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SteerPad

Development and Evaluation of a Touchpad in the Steering Wheel from a User Experience Perspective

Master's Thesis in Interaction Design & Technologies

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Chalmers University of Technology
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Abstract

Driver safety has since the birth of automobiles been paramount. In a time when technologies are changing the way people interact with the outside world, the vehicle industries need to keep up with these changes in terms of both safety and user experience. When trying to assess this complication, some of these technologies have been integrated into the cars, thus leading to more distractions while driving. This thesis describes this dilemma as the gap between automobile safety and in-vehicle infotainment. By the use of a touchpad installed on the right hand side of the steering wheel, the thesis has developed and evaluated a prototype interface that is located in the vehicles dashboard display with goals to lower *driver distraction*. This touchpad is developed with three main sources of interaction; *swipes*, *tactile interaction* and *character recognition*. By merging and combining these sources the thesis has successfully developed a test prototype to be used for evaluation. The prototype was tested against an already existing *in-vehicle information system* where a number of use cases and scenarios were used to test the systems in terms of usability and user experience. Guidelines on safety regulations set by NHTSA have been studied and applied to the projects development and user studies. Test results indicate that this technology has the potential to lower the driver distraction while still maintaining a high level of usability and user experience. Finally the thesis presents a number of suggestions and ideas in reference to further development and studies.

Acknowledgements

We would like to thank our supervisor at Chalmers University, Fang Chen for support and great insights, as well as our opponents David Eriksson and Martin Ohls for their valuable time and input. Further we wish to thank the supervisor at Volvo Car Corporation, Samuel Palm who has guided us through this project with much needed experience and reflections, this also goes to Patrik Palo. This thesis would never have been possible without the initiation from Claes Edgren, who has helped a great deal during the project. Big thanks to Reetta Hallila for helping us during the user studies and lab-predicaments. Another thanks to all the participants that attended our user tests, for lending us your eyes. Last, but not least, the thesis members wish to extend gratitude to our friends and families that have supported and bore with us during this thesis.

Daniel Gunnarsson & Viktor Swantesson, Gothenburg June 11, 2014

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Introduction

TODAY'S CARS ARE CENTERED ON THE DRIVER, the main user of this large and complex mechanical- and digital driving system. Understanding the needs and behaviors of the user is naturally of utmost importance. One of these needs, and arguably the paramount one is safety. Of course the main task of any vehicle is to transport someone (or something) from location A to location B, however when this task is fully provided the next layer is to ensure that the vehicle can do the first task while maintaining and ensuring safety.

The industry is developing, and cars are getting smarter and smarter by the hour. Multi-faceted sets of sensors are placed in every unthinkable location on the car that enable; crash avoidance, car to car communication, pedestrian protection, etc. [1]. The conception that the 'vehicle assists the driver' on the road, is slowly but surely turning into the 'driver assists the vehicle' to drive. Questions are asked regarding how much non-driving related functionality should be given to the driver.

Safety can, for the ease of explanation for this thesis, be divided into two categories; feeling safe, and actually being safe. The thesis will in its way tackle both angles of this paradox. The notion of trust is also a very crucial factor and should be carefully dealt with, to assure that the driver is at ease.

This thesis has inquired in the intriguing gap that exists between automobile safety and in-vehicle infotainment, and has sought knowledge to decrease this gap by developing and testing a prototype for the automobile manufacturer Volvo Car Corporation. With a touchpad that can be installed onto the right side of the steering wheel was delivered from one of Volvo's sub-suppliers. This thesis was given the means to study, design and develop an environment that assesses this gap. From studying the field and interacting with the hardware, a research question took form:

> *How can a touchpad that is integrated in the steering wheel that controls the DIM functionality, fulfil the requirements from the regulations de-*

> *fined by NHTSA for safety issues, while also providing a positive user experience?*

This question will be explained and discussed in detail in this report. By implementing and operating this new piece of hardware, the thesis has developed a new driver-to-car interface with a befitting structure of interactions. As today's car industry does not offer touchpad based interactions in the steering wheel, specifically that controls the DIM, it was of great importance to test and study whether or not this system could potentially lead to a safer and more enjoyable driving experience.

