favoured to advance. "Feel Good" got eliminated as it performed worse regarding this matter. Looking at "Feel Good"'s result shown in figure 4.21 one can realise its poor rating concerning "Incentives driver's gaze toward road centre".

With four concepts left standing, the possibility to merge concepts in order to eliminate concept drawbacks and improve the overall standard was explored. Four concepts could successfully be reduced to two, where "Three View" merged together with "Rize", and "J4" merged with "Ambient Screen". The biggest differences between these two concepts standing were the way of how to input data into the system, "Rize" using keyboard and track pad whereas "Ambient Screen" using a touch screen.

Figure 4.22: Concept "Rize"

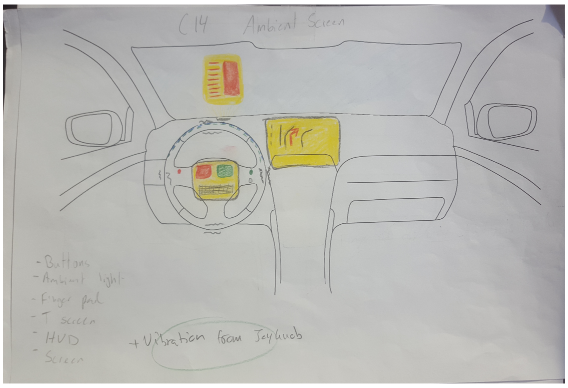


Figure 4.23: Concept "Ambient Screen"

4.3 Findings

As the goal of the concept development phase was to visualise and realise examples of how an improved HMI-system, based on the findings from the pre-study phase could look like, there was no justification to discard any of the two remaining concepts. Both did theoretically fulfilled the key characteristics mentioned in chapter 3.3.1, with only a distinctive difference concerning the tool for input data. In discussion with employees at Autoliv AB it was found to be enough, and rather unfruitful to spend more time dig deeper into this matter. Instead, both could serve as guides for further development and test the effect of the different parts of the concepts.

5
Simulation

In order to test the hypothesis regarding the effect of secondary task versus monitoring task, a simulation setup was constructed in a test lab at Autoliv Sverige's research facility at Vårgårda. With a total of 15 participants, testing could be carried out where statistical and subjective data was gathered. Questionnaire, first impression interviews and measuring the response time were some methods used. The following bullet point list displays the simulation process steps to ease the creation of a holistic overview.

1. **Introduction & Practice run** - One of simulation leader introduced the participants to the test rig, told them what rules there were, and answered potential questions. The other leader conducted the practical work such as preparing for the simulation and executed the practice run.
2. **Simulation execution** - The participants conducts the core test while both of the simulation leaders observes the participant and kept track that the equipment functions properly.
3. **Interview & Questionnaire** - As the video sequence ended. One simulation leader asked the participant about first impression while the other wrote the answers down. The simulation concluded with the participant answered a questionnaire on a computer, both simulation leaders were stand by if the participant did not understand a question.

5.1 Secondary tasks for simulation

To be able to gather data that could be associated with the research questions, it was decided that the simulation would test three different secondary tasks against each other. Each secondary task would require its own setup to be built in the car.

1. **Setup 1**: HUD setup
2. **Setup 2**: Cell phone setup
3. **Setup 3**: Passive setup

The goal of the first setup was to provide the participant with features in the car that were thought to ease a take-over act. These features were taken from the design guidelines chapter 3.3.1 and the final concepts in the development phase, chapter 4.3. Second setup was to imitate how a participant would carry out the take-over act if they were provided with a cell phone. Third setup was to imitate a car where the participant was only allowed to monitor the system.

Two main factors were chosen to be focused on with the HUD setup, incentives gaze towards the road centre and letting the car system control the shutdown of the secondary task. It was a conscious choice not to test too many factors at once since then it would be difficult to tell which of the factors that made a difference. To test these features, a heads-up display was created which will be known as HUD from now on. The HUD would satisfy the goal of incentives the participant to gaze towards the road centre. To control the HUD a keyboard that included a touch pad was provided as well. With this keyboard the participant could interact with the heads-up display both by writing on the keyboard, and moving the pointer and scrolling using the integrated touch pad. Since the goal of this HUD setup was to replicate that the car was controlling the secondary task, the HUD automatically shuts down once the take-over request was presented. The HUD setup was used for a writing and reading activity. This task consisted of a text around three to five hundred words, and then two to four questions upon this text. The goal of this writing/reading task was to distract the participant from the road as much as possible while still letting the participant gaze towards the road that lies behind the screen.

The second setup included the participant to only use a provided phone, a Lenovo Tab 7 Essential. It was desired to test this setup due to the beliefs that, if a driver cannot use the car system for a secondary task, it is likely that they will instead use their own phone. The phone was also provided with a writing and reading task, similar to the one used with the HUD setup.

To get a baseline to compare with, the final setup was for the participant to not conduct any secondary tasks at all. The goal with this setup was to get the participants in a state of mind that would be similar to taking the bus to work. The participants did not have any requirements regarding having eyes on the road, nor hands on the wheel. This decision was made due to the belief that a SAE level 3 car would not require it once that car has taken over the driving.

5.1.1 HUD realisation

In order to test the simulation a HUD prototype was needed to be created. It was important to make a HUD with rather good quality in order to make the simulation feel real and get realistic results. Since the HUD that was made during the rapid prototyping phase 4.2.5 lacked the proper quality, a new and more advanced one was developed.

The new HUD was created with three major parts, a screen, a frame and a plastic film. Firstly, the screen of the right dimensions and specifications that could project a display upon the windshield. For this project it was found that a seven-inch screen worked the best. Secondly, a frame to place the screen at the right place and at the right angle on the dashboard. Since the windshield was curved in all three dimensions, the screen on the dashboard had to be tilted in such a way that the resulting angle between the screen and the windshield needs to be as close to 90 degrees as possible. The frame was 3D-printed to achieve these rather exact angles where each corner of the screen was lifted up individually. This frame also included a visual barrier to prevent the driver to see the screen directly, this barrier was tilted 30 degrees to allow the projection to be fully visible from the driver seat. A picture of the frame can be seen at figure 5.1

Figure 5.1: Screen and the 3D-printed frame for heads-up display.

Lastly, a plastic film was cut out and placed on the inside of the windshield to remove the created distortion. Since a modern windshield is built up with two layers of glass, a projection on the windshield gets distorted. The distortion works in such a way that a duplication of the projection appears right next to the primary projection. This duplication makes the projection difficult to read from. To counter this effect, this plastic film was placed on the inside of the windshield where the projection appears for the driver. An illustration of the effect can be seen in figure 5.2.

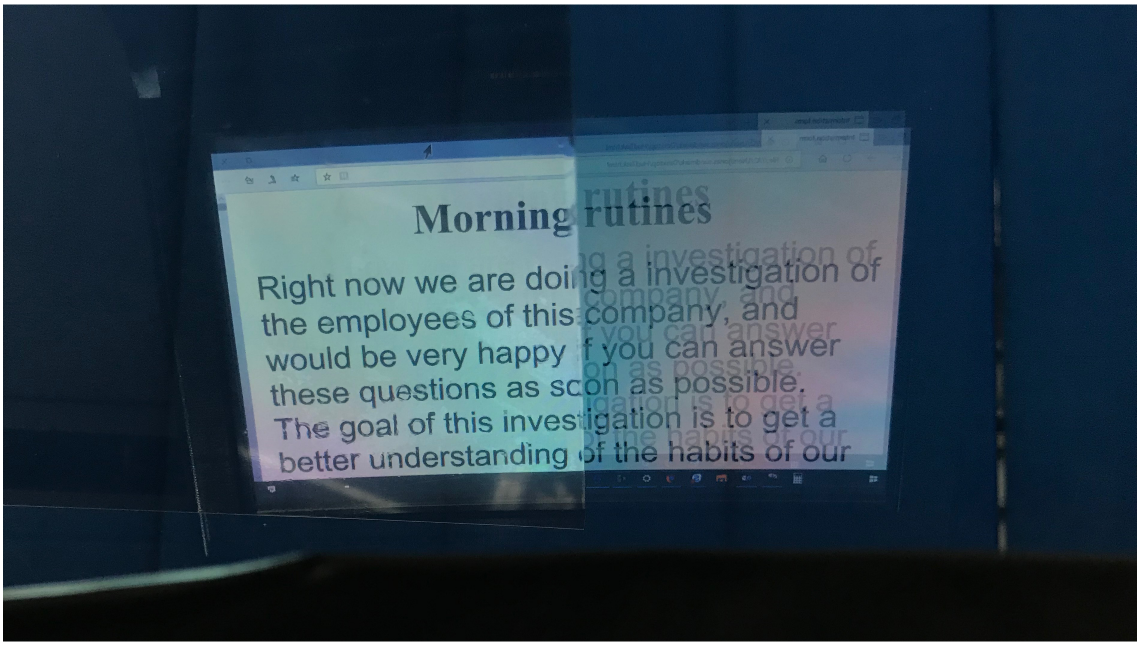


Figure 5.2: The effect of a plastic film on the windshield, plastic film on the left side

The writing and reading text was created as a HTML site to allow for the display to be inverted. It was necessary to invert the display due to the screen projection being reflected in the windshield and therefore the resulted display was mirrored for the driver. Another solution to this problem would be lower the screen into the dashboard and reflect the projection one time before it hits the windshield, and therefore the two mirror effects would cancel out. But since it was not possible to modify the dashboard, the mirror effect had to be dealt with via the software.

5.1.2 Subjective data methods

In order to elicit subjective knowledge and to complement the statistical data, short interviews, observations and a questionnaire was constructed.

NASA-TLX is a subjective workload assessment tool that is used to assess different tasks and operations in-which a human-machine interface systems are included. The tool is built-up by assessing the six sub-scales being, Mental demand Physical demand, Temporal demand, Performance, Effort and Frustration, and by adding the average weighting respectively, a total perceived workload can be established, and find where the tasks are the most problematic for the human. [36]

5.1.3 Simulation setup

The entire setup was built in a real car, a Volvo s60, but with some modifications to the car. First of all, the car did not have a front, which made it possible to place a TV screen right above where normally the engine block sits. A 50" TV was used for simulating that the car was on a road by showing a video of a real car driving on the highway. The entire setup seen from an outsider's perspective can be seen in figure 5.3.

Figure 5.3: Simulation setup seen from the outside of the car.

The video was split into the three sequences using each of the setups. To reduce variance noise of the test, the order of the different tasks varied between participants. In total were three variants of the video created so that each task would fall into every time slot, first, second or third. The goal was to try to cancel out any different between using a particular task first versus last. Each sequence started with declaring which secondary task the participant should enact in, then between six to eight minutes of road simulation, and end in a take-over request.

The take-over request required the participants to look at the screen, assess and decide which side hosted more figures. This kind of task was used because it could simulate a real take-over request in the sense that it requires the participant to look out in the traffic, decide what type of information that is valuable, and then act on the information. The take-over request tried to replicate the active and conscious decision-making a driver would need to make in a real traffic situation. In figure 5.4 is an example of the practice run that the participants got to conduct before the start of the simulation.

Figure 5.4: Practice run for participants to try out the take-over request before the simulation start.

Figure 5.5 displays the complete simulation setup from a driver's perspective. As can be seen in figure 5.4, there are figures on both side of the screen with one of the side hosting more figures than the other side. The task for the participants were to change his or her attention from the secondary task to the take-over request task, and then decide upon, which side had the most number of figures on it. Once the participant had made up his or her mind on which side had most figures, they answer by pushing one of two buttons on the steering wheel, the button on the left side of the steering wheel or the button on the right side of the steering wheel. The computer then records the time it takes for the participants to answer, and if they gave the right answer.

Figure 5.5: Simulation setup from inside the car

In order to lessen the effect of the order of the take-overs, the participants had a training session before the actual test. This was thought to minimise the learning curve of the participants. This included both instructions, see appendix C.1, of how the procedure would look like and a practice run where the participants were able to become more comfortable with the controls provided inside the car. The participants were briefly told that the simulation aimed to recreate a scenario of one sitting in a self-driving car and was able to conduct secondary tasks with a following take-over phase. The practice run consisted of simple interactions such as letting the participants know how to unlock the phone, using the touch pad to navigate the HUD and making them aware of how the sound of the take-over request would be. This would further help setting a baseline of the skill needed to properly conduct the test.

To conclude the simulation and gather subjective thoughts, a questionnaire was created, see appendix C.2. The goal of the questionnaire was to gather basic knowledge about the participants as well as to find out their subjective feelings and experience about the simulation. The questionnaire consisted of three parts which focused on information about the individual participant, the execution phase itself, and the experience using the different setups respectively. The lesser part of the questionnaire was made to be an adapted version of the NASA-TLX method. In this part the participants rated the individual setups based on the sub-scales mentioned in chapter 5.1.2. To also gain immediate first impression information, short questions were asked as the participants stepped out of the car. This to gain even further understanding about results and to discover reasons for potential deviations in the result.

5.1.4 Sample

The test sample of the study consisted of ten men and five women that due to confidentiality reasons all worked at Autoliv Sverige Vårgårda. The average age of the participants were 40 years, with a standard deviation of twelve years old. Fourteen out of the fifteen individuals had had their driver's license for more than six years, where the majority of those have had it for 15+ years, making the participants well aware of the act of driving. Furthermore, the participants had little to mostly no previous experience with HUD.

5.1.5 Simulation execution

After the simulation setup had been finalised and implemented inside the car, pilot tests were held. This was done with people that had previously no knowledge about the ongoing project and thus, their feedback concerning flaws or unclear instructions were important to find and improve before the real simulations would take place. As the feedback had been evaluated and adjustments to the introduction and the take-over request phase had been made, the project could advance into the live testing.

The simulation was carried out in the three stages mentioned in the introduction of chapter 5. The first one, being before the test sequence started, consisted of the introduction and the practice run as mentioned in chapter 5.1.3. As the introduction had been held and the essential information had been transferred, a couple of minutes were dedicated to the practice run. When the participants felt that they had grasped the fundamentals, the simulation could proceed.

The following stage of the simulation was the execution phase itself, which started directly after the practice run when the door was shut. From this moment in time and until the end of the run, no interaction was held with the participants, and instead did the video that was presented on the TV monitor sufficiently present the information needed. Observations were also taken place to ensure that the participants followed the instructions given and the simulation was carried out as planned.

As the video came to an end, the participants were allowed to leave the car and the last stage of the simulation took place, namely the qualitative data gathering. The participants were asked about their first impressions of the test as a whole as well as the individual sequences. The comments given were written down. Lastly, the participants were asked to answer the pre-constructed questionnaire which after completion, concluded the simulation.

5.1.6 Statistic data methods

After all the participants had completed the test, the results were ready to be analysed. The numerical data of the different response times were imported into an excel document for further statistical analysis. Statistical tools were used in order to examine and analyse the results that were gathered from the tests that were carried out. To test whether there was a difference between the different groups the paired t-test together with the null hypothesis was used [37]. The major goal of the statistical analysis was to find out about how the population mean would be for the different secondary task, and how they would differ. The total sample size for the simulation was 15 participants, but due to one of the participants misunderstood some information, he answered much slower on two of the re-take tasks and therefore became an outlier. Since the reason for why this outlier became and outlier was known, this outlier could be removed without further research needed.

5.2 Findings

The information gathered during the simulation was analysed with the goal of finding patterns between the different setups.

5.2.1 Statistical Analysis

In figure 5.6 three curves of the different secondary tasks can be found. These curves represent how the population would perform regarding response time on the simulation, given that the population is normally distributed. All the raw data can be found in appendix D.

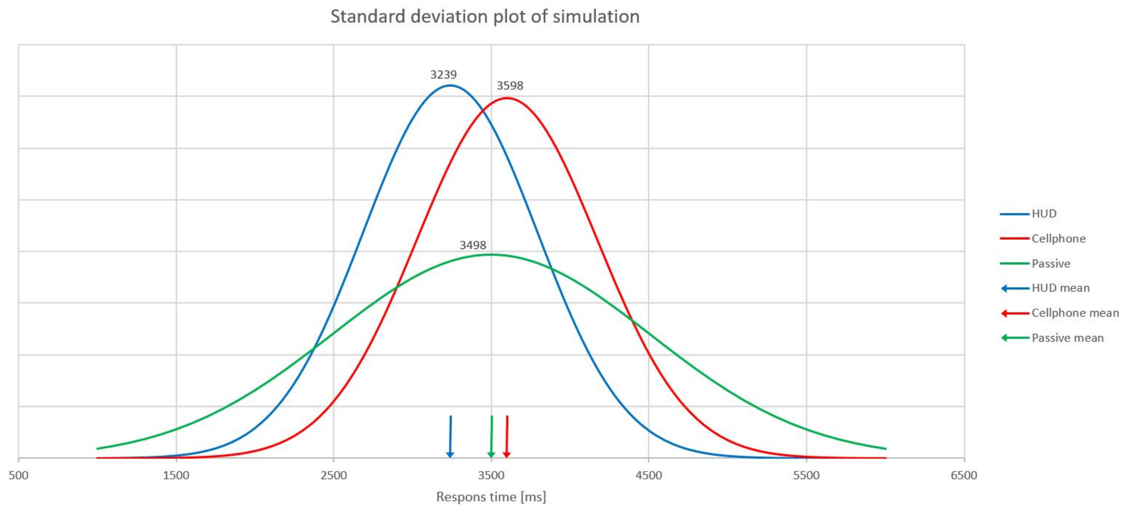


Figure 5.6: Standard deviation plot of the three secondary tasks.

A few things can be derived from this graph: The height of the curves tells about the standard deviation of the sample. A taller curve means a higher probability of a sample to end up close to the mean. The mean of each curve is marked with a coloured arrow and can be found underneath the curves just above the x-axis. As can be seen, the HUD setup had a mean value of just over 3200 milliseconds, the passive setup had a mean value of almost 3500 milliseconds, and the cell phone setup had a mean value of almost 3600 milliseconds. To check how the far away the sample mean is from the true mean, the standard error of the mean is used. A representation of the standard error of the mean can be seen in figure 5.7.

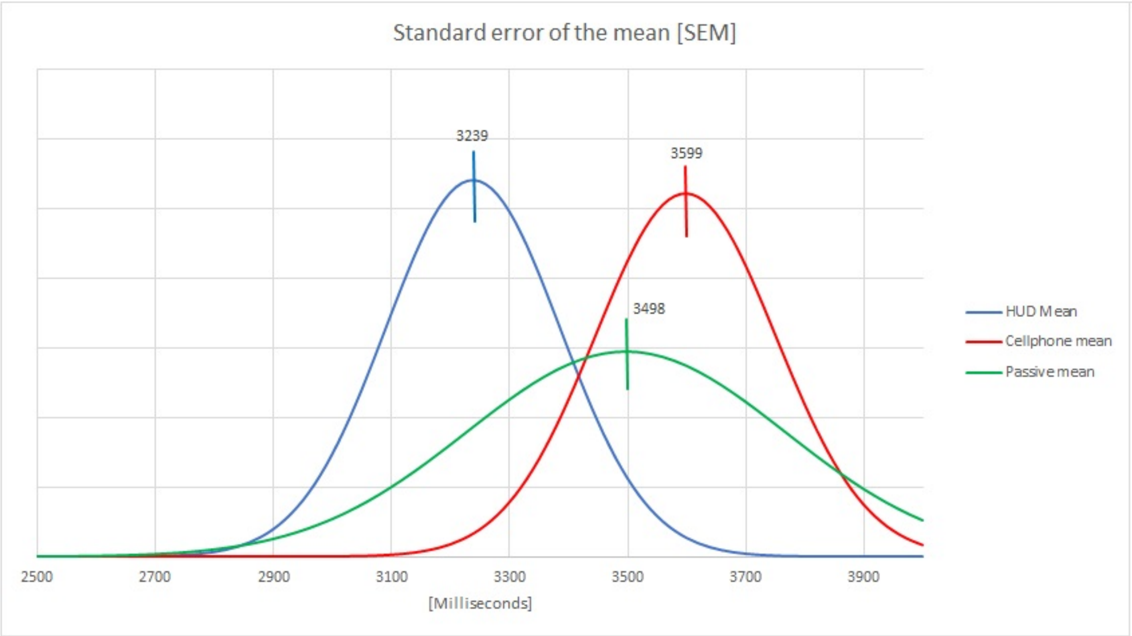


Figure 5.7: Standard error of the mean, displays the relation between the sample mean and the true mean of the population

As can be seen, the HUD setup had the shortest time with over 250 milliseconds quicker response time than the passive setup. For this simulation the cell phone setup was the slowest with about 100 milliseconds slower than the passive setup. Hence the difference between the quickest, the HUD setup, and the slowest, the cell phone setup, is slightly above 350 milliseconds. The thing to keep in mind is that these means that was found, only reflects on this particular test, and they are all subject to change according to the probability of the graph. To check whether the true mean of the population between the setups are statistical significantly different or not, T-tests with the null hypothesis was performed. Since the simulation was set up in such a way that each participant preformed each setup, a paired T-test could be done. Three paired T-tests were made to check the likelihood of these differences between the true means. Two of these paired T-tests, between HUD and passive, and HUD and cell phone, did not show any statistical significance. On the contrary, the paired T-test between the HUD setup and the cell phone setup did show a significant difference. The threshold value for rejecting the null hypothesis was set to be less than or equal to five percent. As can be seen in figure 5.8 the P-value for two tails are slightly above one percent which result in a rejected null hypothesis. This means that there is a statistical significance difference between the true mean of the HUD setup and the cell phone setup.

t-Test: Paired Two Sample for Means		
	Time HUD	*Time Cellphone*
Mean	3239	3599
Variance	305398	327843
Observations	14	14
Pearson Correlation	0,668	
Hypothesized Mean Difference	0	
df	13	
t Stat	-2,936	
P(T<=t) one-tail	0,58%	
t Critical one-tail	1,771	
P(T<=t) two-tail	1,16%	
t Critical two-tail	2,160	

Figure 5.8: T-test paired between the HUD setup and the Cell phone setup

In figure 5.9, the same results are visualised. Each dot in the figure represent one participant, with the x-coordinates showing the response time during the HUD task and the y-coordinates showing the response time during the cell phone task. The black line that cuts through the lower left corner to the upper right corner separates the participants into one of the sides. Dots left of the black line had longer response times for the cell phone compare to the HUD, whereas dots right of the right line had longer response times for the HUD compare to the cell phone. The black line therefore represents where the dots would sit if there was not any difference between the response times, that the mean difference would be zero. The dark blue dotted line shows what the mean difference was for the participants of this simulation. The light blue shaded area shows where the dark blue mean difference line could fall for the population with a 95% significance. Note that the size of the light blue shaded area depends on the percentage significance. A higher percentage significance means a larger area, if the percentage would be above 99% the shaded area would overlap the black line. But since the light blue shaded area does not overlap with the black line, it shows that the mean difference is statistically significant longer for the cell phone task.

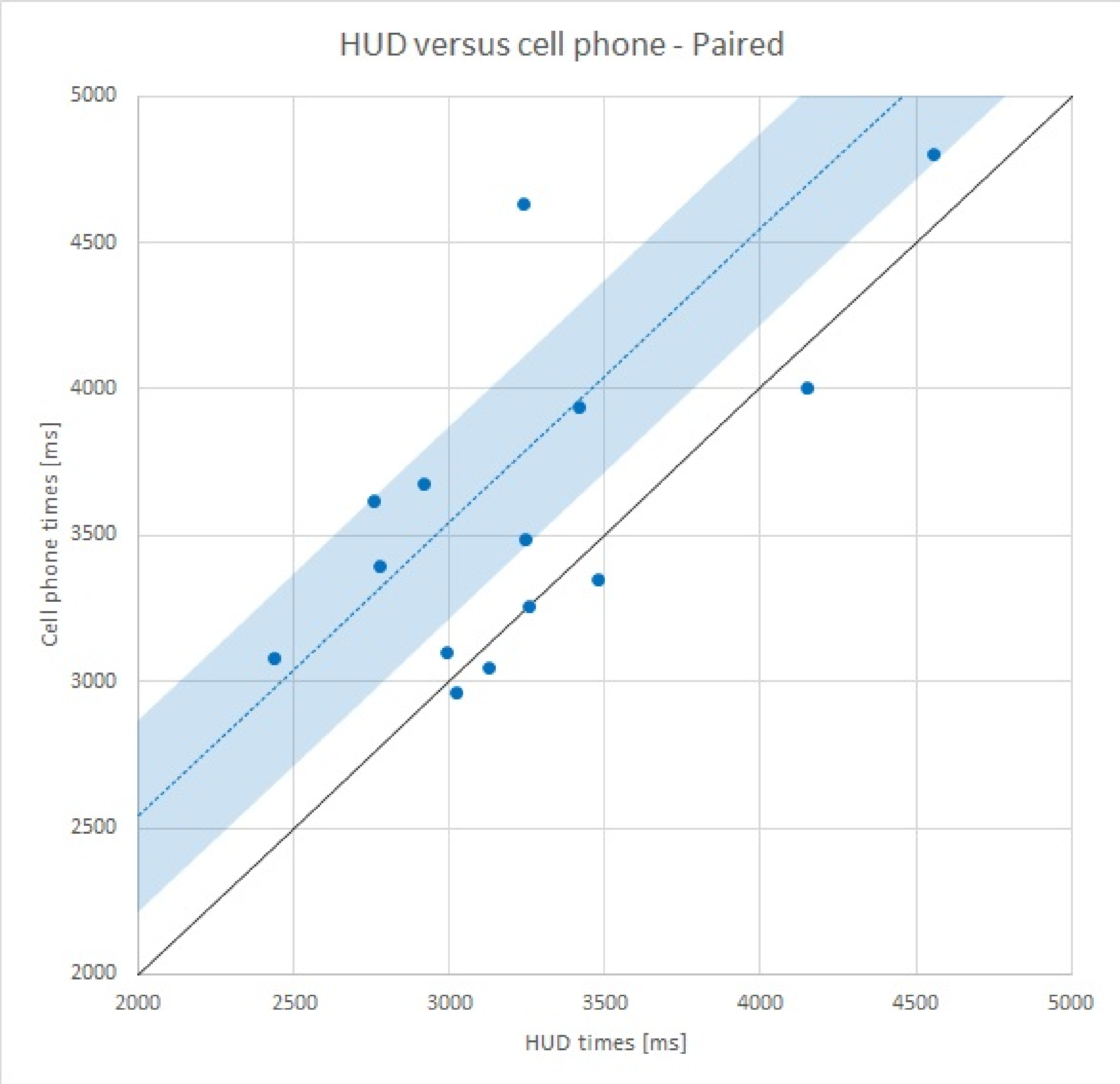


Figure 5.9: Visualisation of paired data for HUD and Cell phone task

In figure 5.10 a similar visualisation is made as the figure 5.9. When comparing the two figures one can see a few differences. The first thing to note is that green dotted mean line is closer to the black line in this figure. This means that the mean difference is closer between the two tasks. The other noteworthy difference is that the light green shaded area do overlap with the black line. This green shaded area does show a 95 % statistical significance level, the same significance level as the blue shaded area in figure 5.9. The green shaded area does not overlap by a lot, meaning that if the significance level would be lowered, they would not overlap. For this graph, a significance level of 90 % would mean that there would not be any overlap. Hence there is about a 90 % likelihood that the mean of the difference is lower for the HUD compare to the passive times.