2

Background

As it is today, the Dashboard Instrument Module (DIM) and the Head Up Display (HUD, a projected image on the windshield) systems of Volvo Cars are being controlled by a set of mechanical buttons (the S/W-buttons) on the right hand side of the steering wheel. The interaction with the Center Stack Display (CSD) is however already controlled by touch screen technologies (see fig. 2.1).

Figure 2.1: Center Stack Display (CSD) implemented with the Scalable Product Architecture (SPA) (source: https://www.media.volvocars.com)

This technology is one of the building blocks of the new *Scalable Product Architecture* (SPA) [1] that will be described later in this report. Different ways of operating the systems creates what the thesis calls a *linguistic barrier*, which limits the understanding of the system for the user. This linguistic barrier is meant to describe the different ways of interacting with a touch based CSD and its flawed partnership with the interaction that the tangible steering wheel buttons are operated by. A supplier to Volvo, ALPS Electric, has recently presented a concept in which they have integrated a touchpad which has replaced the old mechanical buttons on the steering wheel that potentially could control the DIM and HUD. This touchpad has the ability to recognize patterns, characters, and symbols that are entered into it. This pattern recognition could be used for e.g. quick commands and writing shorter phrases and/or names. To stay in the forefront of the design and development of in-vehicle interaction Volvo wants to explore the possibilities and potential that arises with this technology. Both in the aspect of improving the user experience while driving and satisfying the new traffic safety regulations from National Highway Traffic Safety Administration (NHTSA) [2].

2.1 Volvo's Vision

One of Volvo Cars expressed goals is to develop the brand and the cars to have a more *premium* status. Premium in this context is the notion that the feel of a Volvo car should be more elegant and modern than other competing car brands. One might argue that the implementation of touch technologies into the driver-to-car interaction is a great step towards that direction. An example of another brand in the automobile business that has expressed and is undergoing such a transformation is Audi AG. The Audi group sets the goal to become the leading brand in the premium car segment worldwide which was disclosed in 2010 [3].

2.2 Linguistic Barrier

Up until recently, most of the interaction in the car has been operated by mechanical buttons and switches. Examples of these are: air condition buttons, flashers, Cruise Control, seat heating, volume control etc. These tangible objects often have 1:1-mapped functionality, which means that they control one or several parameters of the car. With the introduction of a touch based CSD, many of these controls gets boiled down into one big touch screen (see fig 2.2).

An obvious complication arrives with having different ways of interaction in between the CSD and the DIM, which currently is controlled by a set of tangible buttons on the steering wheel. To remove this complication, which the thesis call linguistic barrier, has also become a goal expressed by the supervisors at Volvo. By installing and developing touch interaction that controls the DIM, Volvo hopes to create a more fluent and easy-to-learn system between the two systems and therefore create a more secure and enjoyable driving experience.

(a) The mechanical Center Stack. **(b)** The touch based Center Stack.

Figure 2.2: The linguistic barrier between the old and new center stacks. (source: https://www.media.volvocars.com/)

2.3 S/W-buttons

The current set of mechanical buttons on the steering wheel, otherwise known as the S/W-buttons (Steering Wheel-buttons), allows the driver to interact with the DIM (see fig. 2.3). Functions that map well with these are; car information displaying, simple telephone functionalities, and music controls (volume, next/previous track). This thesis finds that the main setback with these buttons is the inability to fluently administer bigger lists and interface hierarchies. If a better and more suitable way of interaction is found, which this thesis will research, it should be interesting to consider further functionalities that may be integrated in the DIM system.

Figure 2.3: Mechanical buttons on the steering wheel. (source: https://www.media.volvocars.com/)

2.4 The Delivered Hardware

The hardware that the thesis used during this project was delivered by ALPS Electric. This hardware's architecture was built based on three different components; touchpad, E-box, and a Raspberry. Signals are sent from the touchpad to the E-box which interprets where the touches are. These signals are then sent to a Raspberry Pi-component which in turn sends it via WiFi to a receiver. The receiver in this case is the computer where the system was built. The hardware had the following communication layout (see fig. 2.4).