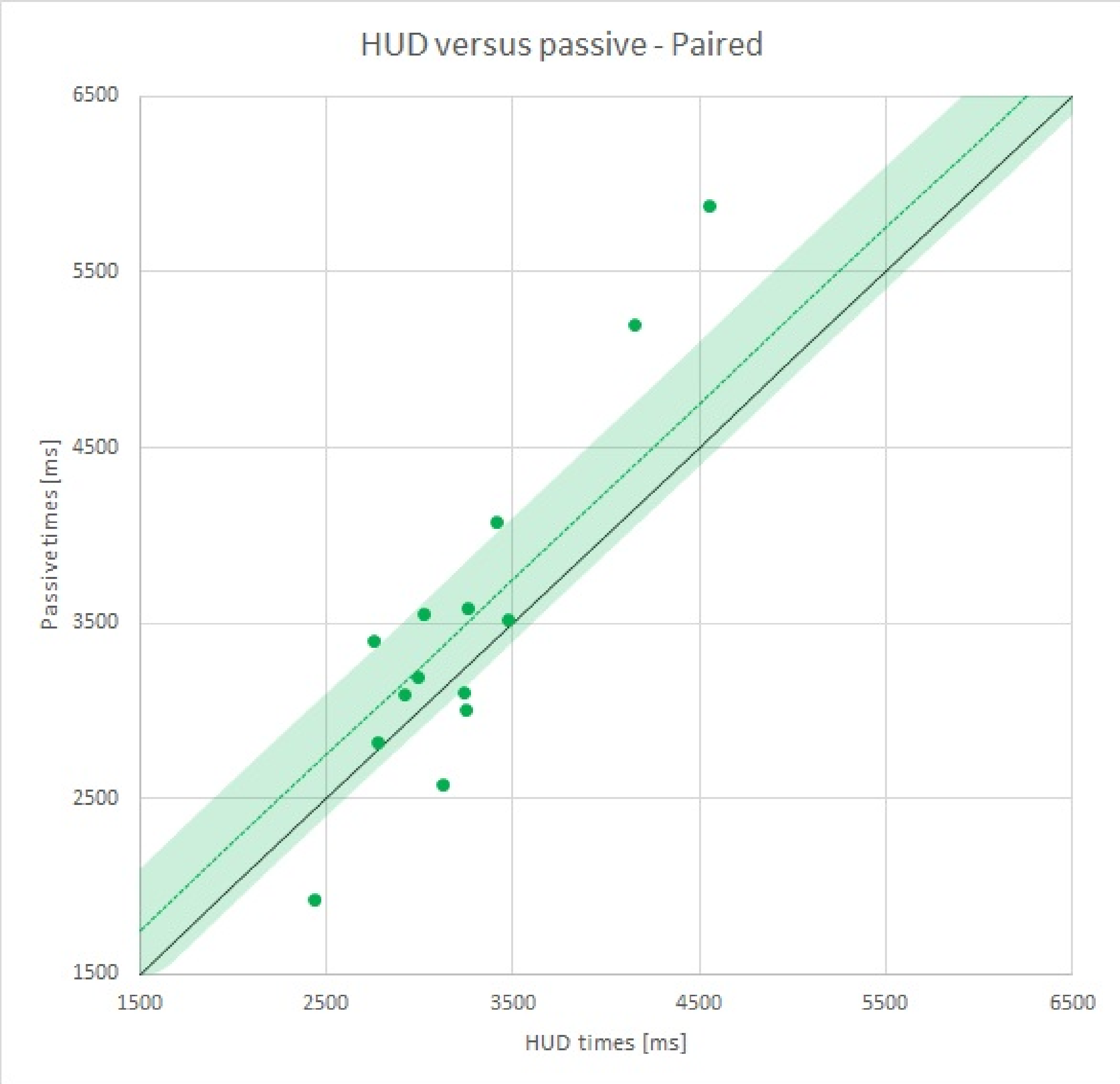


Figure 5.10: Visualisation of paired data for HUD and passive task

To check whether any other factors influenced the simulation in a significant way some additional T-tests were performed. The first of these additional T-tests were to check if the order of the preformed secondary task mattered in the response time. Since no participant did the same task in any different order the paired T-tests cannot be preformed here. Instead, a T-test with two tails and equal variance between the factors was done. This test was made between all secondary tasks individually. This led to nine total T-tests to check if the order had any significant impact on the result. It turned out that none of these T-tests did show a significance, the closest result to show a significance was the difference between the first and last passive setup. This T-test showed a P-value of 15% compare set threshold of less than five % that was needed to reject the null hypothesis.

The group of participants was easily split into two groups of different ages, seven participants were younger than 35 years old and seven participants were older than 40 years old. This allowed for T-tests to check whether the age affected the result in a significant way. These T-tests were made with the following configuration; unpaired, two tails, no equal variance assumed. The T-test between the two groups for the cell phone task did show a significant difference while the other two did not. Statistically the mean response time this cognitive test while being engaged with the cell phone is slower for a person over 40 years old compare to a person younger than 35 years old. This difference is represented in figure 5.11. The other two graphs can be found in appendix E.

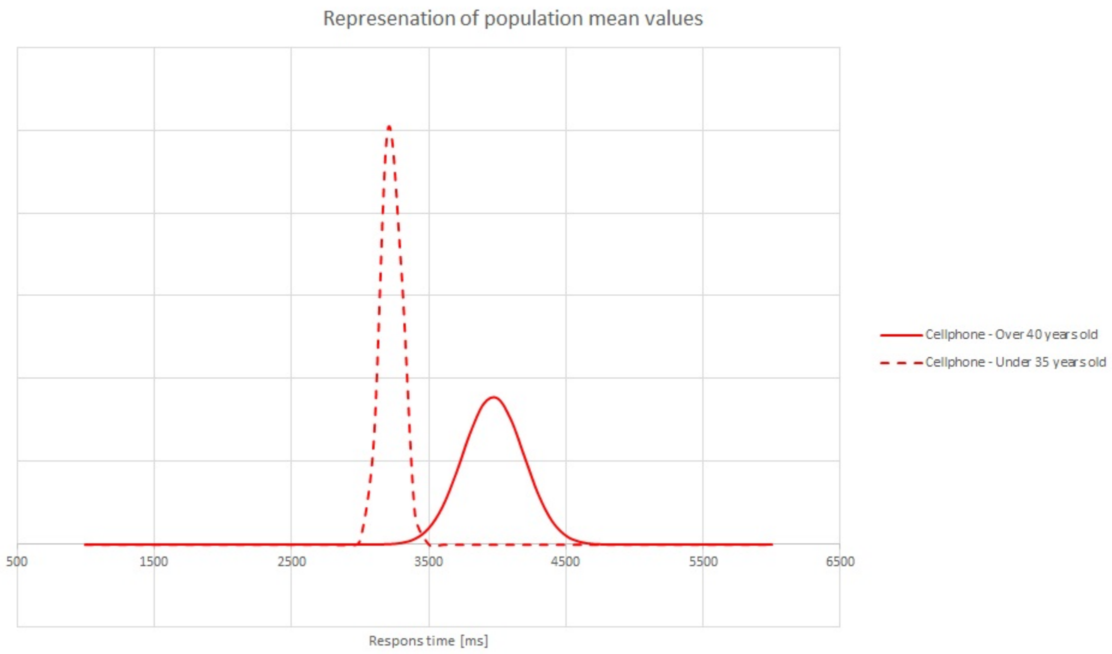


Figure 5.11: Representation of means of response time for population older than 40 years old and younger than 35 years old.

5.2.2 Questionnaire results

Looking into the result of the questionnaire and starting with the participants' simulation experience. It is beneficial if the simulating is felt real and immersive even though it is carried out away from its proper working environment. Becoming engaged into the experience helps generating realistic and comparable results. Figure 5.12 displays the answers concerning the level of engagement felt by the participants. 79% was either neutral, agreed or strongly agreed, while the remaining 21 % felt the opposite. However, the result could be somewhat misleading due to the discovery of some individuals, did not fully understand the question and thus might answered the opposite. The word "drive experience" presented in the first statement was refereeing to, the act of being inside a moving car, and not the act of the participants being the one driving which some thought it meant, hence the result.

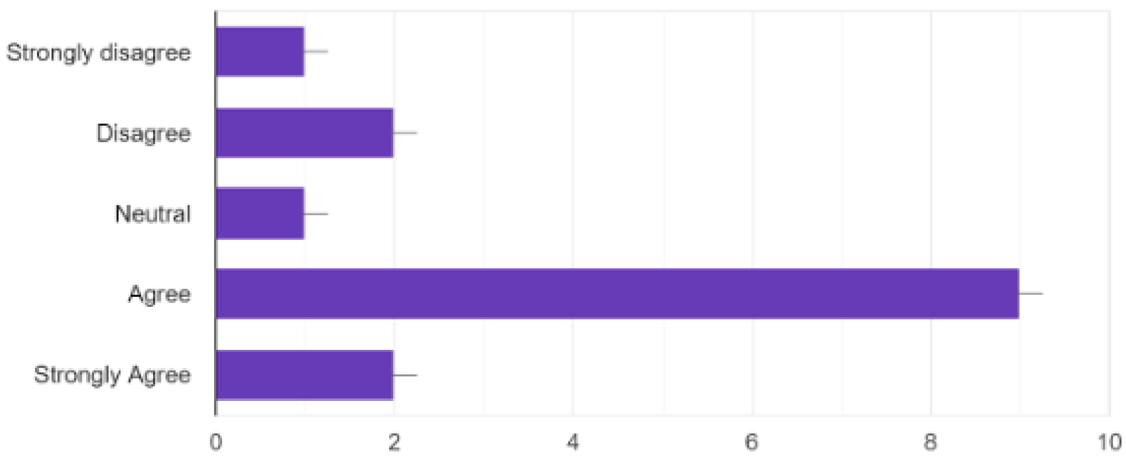


Figure 5.12: The plot displays the rating regarding engagement into the driving experience

When conducting a simulation, it is inevitable that some people have a hard time to relax and lose the tension, even though it is asked of them to do so. It could just be due to the fact that they are placed in a new environment, where the fear of the unknown in combination with them not wanting to perform poorly that creates it. The reason could also be the opposite where the individual wants to perform well and therefore stays more alert than he or she should in a reality. Figure 5.13 shows the answers regarding the participants were "on their guard" during the test. About 73 % felt that they did not need to do so whereas 27 % said that they actually did which could have affected their response times often by decreasing it. The results displayed in the two figure 5.12 and 5.13 could correlate to each other and tell the reason of one an-others result.

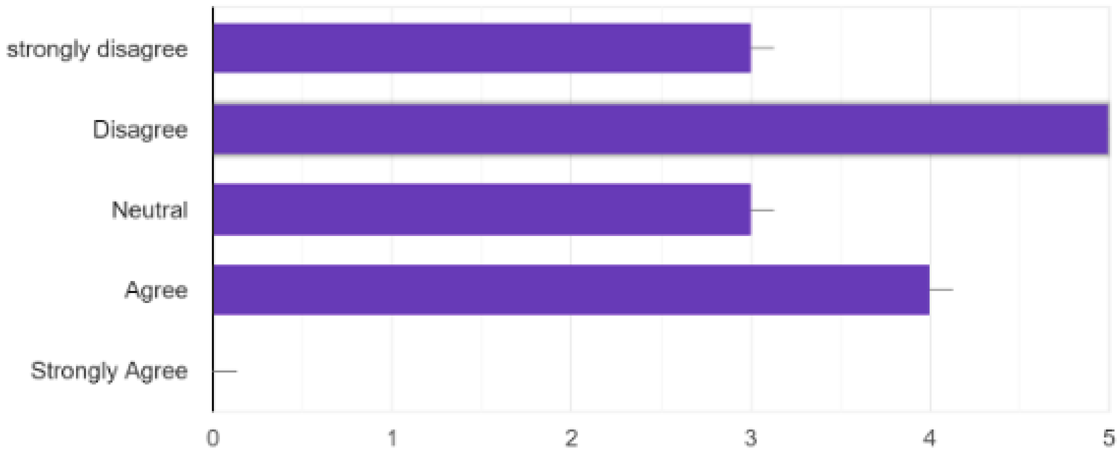


Figure 5.13: The plot displays the given rating regarding the participants' feeling of being on their guard.

Having enough knowledge and minimising the unknowns creates confident, and having both of them are essential for the results. They replicate the feeling of having trust for the system and how it would be used. Those are the results that is desired to find. Figure 5.14 and 5.15 shows the understanding of instructions and the level of confident & control respectively. The first mentioned displays a 100 % rating distributed over "Agree" and "Strongly Agree" indicating a well transferring of knowledge during the simulation. 80 % of the participants were feeling confident or strongly confident in their actions during the re-take phase. The remaining three individuals gave a rating of feeling neutral.

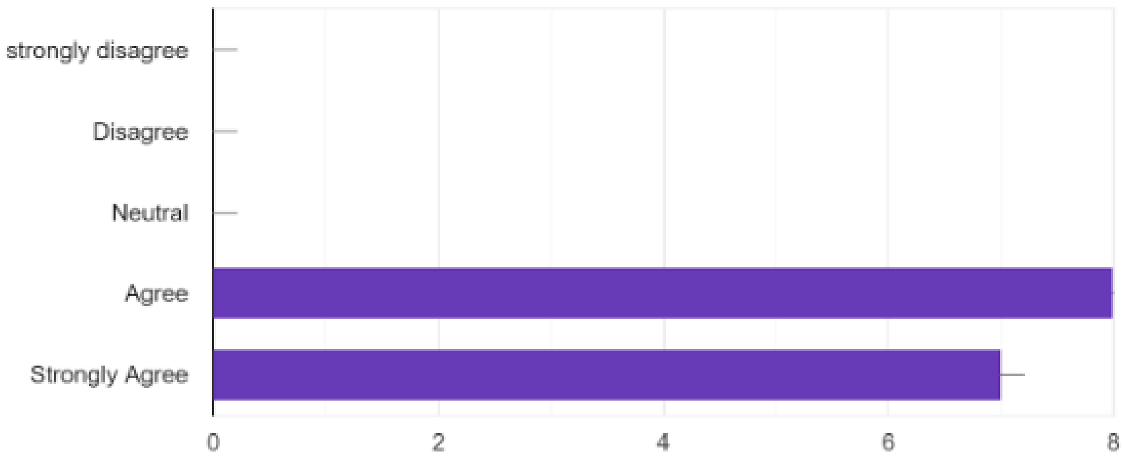


Figure 5.14: The result concerning the level of understandable instructions.

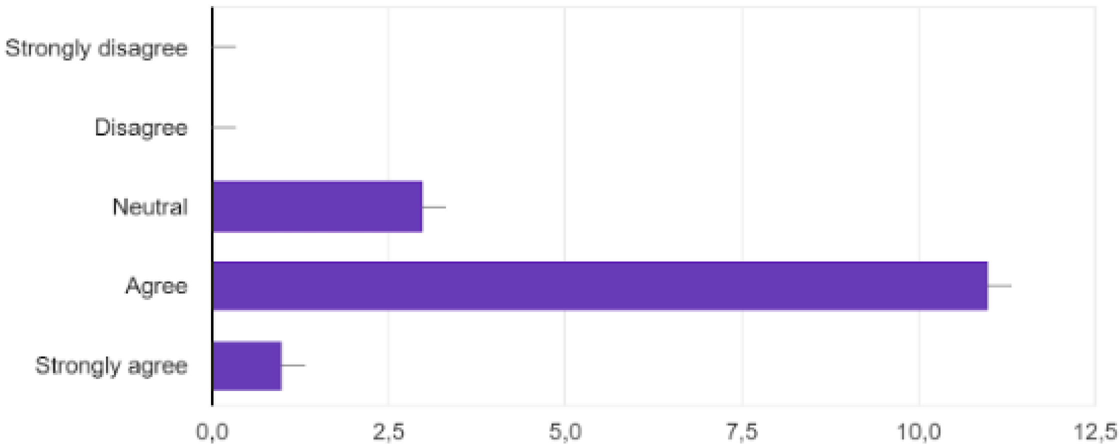


Figure 5.15: The result concerning the level of confident and control during the re-take phase.

The questionnaire also enabled the participants to give own thoughts about the simulation, as well as giving a written answer concerning how the peripheral view got affected by either using the HUD or the phone, see appendix C.2 for the entire questionnaire. The following paragraph will summarise the replies given for the HUD versus the phone.

Firstly, the majority felt like the HUD gave them a better peripheral view and became more aware of what is happening around them than when using the phone. This because the feeling of being shut out from the surroundings. However, three people were describing that they became invested into the secondary task in such a way that they lost the sense of the traffic with either of the setups. Motion sickness when using the HUD was felt by two participants. Although, these people did say that it was a common problem for them in general when conducting tasks as a passenger. Another problem issued by one individual was that the surroundings distracted him when using the HUD. It was also noted that the lack of feedback when pressing the re-take buttons making them unsure of if they had done the right thing or not. When this was found to be an issue, it became included in the introduction phase to tell this to the participants.