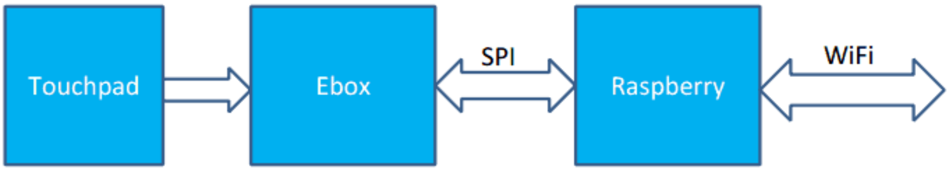


Figure 2.4: The communication layout of the hardware.

Raspberry Pi is a small computer which has an ARM1176JZF-S 700 MHz processor, VideoCore IV GPU, and 256 megabytes of RAM. It has a slot for SD-card to store data because it does not have a built-in hard disk. On a Raspberry it is possible to surf on the Internet and send emails just as any other computer. The Raspberry is an excellent tool for getting to know how computers work and is often used in schools to make younger people interested in computing [4]. The Raspberry Pi that the thesis has in possession is already installed with the necessary systems to interpret the signals sent from the E-box. These systems are designed and implemented by ALPS Electric. The hardware has the ability to interpret characters that are being entered on the touchpad. The character library of the delivered hardware can only interpret one character at a time, meaning that the hardware cannot interpret if multiple characters are sequentially entered. ALPS Electric has however stated that a character library that can interpret multiple characters in sequence is however available.

2.5 Similar products and projects

There are examples of other manufacturers that have moved towards touch-based interaction in the vehicle. Audi, for instance, has already introduced a touchpad in their in-vehicle systems, as a complement to the rotary push-button [5]. Mercedes has also begun to introduce a touchpad in their vehicles to control the infotainment unit [6]. Many studies have been made on in-vehicle interactions with both voice and touch interactions. The voice interaction is however still in its cradle stage, and has been said to be unfriendly and awkward to use [5] (see fig. 2.5). Touch interactions have however been studied with many variations of feedback; audio, haptic etc., and have been well received by users and safety statistics. This implies that there are great possibilities with

Figure 2.5: Audi's Rotary Push Button next to the gear shift. (source: http://www.audi.co.uk/)

implementing touch functionality into the automobile to further improve driving and user experience. In a time when the need for meeting the goals of NHTSA regulations is required, it is an interesting approach to try to make this technology well functional with Volvo's current systems and standards. With the potential value of this technology, Volvo could be able to take a great leap forward in the area of interacting with the car's infotainment systems. This while both enhancing the user experience and lowering the driver distraction, thus making the driving experience more enjoyable and safe.

2.6 The Thesis members

As interaction designers, the interest lie in how the User Experience can be enhanced in a large and complex user interface that is the car. Design and development for in-automobile interaction is an explored field, but with this new addition the team felt engaged to take on the study. Being able to perform thorough user tests is also a factor for the interaction designer, which Volvo Cars certainly facilitates with different labs and simulators. The thesis members also found the proposal and topic quite compelling towards their own personal interests. This is due to a background that is heavily connected with design of touch screen interactions and gestures, with the addition of developing user interface design.

2.7 NHTSA regulations

There are a number of regulations that has to be followed when creating car systems, one of the strictest however comes from the National Highway Traffic Safety Administration

(NHTSA). These regulations are harder than most (e.g. European regulations) and are the ones that Volvo is aiming to meet. NHTSA have released recommended guidelines that concern Visual-Manual Driver Distraction [7]. On these grounds this thesis will work under the guidelines as strict standards during development, testing and evaluation. NHTSA states that the guidelines are directly applicable onto in-car electronic devices that are used to perform non-driving-related tasks, as well as driving-related tasks. Some of the many tasks are: Incoming call management, text-based communications, video, social media interaction, cruise control and destination entry. Two main areas of practice headline the guidelines, one of which is *Device interface recommendations*, that comprises written recommendations that aid in how to develop and implement electronic devices in the car. The other area is *testing*, that lay the rules for successful testing by informing about exact data that need to be satisfied. Apart from learning and facilitating the guidelines that NHTSA proposes, the thesis has also used NHTSA:s database as a great source for theoretical studies.