More replies, concerning possible improvements, or conditions of the individuals were received, which indirectly could have affected the results. In the bullet list bellow some of the answers are displayed.

- "I felt a little bit sleepy during the test. maybe it was good to include short nap also in the test. or maybe together with reclining the seat for more relaxation."
- "Interesting simulation, but I looked much more straight forward toward the TV-screen and the road, then what I would have done if it was a nice view on the sides and the roof top window as well."
- "A way of attaching the keyboard would have been good."

The last part of the questionnaire focus was put into perceived workload factors that were experienced during the tests. This gives an insight in how the use experience was with the different setups.

The first sub-scale measured is the "Mental demand" which looks to describe how much mental activity that is needed to conduct a task. The result can be seen in figure 5.16 and shows that using the HUD and keyboard was rather demanding to use where 10/15 individuals rated it a 4. The answers for using the phone and conducting the re-take task was seen as less demanding by generation lower overall scores.

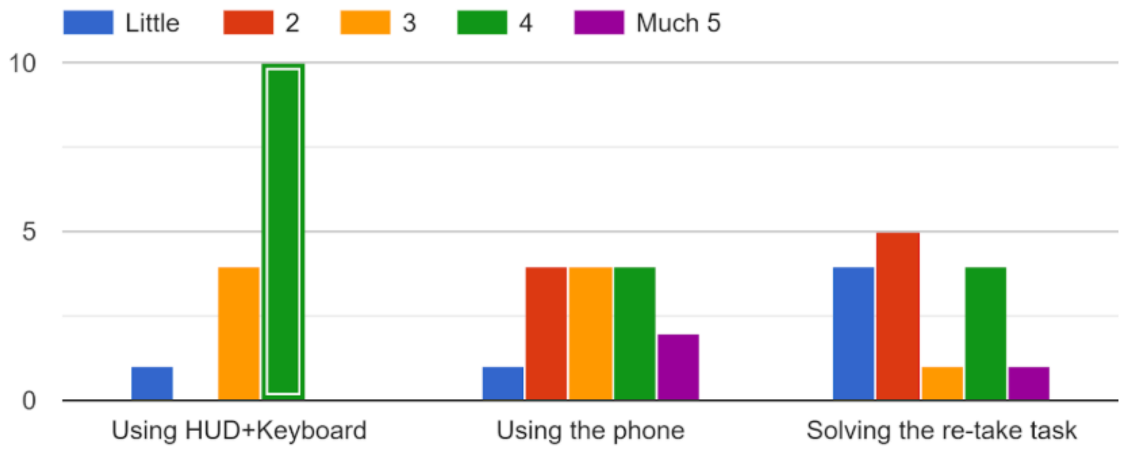


Figure 5.16: The result displaying the perceived mental demand using the setups.

Regarding the ergonomic aspects of the setups the result shows a mixed feeling about the HUD and keyboard which scored both high and low and where the difference between using the HUD + keyboard and the phone was relatively low. The result concerning physical demand can be seen in figure F.1 in Appendix F. The placement of the re-take buttons showed to be desirable according to the result where 11/15 participants rated it a scoring of 4 or 5. The following workload factor namely, temporal demands describes the level of stress felt by the participant. The result can be found in Appendix F, figure F.2 and shows that they when using the setups, before the take-over request was issued, the participants were calm in majority of the cases. A slightly increase rushed feeling was felt during the take-over request.

The performance factor looks into how well the participants reviews their own level of accomplishment of what was asked of them to do. The perceived level of performance by the participants were generally high and the result can be seen in Appendix F, figure F.3. However, in some cases, namely three participants for the *HUD+Keyboard*, and two individuals when using the phone rated them scouring of one or two. The take-over request scored the highest with all of the participants rated it a three or higher and where the majority rated it a four out of five.

To correlate to performance, Effort focus on the level of hard work needed to be done to achieve the performance. Figure F.4 in Appendix F displays the results which shows a varied level of workload needed to accomplish the task. All five of the rated levels were picked in all three of the setups. What can be elicited is that the HUD+Keyboard was marginally perceived as needing the most work put in.

The last remaining sub-scale to be included was regarding the level of frustration felt during the simulation, and the result can be seen in figure F.5, Appendix F. Worth noticing is that neither of the setups scored a three and thus the colour coding has changed. This means that the orange coloured pillars, in this figure represent a scoring of four instead of three in the earlier included figures. The HUD+Keyboard gave once again the most varied response where 33% rated it as low as one, and 40% rated it four. Interaction with the phone generated a similar but slightly better result. The re-take task was experiences as the least frustrating task where 87% of the result rated it either a scoring of two and one.

6
Discussion

Our own thoughts and ideas regarding the findings, validity and subject area of autonomous driving will be expressed in this following chapter.

6.1 Analysis of findings

The first section will cover what the results of the study and what the statistics say about these results and how we interpret these results. This will be followed by a discussion about the subjective responses and its possible correlation to the statistical findings.

6.1.1 Statistical Analysis

The most important results we found was the 95% statistical significance between means for the HUD and cell phone setup, and that the HUD had the lowest response time for the simulation. We see this as a good indication that a car which is designed for secondary tasks can improve the take over time in real situations, and that a study covering this would be the most interesting follow up. The statistical significance between the HUD and cell phone setup also gives us a good indication that lifting up the gaze towards the road and letting the system control the secondary task is a way to ease the act of getting back into the loop. Since the alpha value was set to account for a 95% significance we could not reject the null hypothesis between the HUD and the passive task. But the p-value for the difference between the HUD and the passive task showed that there is over a 90% likelihood that there is a difference of the means. Since this is close to the commonly used 95 % threshold, we believe that with improvements to the HUD setup another test could prove a 95% significance. In this study we never got to try the HUD with the interaction on the steering wheel, but we think that this could improve the result even more. We think that testing how interaction with the steering wheel affect these times could be an interesting research project to follow up on.

Beyond the advantage of choosing when the driver can use the secondary task, the system would also have input on what the driver is up to. The system would for example know that the driver gaze on the secondary task display and have the hands on the secondary task interaction device. This could lower the need of eye-tracking systems as well as hands on detection systems.

It is important to note that we cannot claim that it is safer to perform a secondary task on a HUD in a real traffic situation due to the test configuration. Since the test was in a stationary simulation, and the participants were fully aware that they were not in any real danger, we do not know if they would react the same way in a real situation. The participants were also not required to make any difficult or quick manoeuvres, meaning that this is another area not covered in this study. However, we think these results can tell of something about the cognitive load, ease of changing tasks, and active versus passive mind state. The active versus passive mind state is an open question that we think is especially interesting; could being distracted from the main driving task be beneficial if one is active compare to looking at the road but being mind of? This study only scraped the surface on this subject and showing that it might not be as easy as to say that secondary tasks decreases the safety. Therefore, we think that further studies on this matter could serve to improve the understanding of how we are affected in our cars. Another study we recommend is a continuation study but with more difficult settings and situations. One example of a study would be to conduct a similar configuration as ours but do it in a real car on a road.

For this study we have only investigated one type of secondary task, the writing/reading task compared to a passive task. Our choice stems from the business case argument, as well as limiting the number of factors that separate the different setups.

The business case argument is laid out so that it would be easier to justify a more expensive car if you can get something in return, and the argument of the ability to work in the car is one of the most important features. We think that the writing/reading task is a vital task for work today and therefore this suited well to test the ability to work from the driver seat.

The thought of limiting the number of factors goes as follows. If the HUD setup showed a video while the cell phone required a writing/reading task, we would not be able to tell if the difference in mean time came from the specific task or the way to conduct the task. It might be the case that the cognitive recall time is different if a clip from animal planet was displayed in the HUD compare to reading a mail on the HUD. If for example it shows that watching a video clip on the HUD increases the response time, then it might come down to that a self-driving car will allow you to perform some secondary tasks but not all. This could also be depending on the current traffic situation. Maybe you would be able to watch video clips in a traffic jam, but only allowed to sort your mail in-box on the highway. To be able to make these decisions however, a system would need to be able to judge the traffic situation beyond "take over" or "not take over". This kind of AI judgement is something which we have not seen so far which make these ideas quite speculative. But to understand this better, we would recommend a research project for exploring the use of different secondary tasks on the same media.

The significance between users over 40 years old and users under 35 years old regarding the cell phone task could be further explored. Since it was over a two standard mean error significance, it suggests that there is a difference between the population means. Car brands with a higher average age of drivers might benefit more from enabling the drivers to interact with the car from a cognitive recall perspective.

6.1.2 Questionnaire

It is important to talk about the subjective generated results and the reasons for why they ended up as they did, all to gain a better understanding of them. This following section will therefore discuss the more interesting results that were gathered from the questionnaire described in chapter 5.2.2.

Mental demand
Doing anything for the first time does in general require more mental resources. This means that with more experience of doing something, will make it easier for you to conduct the task at hand while also enabling you to put mental resources onto other tasks as well. Imagine how much energy and thought a novice first time driver requires in order to just change gear and find the biting point. Compare this to the practically automated action done by a professional racing driver. In our case, most of the participants had no previous experienced with using a heads-up display, and no one had interacted with it in such a way as they did in the simulation. Hence, the result of it being the most mentally demanding is expected to correlate to this argument. This further states the question of, if inexperience could have prolonged the retake phase due to a higher amount of mental resources were dedicated, did this make them less responsive. Today smart phones and tablets are frequently used and thus it should be more familiar to the participant of how to use the one provided in the simulation, even though no one of them had used the same model before.

Physical Demand
The various scoring received was somewhat expected due to the setups understandable lacked the optimisation needed. The HUD+Keyboard could drastically be improved concerning both the screen and the keyboard. Moving the keyboard away from having it in the lap, which is unsafe in the first place, and instead implement an alternative, more user-friendly and rigid solution would most certainly improve the results. The screen could also be improved in many aspects. First, having a brighter light emitted from the screen now used would make the appearance of the HUD clearer. The perceived view distance of the HUD could also become more optimised which would increase the peripheral view. It would be interesting to see if this could have any effect in lowering motion sickness felt by some.

Temporal Demand
One thing we realised after having completed all the simulations was that when looking into the stress level felt, the passive sequence should have been included. Maybe, due to being passive in a test environment one are less immersed and rather making themselves more prepared for the soon upcoming re-take task. The partici-

pants were asked to be relaxed during this phase but if the subjective result would have showed the opposite, it could describe the reason for the passive time results. Age could also have an impact concerning temporal demands and this due to the different perspective of wanting to perform well. Younger people might feel the need of being on the edge and remain alert in order to, what they think is "performing" and scoring the lowest possible time, even thought they were asked to be relaxed. Whereas older people tend to be able to remain calmer in test situations and in turn would generate more realistic results.

Frustration
The spread result of the HUD+Keyboard seems to be a result of the very lacklustre interaction concerning mainly the keyboard placement and usability, but also for some, due to their novice level of using such a system. From the observations made during the simulations it was noted that older individuals had a harder time using the touch pad that was attached to the keyboard which was used for scrolling up and down in the document. In a high number of occasions people scrolled too much and thus needed to correct their first attempt. This forced them to frequently switch focus between looking up at the HUD and down at the keyboard. The reason for the high scoring regarding the phone is likely due to its slow processor and the unresponsive touch sensors leading to multiple presses were sometimes needed. If the participants would have gotten the opportunity to instead use their own phones, the result would probably have differed for the better.

6.2 Validity & improvements for future studies

Numerous simplifications were made in this study, some due to time and resources, some to make sure a limited amount of factors were tested at once. The following section discusses these implications.
For this simulation there has been a couple of different factors that has separated the result compere to how they would have been in reality. The obvious difference was that the car that the simulation was set up in was stationary inside a prototype lab. The car was also not connected to a simulation game on the TV, so if a participant moved the steering wheel the TV feed would not react to that. The TV screen that showed the video feed did also not occupy the entire view of from the driver seat. More realistic car sounds and the feeling of vibration would further enhance the experience. These are some things we believe took away the feeling from the driving experience and made it more clear that it was a simulation.

The take over request was also simplified, the participant only needed to press one button register the take over. The information to determine which button to press was simplified as well. We think that these simplifications had different effects on different secondary tasks. The big question is, how much did it impact the result. The information to process was not traffic information but abstract information that was not as complex as a real traffic situation. This meant that there was no advantage to understand the traffic flow right before a take over request, something that is beneficial in a real situation. The information we provided had a clear solution, either right or left side of the screen. A traffic situation is not always that clear to understand.

The HUD setup had some issues during the simulation. Most of these issues was connected to the keyboard that was used to interact with the HUD display. The keyboard did not have a natural placement; it was instead placed on the lap of the participant. Further research could therefore explore more ways to interact with a HUD. We recommend a study to test the interaction via voice command, steering wheel, and an integrated tablet. Another improvement for the HUD compare to our setup is to increase the brightness of the screen. We think the next test for the HUD is to test how valid the use of it is outdoors, and especially for secondary tasks. We noticed that the contrast sometimes was lacking, and therefore we recommend a study to see how well the HUD can be used for secondary tasks in a moving car.

6.3 Opportunities and challenges with autonomous driving

Until this point the focused of the discussion has been on the simulation results, what they said, why they expressed themselves as they did, and how the tests could be adapted and changed based on the prerequisites and resources available. The following chapter will instead go back and focus on the fundamentals of autonomous driving as a whole. We will be discussing the possibilities and challenges that comes along with it based on what was brought up during the conducted interviews, studies and read articles.
It is a common thought that autonomous driving inevitable will be the future of how we will enact in the everyday travel. However, how long it will take to introduce such a technology and what capabilities (designated SAE level) it will or should have from start is a split question within the industry. We can only assume that it will happen and thus the role of the driver will change accordingly. As already mentioned, it is believed that along with offering more automated features, the role of the driver will transform into the one of a supervisor. At the same time, as trust for the system builds up and the driver have monitored the same route over and over again, the incentives for start enacting in secondary tasks will be high enough for it to become a new habit. This states the question, how bad would that really be? As long as the car is in control and it works on its terms, as well as the driver knows under what circumstances it is possible, and what responsibilities it brings when doing so. Would enabling such a feature also incentives more car owners to buy the ADAS system and indirectly help growing the network of smart systems on the road toward a safer traffic environment?

We believe it could be possible. How many times have you yourself not been driving, either to your local supermarket or to work, on the same old road when you suddenly "zone out" until you eventually have found yourself at the target destination? This becomes more paramount when your feel tired or stressed. In these cases would it not have been safer to let the car control the driving, which constantly receives and interpret information about the surroundings? Furthermore, if the driver must continuously monitor the road, instead of enacting in secondary tasks, then the need of having high vigilance would be important. Vigilance is however something we are poor at in general as humans, and it requires practice to be good at. If allowing secondary tasks to be performed could the negative effects caused by passiveness, such as physical fatigue be negated?

Our results show that, if done right engaging in secondary tasks does not necessary reduce the time back-to-loop compared to being passive monitoring, but even doing the opposite if the car works with key aspects of promoting "driver's gaze toward road centre", "hands on steering wheel" and "car in control".

What opportunities could follow autonomous driving? Firstly, reducing the number of accidents by having a system more aware and responsive. Secondly, a smoother and more structured traffic environment which in turn could lower the amount of carbon dioxide being emitted. It is shown that by letting the car drive, the individual is less likely to care about reaching the destination as fast as possible and rather lets the system drive as it wishes. If work tasks would be possibly to be conducted, minor ones during SAE level 3 and more complex ones during SAE level 4, time would become unlocked. Imagine the possibility to have the accuracy and freedom offered by using a car but also able to conduct work tasks. To put it in perspective, let's say one hour is spent travelling back and forth from work every day, and given five weeks of vacation each year, this would approximately generate 210 extra hours each year to be used as desired. Either spend one hour less each day at the workplace and free up more time at home, or use the time in the car to work one hour extra each day without affecting your daily routines as it is now. This would additionally be equivalent to five additional weeks of vacation each year.

Despite all the opportunities that comes along with autonomous driving, there are also many challenges to overcome and questions to find answer to before it can become a reality.
Who should be able to use the feature? Everyone or should it be restricted behind certain certificates? What changes in laws or the infrastructure needs to be adapted to follow the advancing autonomous industry development? The most prominent question is probably regarding when or how good the AI needs to be before it is introduced to the mass market, SAE level 3 or SAE level 4. It is apparent that companies have different mentalities, where some values safety above all and will not launch an autonomous driving system to the public until it is as perfect as it can be. This means that the responsibility on the driver can even be eliminated. These companies does however not believe that SAE level 3 can provide this and thus want to skip that level completely. Whereas other brands promote an earlier launch with less perfect systems but where they put the responsibility on the car driver, even when autonomous driving would be active. This requires that the consumers know what their responsibilities are and act accordingly. It is a problem yet to be solved. Educations and certificate could be a start, but would that be enough? Would cameras be needed to observe and based on what the AI can interpret, decide

what can be offered to do, or even if autonomous driving can be offered at that time.

For instance, a big Swedish car manufacturer values safety above all. The company talks about that the first introduction of such a system would be at earliest when the it generates better results than the ones created by, what would be a highly skilled and highly alerted driver in all situations. This would ensure high safety and probably drastically reduce the number of accidents, and of course, the company would never risk to be put in a bad spot, they value safety after all. However, reaching to that point and creating such skilled system could take a long time. An interesting thought is regarding the number of lives that were not saved due to the prolonged introduction. If the system would be implemented when its only better than 80 %, 70 % or 60 % of the population then it theoretically should save lives. Can that however justify that people still could be harmed by it?

A big issue for the OEMs are concerning insurances, and specifically who should be answered for, the driver or the car manufacturer if an accident would occur. This because the difficulty of proving whose fault it actually was at the time of the accident. This is understandable an important factor for the consumers as well to understand their responsibility likewise. At what time and how perfect the system should be before realise is not in our position to decide, but a compromise between the two mentalities seems to be the most reasonable. Safety should always be as the highest valued factor, but where should one draw the line and say that the AI is good enough? If SAE level 3 would saves life, why should it not be pushed out when its ready?

The autonomous industry will not likely explode where we the next day, sees a majority of highly automated vehicles, but rather a successive, step by step introduction. This might be the key to reveal and solve the flaws and issues early on. More so will the society then better understand and organise how an extensive implementation should be done. It is important to understand that just by giving a product that looks to increase safety and improve the task process is rarely the way to success. The key to a successfully achieving a full implementation of autonomous vehicles is to understand the individuals that are supposed to use the product, what they need and how they are supposed to be treated. This in order to reduce the number of traffic related accidents and resulting in achieving a safer traffic.

7
Conclusion

This study had the goal to investigate the implications of conducting a secondary task in a SEA level 3 vehicle while in autonomous mode. A simulation was conducted with 15 participants to try out three different car setups to see which of them resulted in quicker response times to get back into the loop. The setup that consisted of a heads up display showed the best results. The theory for this result is that the heads-up display incentives the gaze towards the road centre as well as letting the car system shut down the heads up display when the participant needed to take over control of the vehicle. The answers to the four research questions follows:

- ***Should it be allowed for secondary tasks to be performed by the driver?*** We think that the results from this study shows a good indication in favour of allowing secondary tasks to be performed by the driver in a SEA level 3 car. More studies will be needed before a definitive answer can be made, but with the value added from allowing a secondary task to be performed as seen in this study, the first implication of an answer is, yes it should.

- ***How would safety be affected by different secondary tasks compared to passive monitoring tasks?*** It seems like the most important traits to improve the safety during a secondary task is to bring the gaze up towards the road and let the system control the secondary task. Therefore, finding the best way to get these traits right should be the first priority when it comes to letting a driver conducting a secondary task in a SEA level 3 vehicle.

- ***According to current research, what are the biggest challenges in order to allow for secondary tasks to safely be conducted?*** The biggest challenges were found to determine when a semi-automated vehicle is good enough to release to the public, and with this the needed infrastructure, rules and regulations to complement the new way of travelling. Lastly, how an optimal HMI-system for the mass market should look like, to support the various needs each individual has.

- ***How could a conceptual HMI system look like, based on the found guide lines to support ST and back-to-loop?*** A design guideline framework was created together with concept drawings of how a car interior for a SEA level 3 car can look. The main features consist of smooth and clear surfaces to minimise use errors. A HUD is implemented for longer interactions and the remaining screens are placed higher up and closer to the where the road centre is, this to remain the gaze toward the road centre as often as possible. The steering wheel should be utilised with the main controls in order to promote hands on wheel. Lastly, secondary information needed should always be easy fetched and a clear indication of if the system is engaged in autonomous driving or not is essential.

8

Recommendations

Following the conclusion of this master thesis work, we recommend a few studies to be carried out from where we left off. We believe that these studies would help to further increase the knowledge of how to conduct a secondary task, and more of its effects in a SAE level 3 vehicle.

1. ***On road simulation:*** Since this simulation was set up in a stationary car inside a lab, the next step would be to do a similar setup but in a car on the road. This to improve the immersion of the simulation to generate more valid and real reactions from the participants, a real take over request could be used, and the peripheral view would matter more.

2. ***Different STs:*** Test different secondary tasks on the same medium. This would give data on whether the task in hand matter as much as the way to carry it out. For example, let the participant engage in watching a video clip, writing a text, reading a text or gaming on a HUD setup.

3. ***Participants:*** Running the simulation with more participants would primarily lower the impact of potential outliers, but also give a better estimation on the statistics. We recommend to run the tests with participants from different cultures, age groups, and different experience with cars to see if that effects the results.

4. ***Improved interaction:*** Our simulation only tried one way of interacting with the HUD, it would be interesting to see how different ways of interacting with the HUD would feel like for the participants. A few ways that comes to mind are interaction on the steering wheel, via voice control, or via an integrated tablet.

5. ***HUD validity:*** The HUD worked rather well for the setup that was ran inside the prototype lab, but a study on how well it works out on a road would be beneficial to see if this is a good contender for providing a secondary task in the car. Different weather conditions are aspects that could impact the visibility of the HUD.

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A

Use cases

<table>
<tr><td>Use case name:</td><td>Starting SAE Level 3</td></tr>
<tr><td>Use case number:</td><td>1</td></tr>
<tr><td>Actor:</td><td>Driver</td></tr>
<tr><td>Context:</td><td>In the car</td></tr>
<tr><td colspan="2">Abstract: ADAS safely takes control over the car</td></tr>
<tr><td colspan="2">Goal: Engaging the car in SAE Level 3</td></tr>
<tr><td colspan="2">Pre condition: Driver drives the car on SAE level 2 or less & enters a SAE 3 zone</td></tr>
<tr><td colspan="2">Normal course:
Initialisation (triggers):
- Enters SAE level 3 zone
Process:
1. Car signals SAE level 3 readiness
2. Driver approves SAE level 3 take over
3. Car takes control over the vehicle
4. Car signal take over completed
Termination
- Driver release motor control</td></tr>
<tr><td colspan="2">Alternative course: N/A</td></tr>
<tr><td colspan="2">Post condition: SAE level 3 engaged</td></tr>
<tr><td colspan="2">Exception(s):
- Technical failure prevents signals/ take over
- Driver does not notice signals
- Car does not notice drivers approval
- Driver do not know how to approve request
- Driver interfere with motor control (steering wheel)
- Driver do not want to engage in SAE level 3</td></tr>
</table>

Figure A.1: Use case number 1 describes the process of starting a SAE level 3 drive.

Use case name	Secondary task- Work
Use case number:	2
Actor:	Driver
Context:	In the car
Abstract: Driver wants to conduct work during ongoing SAE level 3	
Goal: Successfully conducting work tasks safely	
Pre condition: SAE level 3 engaged	
Normal course: *Initialisation (triggers):* - Driver **request** work mode (uses apps) *Process:* 1. ADAS **acknowledge** request 2. ADAS engage work mode (does something happen?) 3. Driver **uses displays, navigation and input functions** to work 4. Driver **exit** work mode 5. ADAS **updates** the driver with **information** about the current traffic situationen. *Termination* - ADAS disengaged work mode	
Alternative course: - Depending on work task different screens and functions can be used. - Earlier stopped work mode due to system request take over.	
Post condition: Work conducted by driver who gets freed up time	
Exception(s): - Technical failures - Driver do not understand how to use the work related functions. - Driver do not understood the current traffic situation information	

Figure A.2: Use case number 2 describes the process of engaging in a work related secondary task.

Use case name:	Secondary Task- Relax
Use case number:	3
Actor:	Driver
Context:	In the car
Abstract: Driver uses relaxing mode	
Goal: Satisfied driver relaxation	
Pre condition: SAE level 3 engaged	
Normal course: *Initialisation (triggers):* - Driver **request relax mode** *Process:* 1. ADAS **acknowledge** request (how to make the driver understand) 2. ADAS engage relax mode 3. Driver relaxes 4. Driver **request exit** relax mode 5. ADAS **acknowledge** request 6. ADAS disengages relax mode 7. Driver back to **standard position** *Termination* - ADAS **updates** driver about the current traffic situation.	
Alternative course: - Driver relaxes without using relaxation mode - Relax for too long (15-20 min), ADAS disengage relax mode - Driver sets timer for disengagement.	
Post condition: Driver feel rested	
Exception(s): - Technical failures - Driver relaxes until ADAS request take over - Driver does not wake up (no response), check for vital signs. - Driver not understand the current traffic situation information	

Figure A.3: Use case number 3 describes the process of enacting in a relaxing secondary task.

<table>
<tr><td>Use case name:</td><td>Planned take-over</td></tr>
<tr><td>Use case number:</td><td>5</td></tr>
<tr><td>Actor:</td><td>Driver</td></tr>
<tr><td>Context:</td><td>In the car</td></tr>
<tr><td colspan="2">Abstract: ADAS safely gives control to driver</td></tr>
<tr><td colspan="2">Goal: Driver manually drives the car</td></tr>
<tr><td colspan="2">Pre condition: SAE level 3 engaged and the car leaves SAE level 3 zone</td></tr>
<tr><td colspan="2">Normal course:
Initialisation (triggers):
- About to leave SAE level 3 zone and SAE 3 engaged.
Process:
1. ADAS signals/notifies about to leave SAE 3 zone, 30 (x) seconds before take over. “Prepare for exit ST”
2. ADAS reminds driver, 10 (y) seconds left
3. Inform driver when to take-over (countdown)
a. Seconds
b. Distance
4. Secondary tasks shut down at minimum needed take over time
Termination
- Driver takes motor control</td></tr>
<tr><td colspan="2">Alternative course:
- Driver takes control after first signal.
- If driver do not take control, the car brakes, maneuver to the side of the road and check for life signs.</td></tr>
<tr><td colspan="2">Post condition: Driver manually drives car in SAE level 3</td></tr>
<tr><td colspan="2">Exception(s):
- Technical failure prevents signals/ take over
- Driver does not notice signals
- Driver does not take over control within time frame</td></tr>
</table>

Figure A.4: Use case number 5 describes the process of retaking control of the vehicle during a planned take-over.