2.8 Time Plan

The planned time plan for the thesis worked well, even though two major delay factors were present. The first factor was the hardware which arrived late, and when having arrived was installed with the wrong software. A quite suitable solution to the delay was to engage in interaction design while waiting and solving the malfunctions. Considering the thesis was already familiar with the hardware when testing it at the sub-supplier this went smoothly.

The second delay factor was that it deemed very hard to book the HMI-lab for testing, this belated the planned tests with several weeks. However, the thesis solved this by putting more focus on the development and writing the report while waiting for the user tests.

Apart from these minor hiccups the work process was smooth with a considerable amount of help and guidance from supervisors and department managers.

2.9 Delimitations

In the initial stage of the thesis project, plans were made to include the HUD into the prototype. That would mean that two displays would be used for the interface, which would give a further depth to the interaction design and possibilities. Two of the main areas that would benefit from the use of a display that is closer to the road are safety and feedback, two of which somewhat go hand in hand. Safety could be heightened with glances that are much closer to the road, and thereby make the prototype stronger in the evaluation. Feedback could be utilized in a fascinating manner, where the interface would display the most important information closer to the road. However, it would bring about a considerable amount of development work, and the thesis together with the supervisors at Volvo decided that the work should be limited to DIM interaction.

Also worth noting is that the laboratory that the tests were conducted in does not provide a HUD display.

One limitation that the thesis set was to keep the number of applications and functions low during the development, as the thesis was given a rather small physical touch area to work with. If too many applications had been implemented into the system, the user experience and safety could be compromised.

Regarding the functionalities in the interface, it was obvious that the structure would not be fully functional. This would need a massive part in the development phase, along with studies on how the current Volvo system communicates between elements. Additionally, the aesthetic design of the interface's different parts was not planned to be fully developed.

A very interesting area that is currently being explored in the automobile industry is voice recognition [8]. This thesis however decided to not include it into the work equation, arguments for this decision are quite straightforward when conceiving the amount of work that it would require.

Furthermore the prototype will not support multi touch input. While this is currently a possible way of interacting with touchpad technologies, and Volvo's sub-supplier ALPS Electric did state that one could be delivered, the usage of multi-touch could be seen as unnecessary and complicated. Using more than one finger while interacting with a touchpad that is located on the steering wheel might also debatably be something that is not feasible in terms of safety.

3

Research Question

Having embraced the initial scope that this field of research presents, the thesis advanced by studying the field further. The thesis deemed to reach a suitable research question that at the same time as being relevant, also could be answered with the time and resources that the thesis possessed.

Considering the background, with Volvo's wishes and the thesis preferences and qualifications, the following research question was created for the thesis:

> *How can a touchpad that is integrated in the steering wheel that controls the DIM functionality, fulfil the requirements from the regulations defined by NHTSA for safety issues, while also providing a positive user experience?*

The research question can be decomposed into three parts:

1. Can a touchpad enhance the usability and user experience of an in-vehicle infotainment system?
   - Meaning that to research whether the time of completion of tasks could be lowered or in some way improved, and also if the satisfaction from the user is heightened.
2. Will a touchpad integrated in the steering wheel decrease the so called linguistic barrier between the current infotainment systems, while also meeting the requirements from the regulations?
   - Because DIM and CSD would now both be controlled by touch based interaction, an understanding on how to control the systems and their architectures in concert is vital.

3. And finally what kind of potential can a touchpad bring to today's car system?
    - Potential in this sense means that this could be something worth investigating further and invest in for Volvo.

With this research question the thesis was determined to deliver a prototype that is functional enough to test the safety and potential of the hardware. To reach this goal, there were however a number of questions and problems that needed to be assessed. Questions that had to be answered and explored were:

- Will the prototype in any way improve or impair the current system, regarding both the user experience and the usability?
- Is this technology something that users find interesting and enjoyable to use?
- Is pattern recognition a feasible technology in vehicles, in a safety and user-friendliness aspect?
- Is the shipped pattern recognition library sufficient or fallible?

A set of meticulous functions and commands has to be implemented to the technology that needs coherence with the planned usage of the CSD. These functions should for instance improve the time of completion that a task has, in order to meet the regulations, and hopefully improve the enjoyment level of the driving experience. The thesis plans to deliver a prototype that fulfills the requirements from Volvo and those that are elicited from current regulations. Furthermore, a study regarding the technology's possibilities and potential weaknesses with the pattern recognition will be conducted with evaluations from field studies where users will test the prototype.

The thesis will offer the thesis members a unique chance to get a deeper understanding and insight of working as an interaction designer in a project, while also being able to test and verify their knowledge that they have learnt during the master programme period. As the project is versatile, with many different components and steps that need to be thoroughly planned and executed, the members will be challenged with problems from both an interaction and a development point of view.

Since this technology has not yet been implemented in the steering wheel it is of great importance to test what it could or should control. The technology could potentially lower the driver distraction and heighten the user experience, thus leading to a safer and more enjoyable driving experience. If not tested properly before put into production, it could lead to devastating problems for the driver. As the technology has pattern recognition implemented in such a small touch area, it is also important to test how the implementation of the system is received. This in order to see where and if to have certain functions installed, whereby which functions should be reachable and sought after for the driver while not compromising the safety of the driving.

4

Theory

THIS CHAPTER WILL PRESENT a number of relevant and interesting articles which were important for the thesis and/or helped the thesis group to create a prototype that is at the forefront of today's technology. Since the thesis work covers a lot of different areas and technologies this chapter has been divided into four different theory parts; *In-vehicle Interaction, Touchpad and Screen Interaction, In-vehicle Touchpad Interaction* and finally *Interaction Design.*

4.1 In-Vehicle Interaction

In-vehicle interaction is a quite explored area that was of great importance in this thesis. The following sub chapters describe the related theory towards this field that the thesis will cover.

4.1.1 Driver Distractions in Vehicles

One of the main issues that are associated with vehicle system interaction is *driver distraction* (see fig. 4.1). The US-EU Bilateral ITS Technical Task Force [9] arrived at a general definition:

> *"Driver distraction is the diversion of attention from activities critical for safe driving to a competing activity."*

Activities critical for safe driving refers to activities that "allow the driver to avoid or not cause a crash", examples of these are: looking for other vehicles, checking traffic lights, etc. *Competing Activity* on the other hand refers to "driver engagement in distraction tasks". These tasks involve both objects inside and outside of the vehicle, and are defined not to be critical for safe driving. Another interesting question that the Task Force [9]

Figure 4.1: Driver distraction (source: http://www.sootoday.com/)

pointed out was whether or not distraction is a binary or continuous phenomenon. This should be interpreted as if distractions while driving should be viewed as an "all-or-none" diversion of attention, or if the attention is distributed by the degree of driving demand and other characteristics. Nevertheless, driver distraction was an important element to consider during the thesis.

4.1.2 In-Vehicle Information Systems

In-vehicle information systems (IVIS), has become a popular way of presenting data such as vehicle position from satellites and other on-board computed information. Gkikas [10] states that the IVIS concept has emerged from the use of cellular data in mobile phones, and the realization that cellular networks grant transmissions beyond only telephone calls. Stevens et. al. [11] presents guidance toward creating safer IVIS with higher usability. The guidance focuses on driver access and use of information, by reviewing information presentation and interface design. Lee and Strayer [12] do however point out that a complex picture of driving risk emerges, that is when systems that are easier to use and with shorter task-completion times are facilitated, they are also used in greater frequency and longer time spans. An apparent consequence of this is that the driver might spend much more time with the system, even more so than with a poorly designed one, this might be referred to as the usability paradox. This aspect might prove to be a major headache for IVIS-designers and developers for years to come, and will be a determinant for decisions made in this thesis.

Gkikas [10] reports that, with IVIS and other technological distractions a complex notion of driving risk emerges, yet some of these complications are uncovered with the evidence found. Under many circumstances, drivers seem to think they have the spare mental capacity to preoccupy themselves in driving-unrelated tasks. Technology is also creating opportunities for drivers to immerse in tertiary tasks with an escalated complexity, and tests show that more often than not, drivers will take these opportunities when given the chance and time. These engagements increase the risk of collision by changing the users driving behavior.