B

Concept-drawings

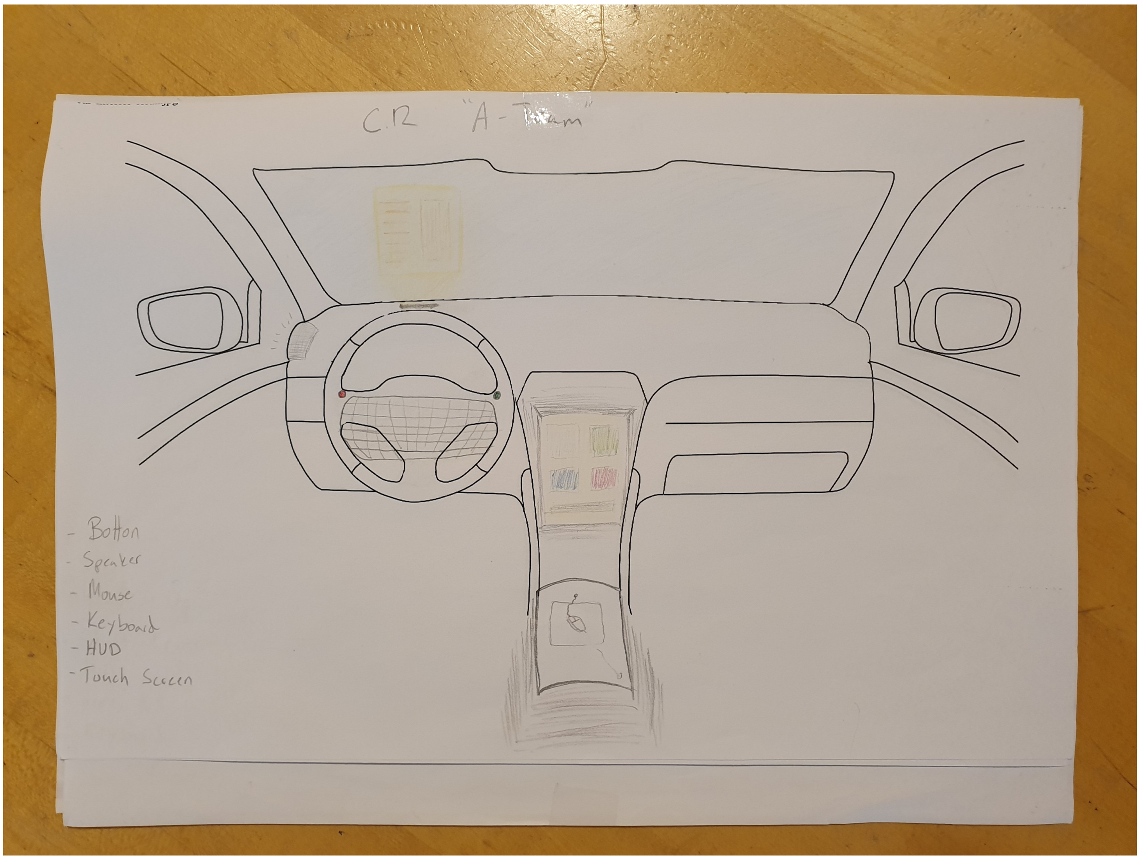


Figure B.1: Concept drawing of A-team

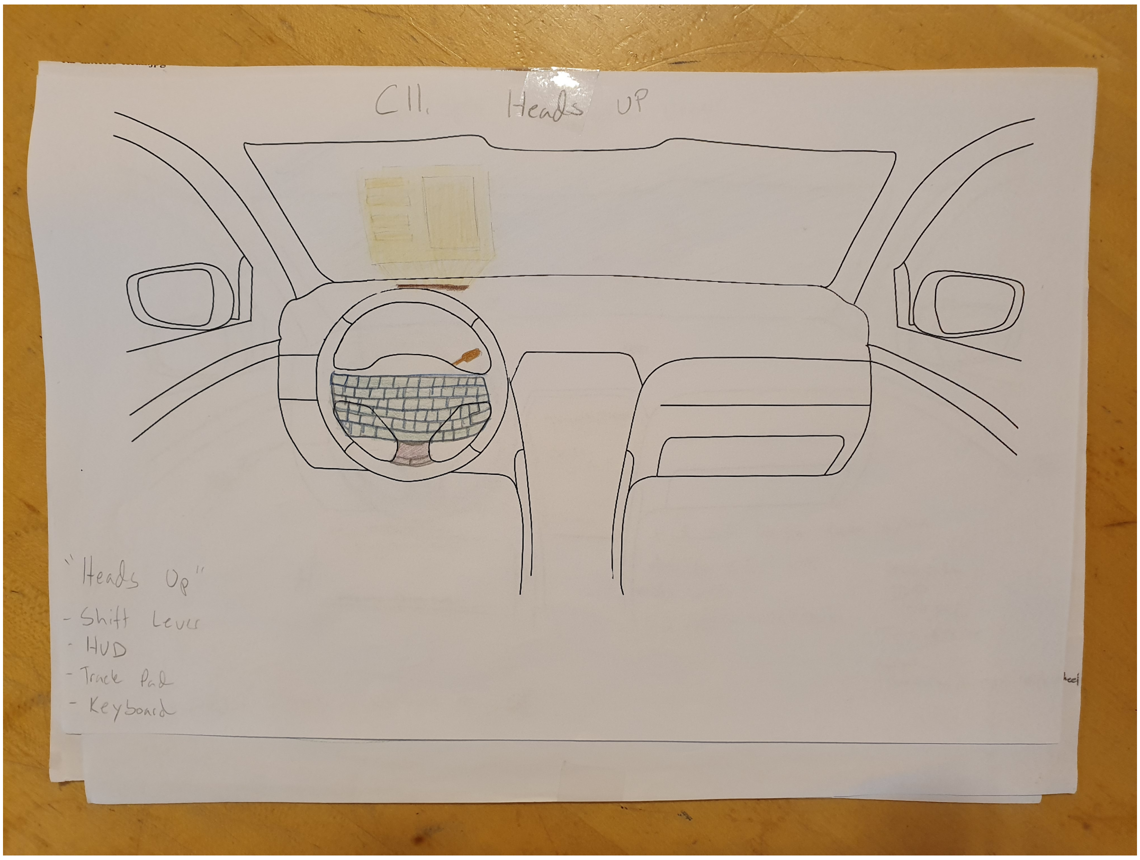


Figure B.2: Concept drawing of Heads Up

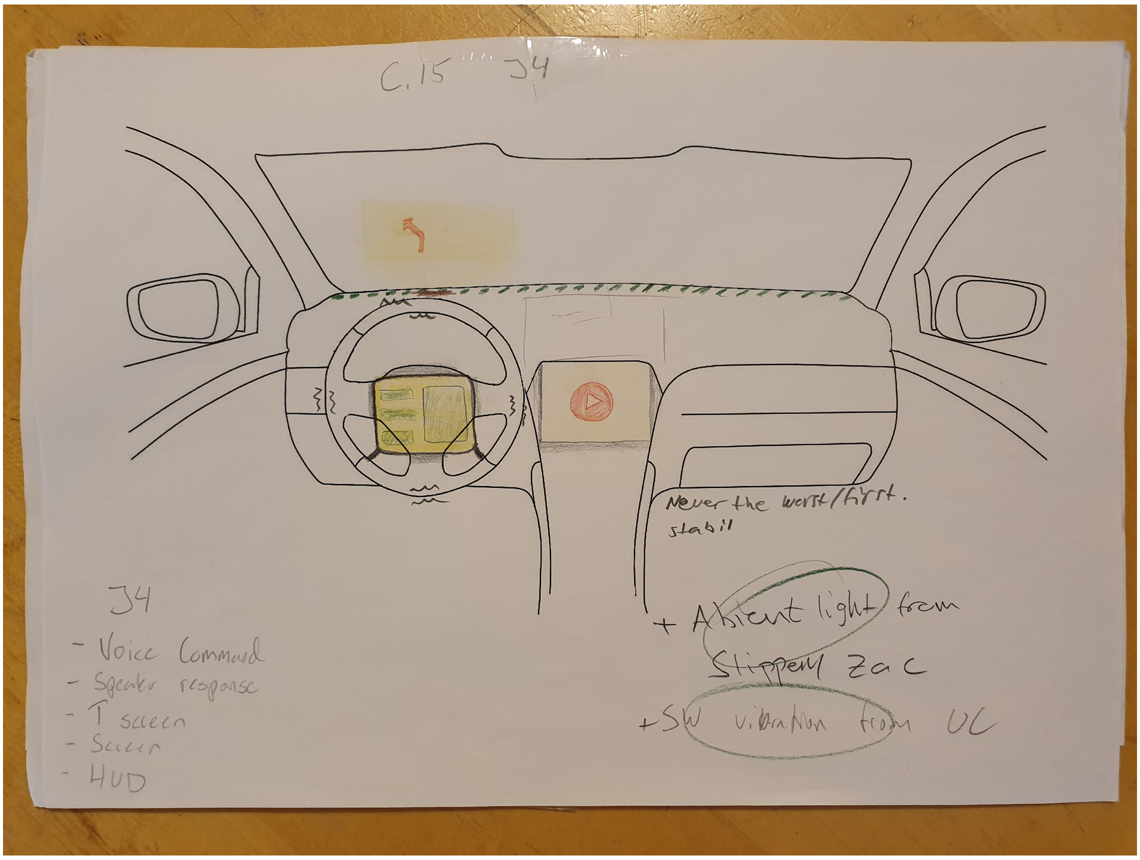


Figure B.3: Concept drawing of J4

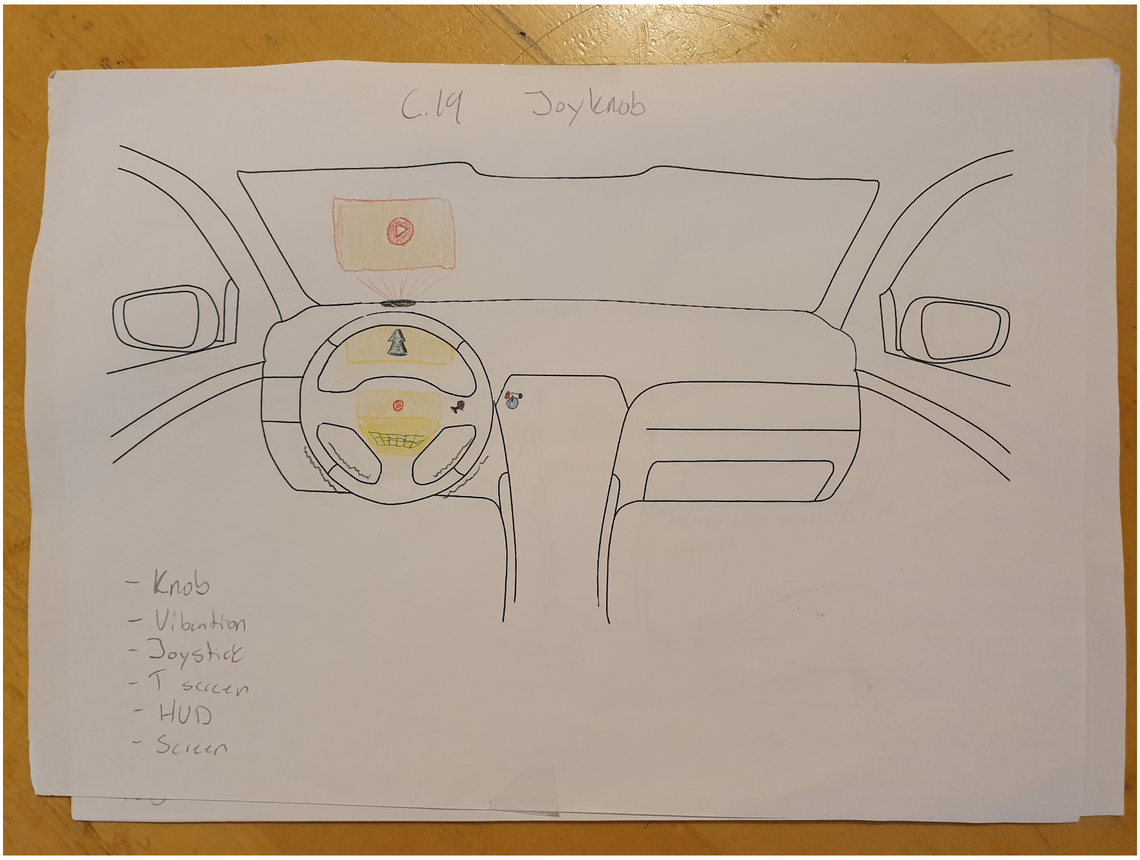


Figure B.4: Concept drawing of Joy Knob

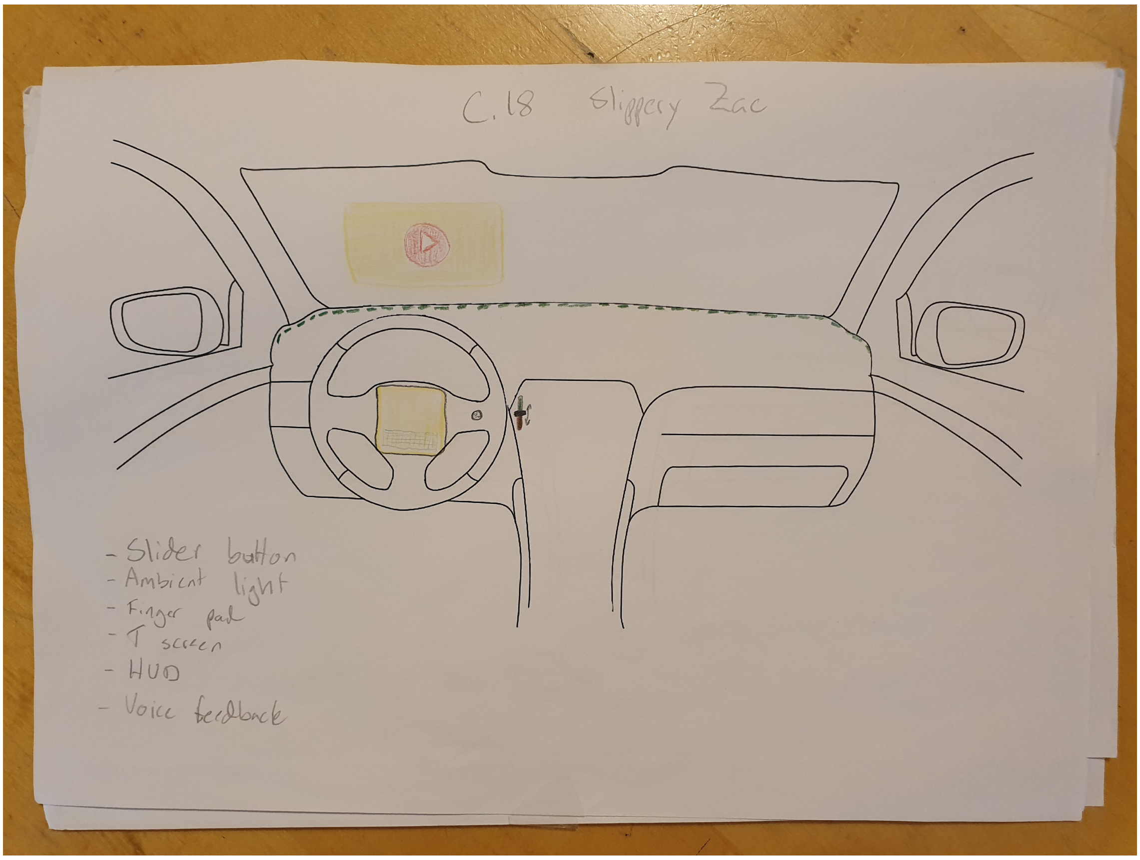


Figure B.5: Concept drawing of Slippery Zac

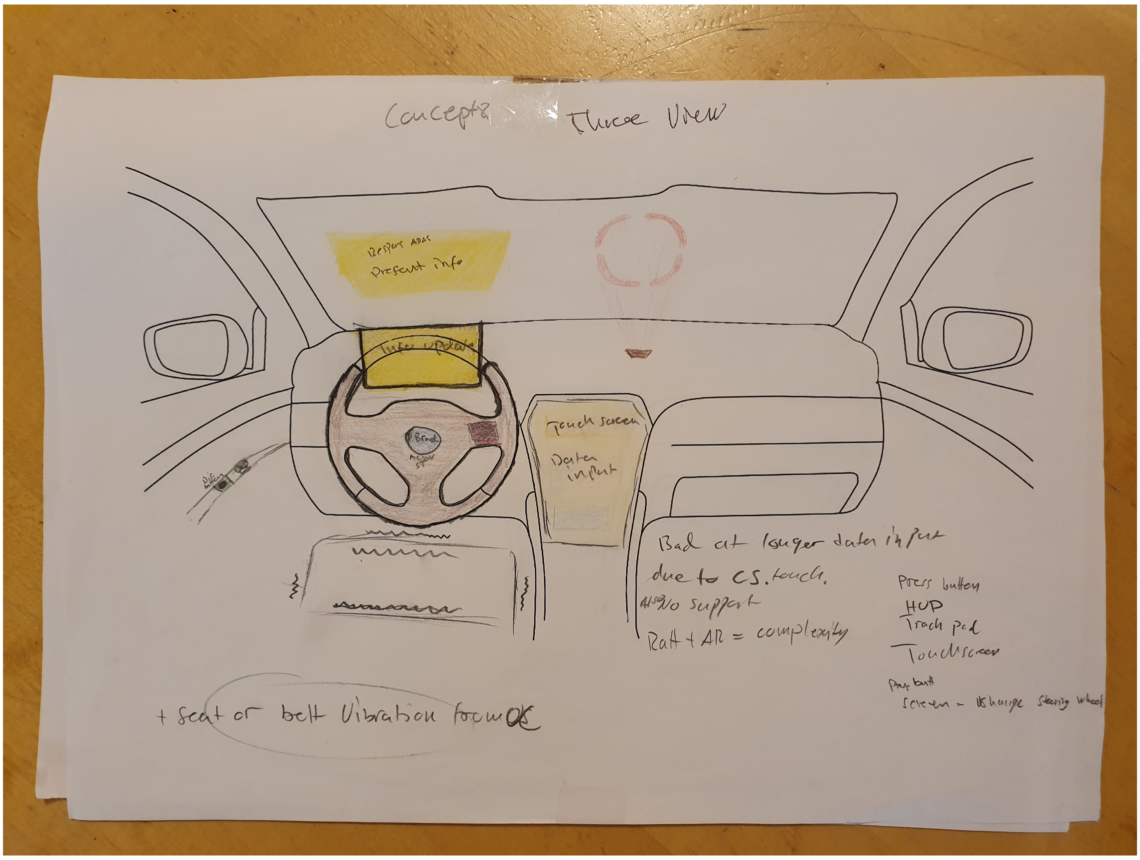


Figure B.6: Concept drawing of Three View

C

Simulation

C.1 Introduction to simulation

- Vi är här för att vi vill ha nya synpunkter och höra om din upplevelse, detta betyder att det inte finns några rätt eller fel, och vi vill att du är dig själv. Detta handlar om utföra olika uppgifter i en självkörande bil, och att sedan "ta över bilen", en så kallad "take over".
- Videon på TV'n kommer ge dig instruktioner om vilken uppgift du ska göra/när(Läsa/skriva på HUD, Läsa/skriva på mobil, eller slappna av).
- För HUD finns det ett tangentbord med touchpad på för interaktion.
- När du ska använda mobil så finns den i mittenfacket.
- När du inte har någon uppgift kan du bara luta dig tillbaka, och tänka att du är påväg till jobbet.
- Försöka att utföra dessa uppgifter så bra du kan, detta är inkluderat i att slappna av. Det finns inga restriktioner kring händer på ratt eller liknande, så du kan sitta så som är mest bekvämt, du kan ställa in sätet som du vill.
- Uppgifterna är skrivna på engelska men det är ok att svara på svenska. Svaren kommer inte att sparas och om det är någon fråga du ej förstår så kan du hoppa över den.
- Du "tar över bilen" genom att klicka på antingen höger eller vänster knapp på ratten, vilken knapp beror på det som kommer upp på skärmen. Om flest figurer är på höger sida så klickar du på höger knapp, och vise versa.
- När du klickar på knapparna kommer du ej att få något gensvar, du kan klicka på knapparna flera ggr.
- Du kommer nu få tre övningsuppgifter.

Figure C.1: Introduction for participants

C.2 Questionnaire

Drive experience

This survey aims to find out how your experience and impression was during the test.
This first part wants you to write down some general information about you.
The information in this survey will be anonymous.

*Obligatorisk

Age *

- ☐ 20-24
- ☐ 25-29
- ☐ 30-34
- ☐ 35-39
- ☐ 40-44
- ☐ 45-49
- ☐ 50+

Gender *

- ☐ Male
- ☐ Female
- ☐ Prefer not to say

For how long have you had a driver's license? *

- ☐ 1-5 years
- ☐ 6-10 years
- ☐ 11-15 years
- ☐ 15+ years

Figure C.2: Part 1 of Questionnaire

This part of the survey focus on the test it self, and want you to point out your feelings about it.
Try to recall back to how you felt during it.

I got fully engaged into the drive experience. *

- [ ] Strongly disagree
- [ ] Disagree
- [ ] Neutral
- [ ] Agree
- [ ] Strongly Agree

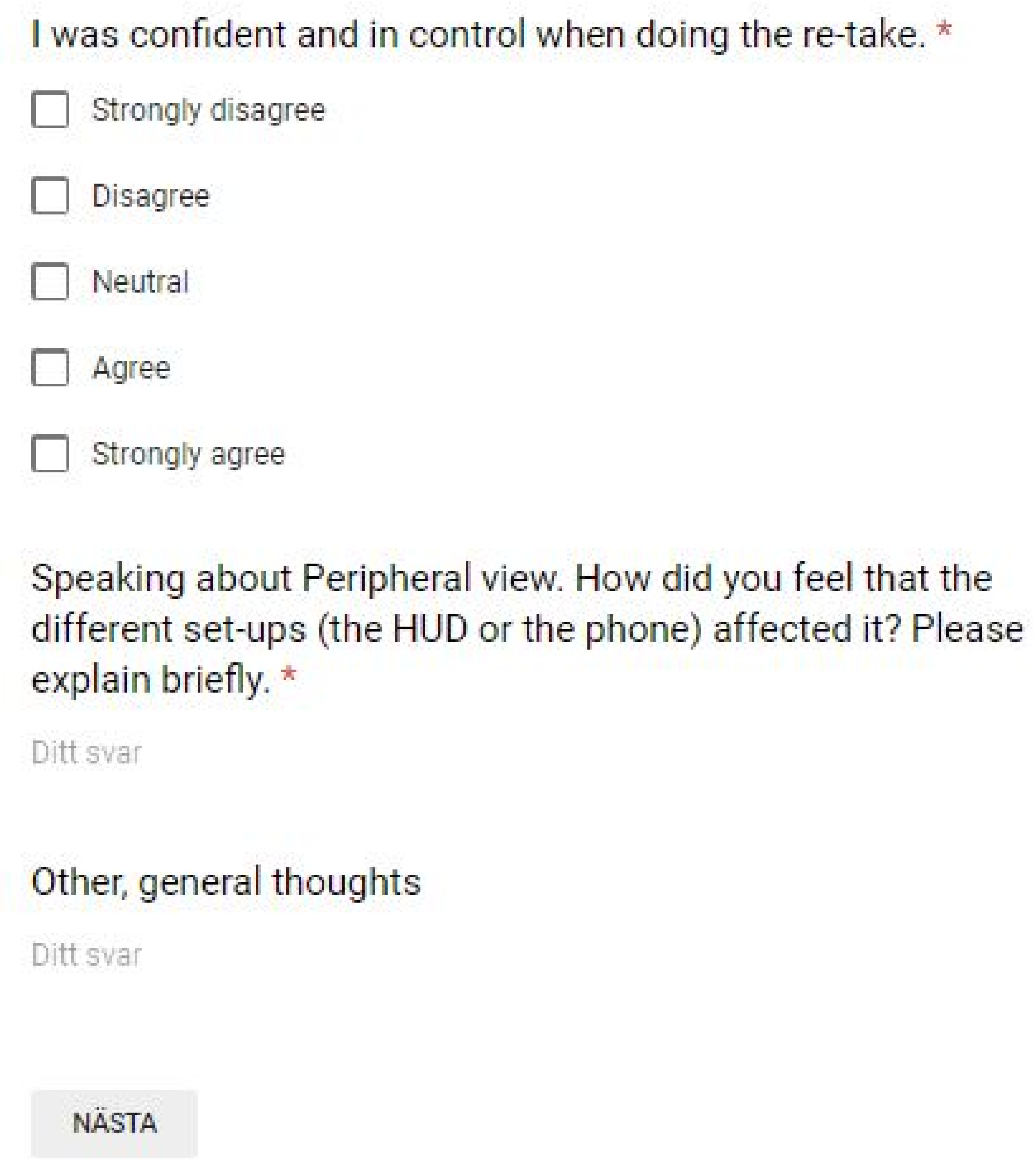
I felt the need of always being on my guard during during the test. *

- [ ] strongly disagree
- [ ] Disagree
- [ ] Neutral
- [ ] Agree
- [ ] Strongly Agree

The instructions during the test was understandable and gave the information I needed. *

- [ ] strongly disagree
- [ ] Disagree
- [ ] Neutral
- [ ] Agree
- [ ] Strongly Agree

Figure C.3: Part 2 of Questionnaire



I was confident and in control when doing the re-take. *

- [ ] Strongly disagree
- [ ] Disagree
- [ ] Neutral
- [ ] Agree
- [ ] Strongly agree

Speaking about Peripheral view. How did you feel that the different set-ups (the HUD or the phone) affected it? Please explain briefly. *

Ditt svar

Other, general thoughts

Ditt svar

NÄSTA

Figure C.4: Part 3 of Questionnaire

The last section of this survey wants you to use the point scale to answer some short questions.
The questions focus on the experience you had when you used the HUD+Keyboard setup and the phone setup, as well as when you solved the re-take task.

Mental Demand - How much mental activity did you spend when...? *

	Little	2	3	4	Much 5
Using HUD+Keyboard	○	○	○	○	○
Using the phone	○	○	○	○	○
Solving the re-take task	○	○	○	○	○

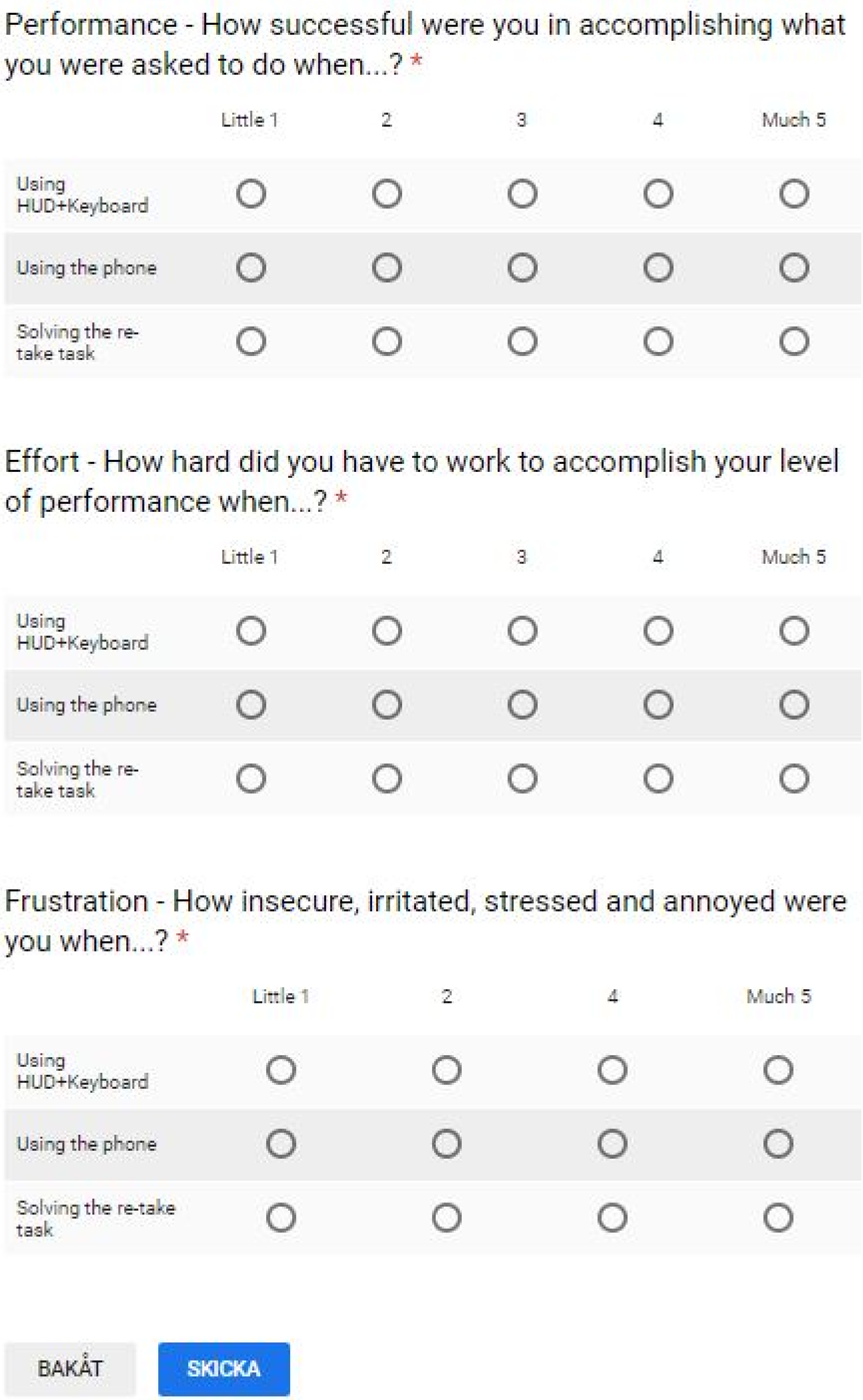
Physical Demand - How ergonomically pleasing was the setup when...? *

	Low 1	2	3	4	High 5
Using HUD+Keyboard	○	○	○	○	○
Using the phone	○	○	○	○	○
Solving the re-take task	○	○	○	○	○

Temporal Demand - How hurried or rushed did you feel when...? *

	Little 1	2	3	4	Much 5
Using HUD+Keyboard	○	○	○	○	○
Using the phone	○	○	○	○	○
Solving the re-take task	○	○	○	○	○

Figure C.5: Part 4 of Questionnaire



Performance - How successful were you in accomplishing what you were asked to do when...? *

	Little 1	2	3	4	Much 5
Using HUD+Keyboard	○	○	○	○	○
Using the phone	○	○	○	○	○
Solving the re-take task	○	○	○	○	○

Effort - How hard did you have to work to accomplish your level of performance when...? *

	Little 1	2	3	4	Much 5
Using HUD+Keyboard	○	○	○	○	○
Using the phone	○	○	○	○	○
Solving the re-take task	○	○	○	○	○

Frustration - How insecure, irritated, stressed and annoyed were you when...? *

	Little 1	2	4	Much 5
Using HUD+Keyboard	○	○	○	○
Using the phone	○	○	○	○
Solving the re-take task	○	○	○	○