4.1.3 Regulations

The National Highway Traffic Safety Administration (NHTSA) has published guidelines on driver distraction that is recommended to follow [7]. Non-driving tasks are categorically addressed as tasks that "interfere inherently with a driver's ability to safely control the vehicle". The guidelines express that devices and other technologies should be designed in such a way that the driver's glances away from the road and cognitive distractions are reduced. NHTSA proposes that tasks should be completed by using glances less than two seconds with a final aggregate of twelve seconds. In the guidelines one can read of what tasks that are accepted during driving and what tasks that are not (see tables 4.1 and 4.2).

Adjustment of climate controls not required by a Federal Motor Vehicle Safety Standard (e.g., temperature and fan adjustment)
Operation of cruise control
Performance of a task via multi-function display interface
Resetting trip odometers and/or trip computers
Navigation of the vehicle—Destination entry
Navigation of the vehicle—Route following
Real-Time Traffic Advisory
Trip Computer Information
Observation of vehicle information centers
Observation of emissions controls
Observation of fuel economy displays
Adjusting vehicle suspension and/or ride

Table 4.1: Driving-related tasks to which the NHTSA guidelines apply.

Type	Action
Communications	Caller Identification
	Incoming Call Management
	Initiating and Terminating Phone Calls
	Conference Phoning
	Two-Way Radio Communications
	Paging
	Address Book
	Reminders
	Text-Based Communications
	Social Media Messaging or Posting
Entertainment	Radio (including but not limited to AM, FM, and Satellite)
	Pre-recorded Music Players, All Formats
	Television
	Video Displays
	Advertising
	Internet Browsing
	News
	Directory Services
Information	Clock
	Temperature

Table 4.2: Non-driving related tasks to which the NHTSA guidelines apply.

Depending on the situation of the current driving state and the system's positioning and implementation, some of the actions in table 4.2 are in certain cases accepted. These situations are stated in the guidelines, and the situations when manual text entry is accepted or not is shown below:

Accepted:

- Entering a phone number, an extension number, or voice-mail retrieval codes and commands for the purpose of initiating or receiving a phone call.
- Fleet-management functions.
- Entering short driving-related text strings (e.g. an address in a navigation system).

The maximum amount of text that should be allowed to enter during a single testable task is determined by the task acceptance test.

Not recommended:

- Manual text entry by the driver for the purpose of text-based messaging, other communication or Internet browsing.

Guidelines regarding images and photos are stated as shown below.

Accepted:

- Driving-related images including maps, icons and line drawings.
- Static graphical and photographic images displayed for the purpose of aiding a driver to efficiently make a selection in the context of a non-driving-related task (e.g. contact photos, album art) if the image automatically extinguishes from the display upon completion of the task. If appropriate these images may be presented along with short text descriptions that conform to the guidelines.
- Internationally standardized symbols and icons, as well as TrademarkTM and Registered® symbols.
- Aesthetic images (e.g. screen saver).

Not recommended:

- The display of informational detail not critical to navigation, such as photorealistic images, satellite images, or three-dimensional images.
- Personal photos, e.g. photo stream on iPhone, iPad or iOS.

When it comes to text that is displayed, the following guidelines are stated as shown below.

Accepted:

- Limited amounts of text (not books etc. as defined below) is acceptable.
- Reading, selecting, or entering a phone number, an extension number, or voice-mail retrieval codes and commands for the purpose of initiating or receiving a phone call.
- Fleet-management functions.
- Text read by text to speech.
- The maximum amount of text that should be visually presented during a single testable task is determined by the task acceptance test.

Not recommended:

- Books, periodical publications (including newspapers, magazines, articles), web page content, social media content, text-based advertising and marketing, text-based messages (transmitted via short message service, email, instant messaging service, internet-based messaging, or social media internet-based applications including Posting).