BAKÅT SKICKA

Figure C.6: Part 5 of Questionnaire

D

Raw data simulation

Numbers in milli seconds
Outlier marked in orange

#	Gender	Age	Video	Order of ToR	Time HUD	Time Cellphone	Time Passive	Pas -> HUD	Pas -> Cell	HUD -> Cell
1	M	40+	1	H-C-P	2754	3617	3404	-650	213	863
2	M	40	1	H-C-P	2916	3676	3095	-179	581	760
3	*M*	*35-*	*2*	*C-P-H*	*5338*	*4363*	*3328*	*2010*	*1035*	*760*
4	F	35-	3	P-H-C	2437	3082	1927	510	1155	645
5	M	35-	2	C-P-H	3018	2965	3558	-540	-593	-53
6	M	35-	3	P-H-C	3257	3259	3585	-328	-326	2
7	M	40+	1	H-C-P	4151	4009	5201	-1050	-1192	-142
8	F	35-	2	C-P-H	3476	3350	3522	-46	-172	-126
9	M	35-	2	C-P-H	3123	3051	2584	539	467	-72
10	F	35-	3	P-H-C	3241	3487	3015	226	472	246
11	M	40+	3	P-H-C	3413	3942	4078	-665	-136	529
12	F	40+	1	H-C-P	2988	3103	3192	-204	-89	115
13	F	40+	2	C-P-H	3235	4637	3110	125	1527	1402
14	M	35-	3	P-H-C	2776	3400	2822	-46	578	624
15	M	40+	1	H-C-P	4554	4802	5875	-1321	-1073	248

Figure D.1: Raw data from the simulation

E
Age difference graphs

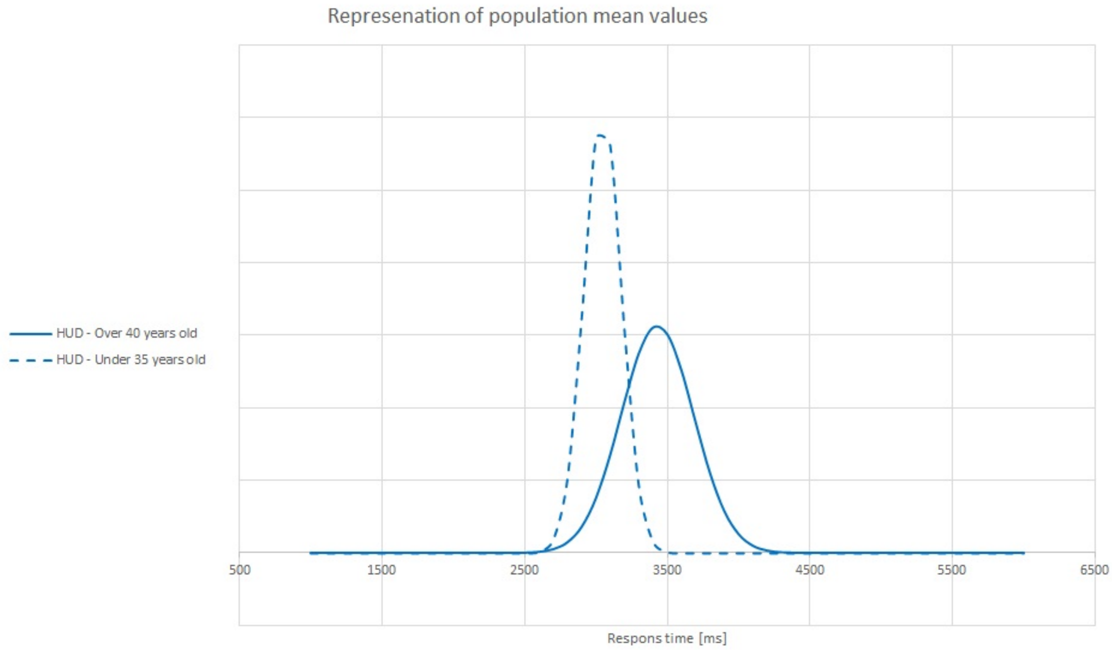


Figure E.1: Raw data from the simulation

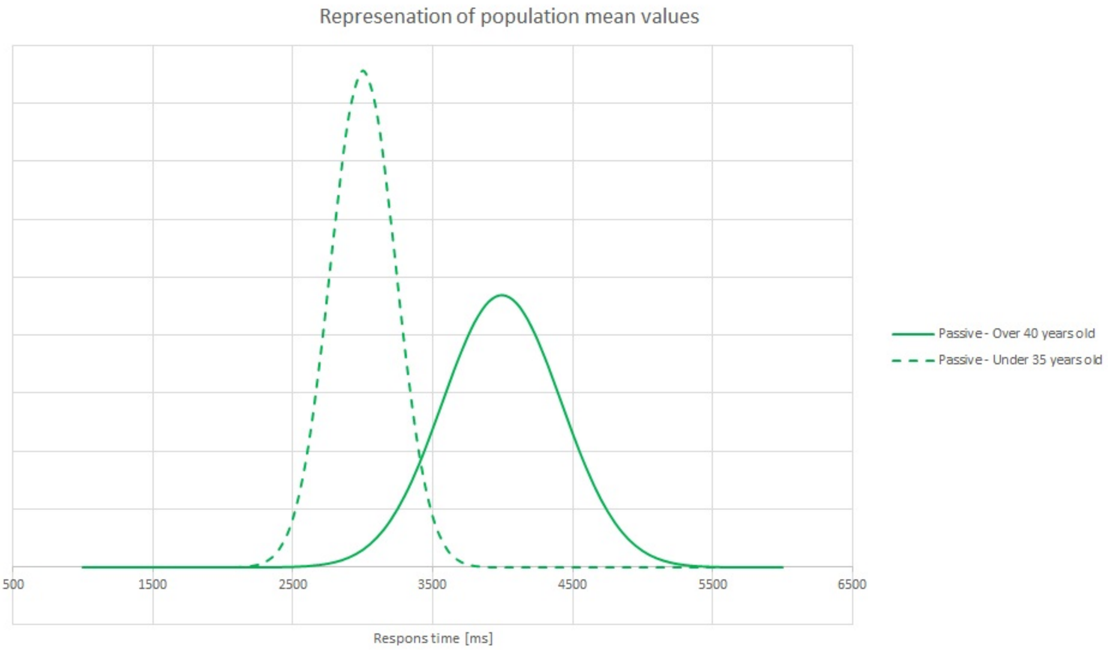


Figure E.2: Raw data from the simulation

F

Result questionnaire

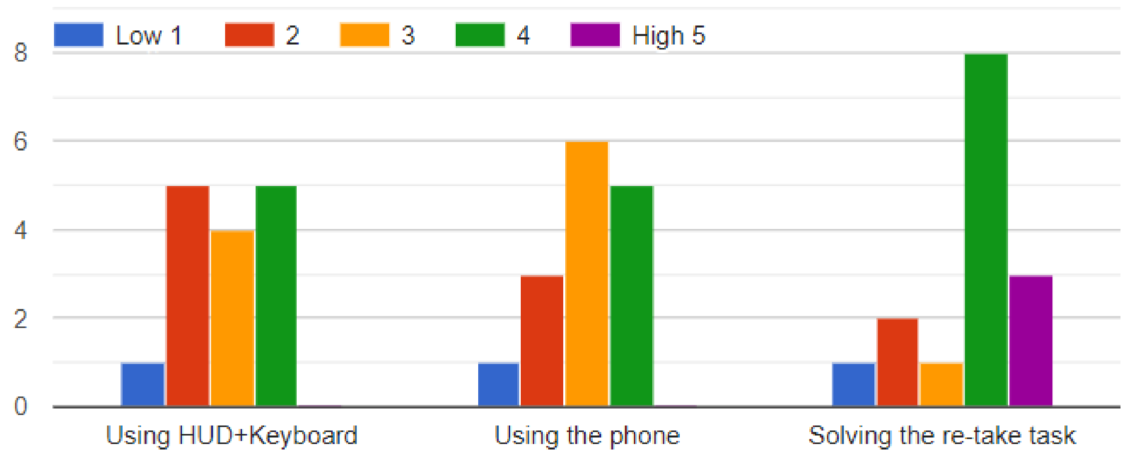


Figure F.1: The figure displays the perceived physical demand caused by the setups.

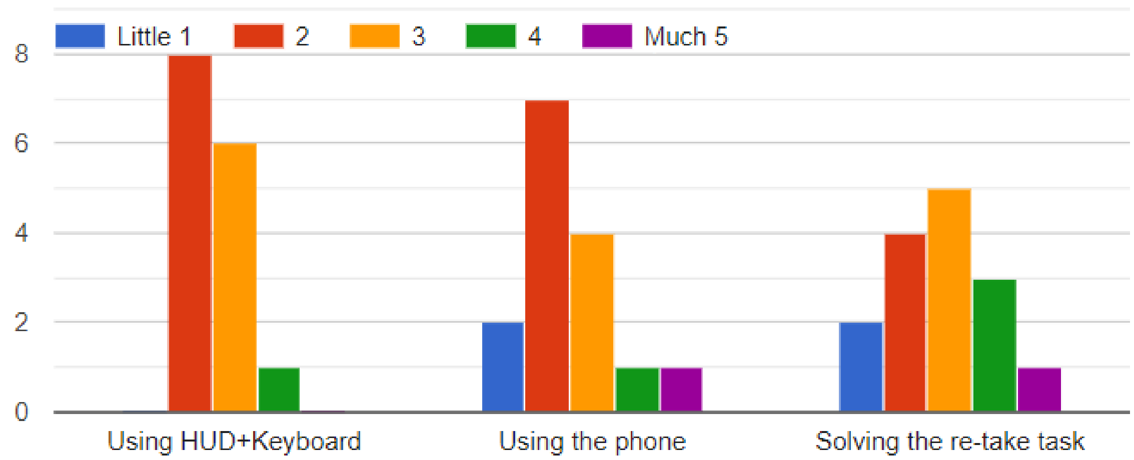


Figure F.2: The figure displays the result of the temporal demands affecting during the simulation.

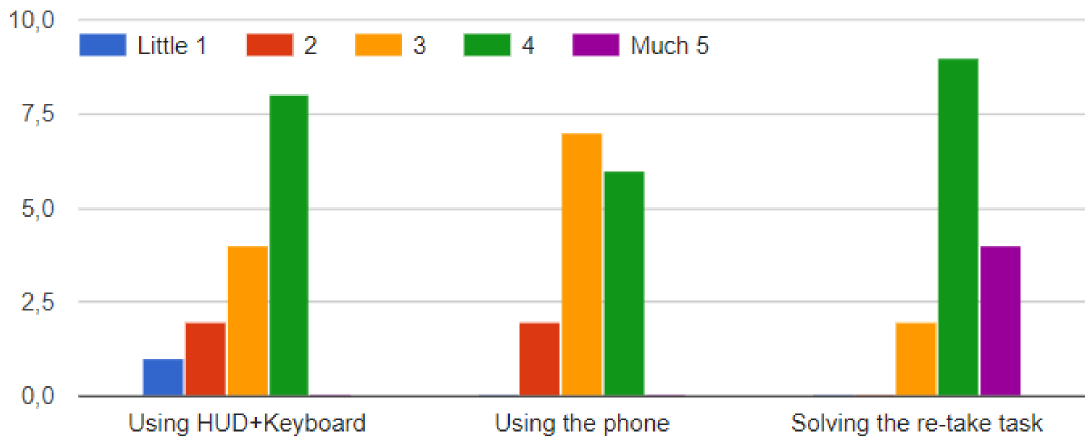


Figure F.3: The figure displays the felt level of performance of conducting the different tasks during the simulation.

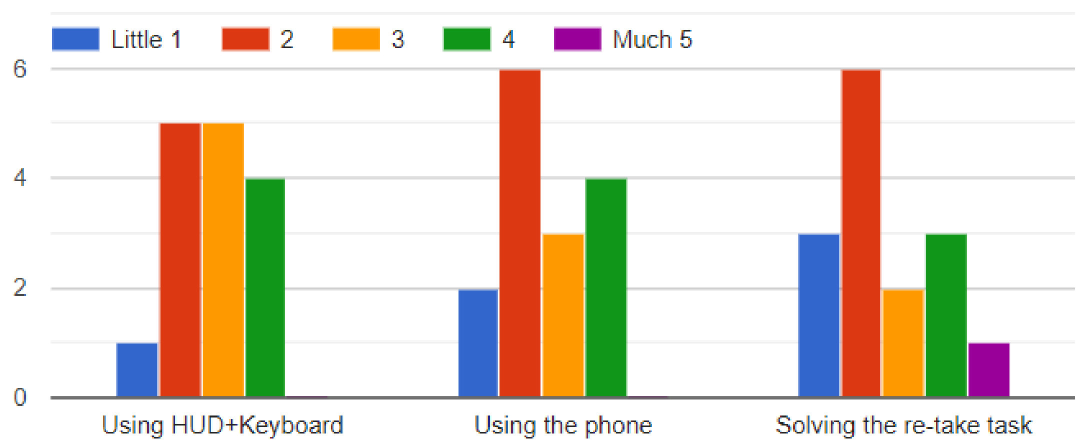


Figure F.4: The figure displays the level of effort needed to commit in order to achieve the task at hand.

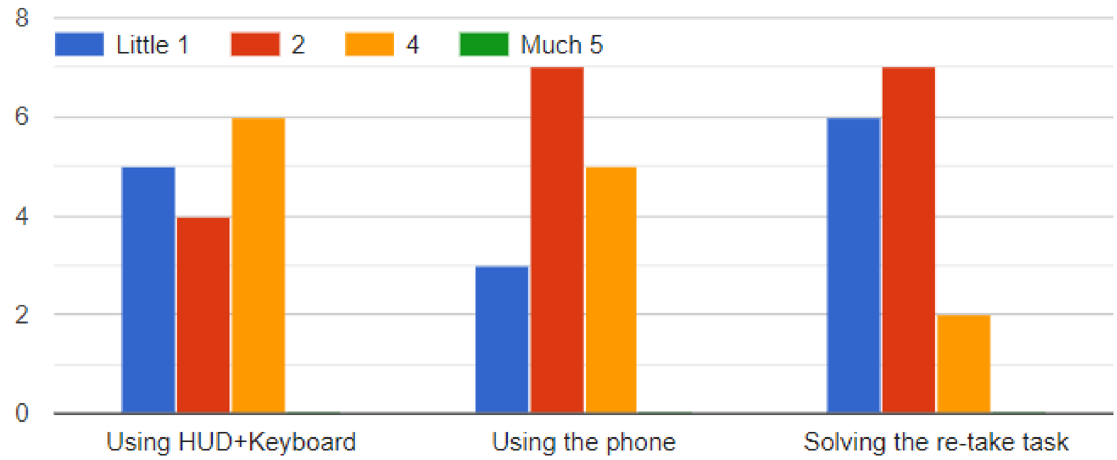


Figure F.5: The figure displays the level of frustration that occurred when using the different setups.