When it comes to the level acceptance of testing tasks, eye glances are measured to see whether or not these should be available when driving and are stated in the guidelines as so called *accepted criteria* (AC).

Eye glance acceptance criteria [7]:

- *AC1: For at least 21 of 24 test participants, no more than 15 percent (rounded up) of the total number of eye glances away from the forward road scene should have durations of greater than 2.0 seconds while performing the testable task one time.*
- *AC2: For at least 21 of 24 test participants, the mean duration of all eye glances away from the forward road scene should be less than or equal to 2.0 seconds while performing the testable task one time.*
- *AC3: For at least 21 of 24 test participants, the sum of the duration of all eye glances away from the forward road scene is less than or equal to 12.0 seconds while performing the testable task one time.*

The first bullet point (AC1) means that if a person for instance has ten glances away from the road and one of those glances is greater than 2.0 seconds, it will generate a percentage of 10 and is therefore accepted. If a person instead has ten glances away from the road and two of those glances are greater than 2.0 seconds, generating a percentage of 20, it will not be accepted. The second (AC2) and third (AC3) bullet points are rather straightforward and self-explanatory. During testing of a task the user has to be able to complete a task without errors and should therefore be allowed to get to know the system before the actual test is carried out.

4.1.4 Eye Tracking

In Andrew Duchowski's book *Eye Tracking Methodology*, he asks the question "Why is eye tracking important?". He then continues to answer that we move our eyes all the time, constantly changing the gaze to put new areas of the field of view in high definition, thereby focusing our concentration on regions of interest. Thus, it can be presumed that if one follows someone's eye movements, this can be mapped into the path of attention of the subject. With this information one can get an insight in what the observer does and find interesting, and so get a clue on how the observer perceives the current scene [13].

It is pointed out that the problem is to interpret the data [14], it is not as straightforward as with typical tasks as performance or speed, or as simple as interpreting data that would come from use of mouse or keyboard input[14]. One of the most significant barriers when using eye-tracking in usability studies is the physical relationship between the tester and the system, the goal is to reach a solution where the tester does not feel or is intruded by the system so that the actions are as natural as possible.

Another big issue with eye tracking is how to interpret and relate to the immense amount of data that the procedures accumulate. The usability researcher must find means to relate to task-related cognitive activities. Some aspects in the form of variables and metrics must be chosen to analyze the data stream, and it is often recommended to use the guidance of predefined cognitive theories. This thesis is set to use NHTSA's guidelines on how to interpret the accumulated data, and process the interpretations within the acceptance criteria [7, 14].

Eye tracking has up until now largely been used in experimental environments, in a lab or while testing products. The key word here is testing, debatably it can be used for more than that. Today's interfaces output an immense stream of information, while the user of the interface only has a small and limited streamlet of input methods. It is here possible to compare differences in output when: watching a video, playing a game on your smartphone and reading a web based newspaper. In these examples, and roughly in all modern interfaces, the user has a low input amount when considering the output on the other end. While this arguably cannot be seen as something negative, one can only but imagine the benefits that it could have if the input stream from the user were to be significantly heightened. Eye tracking systems have become robust enough to work as a medium to interact through user focus, and even though this area is not touched in this thesis, it found a great interest during the evaluation phase when seeing what the test users were interacting with and what their focus was on [14].

Ergoneers

The Ergoneers eye-tracking system has two major components; the hardware that is mounted on the test subject, and the software that needs to run in the background. Dikablis Glasses is the name of the head-mounted hardware that Ergoneers offers, a small and monocular set of cameras that interplay in order to obtain eye-tracking (see fig. 4.2).

One camera is located in the front of the head-mount and is directed forward into the user's field of view. The second camera is very close to, and pointed directly into one of the eyes of the user. A very valuable trait that the Dikablis Glasses have are that the user does not need to keep the head still while wearing them, the mount is very steady, and the two cameras interplay quite well in any situation [15].

By taking the video stream from both the cameras, the software can show exactly what the user is focusing on with the gaze (see fig. 4.3). Calibrating the eye tracking is also done by the help of the software, that is called D-Lab (along with D-Control), and is done by adjusting the cameras to fit for the current test-person.

Figure 4.2: The Dikablis Glasses for Eye Tracking, one camera forward and one pointing into the eye (source: http://www.ergoneers.com/).

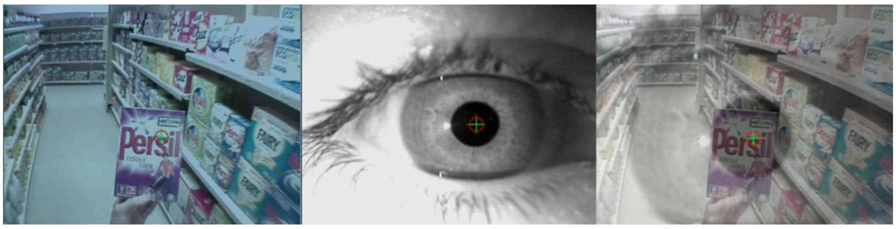


Figure 4.3: The video stream from both of the two cameras is combined to reach eye tracking. (source: Dikablis Software User Manual) [15]

Calibration

Calibration of the Dikablis Glasses is often a lengthy process that that need patience, from both the test subject and the test manager. The reward for a precise calibration is however very high and contributes with excellent test data. First of all, the camera that is pointed outwards onto the user's field of view, needs to be adjusted so that it has the same vertical angle as the eyes will have during the crucial parts of the test. This thesis used eye-tracking exclusively while the test-users were sitting in the simulator's car, therefore the obvious vertical position of the camera was pointing at the road in front of the car. Next, the other camera that is pointed into the eye needs to be adjusted so that the pupil is centered in a "view-grid" when looking at that exact same point mentioned when calibrating the front camera. This is to ensure that the whole eye will be captured when the pupil is moving away from the natural position (see fig. 4.4).
At this point of the calibration, eye-tracing is possible and quite correct. In the next phase of the calibration the testers need to ensure pupil detection, by masking and isolation. Masking is done by decreasing the image that the camera streams onto the software, and reduces the areas that are brought into the calculation of pupil detection. Areas that are problematic in the calculation are dark areas such as shadows, mascara, eyelashes etc. Isolation of the pupil is done by setting a threshold value that separates the dark area of the pupil with the rest of the image (see fig. 4.5).

The final step of the calibration is to fine-tune the eye movement, which is done to

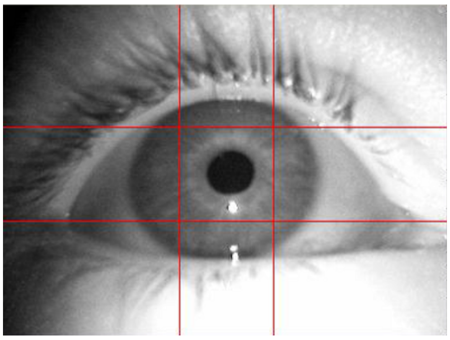


Figure 4.4: Pupil should be in the centre of the grid to ensure the best possible calibration. (source: Dikablis Software User Manual) [15]

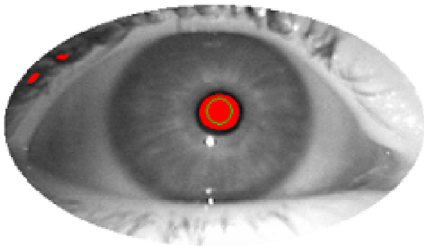


Figure 4.5: Setting the threshold to seperate the pupil from other dark areas. (source: Dikablis Software User Manual) [15]

ensure that the software can calculate the correct motion of the pupil during glances. After this final step, the test masters should test whether the calibration was successful or not, by asking the test-user to focus on different points in the field of view, and so confirm if the video stream is synched by looking at the display.

4.2 Touchpad and Screen Interaction

There is a plethora of theory about the area of touchpads and screen interaction. The following section discusses some of the most important articles about this that was used and considered during the thesis.

4.2.1 History of touch

According to Bill Buxton, touch technologies originated around the 1960s by IBM with the cooperation with the University of Illinois, but in the beginning of the 1970s a number of possible techniques was discarded [16]. It was in 1972 that PLATO IV (see fig. 4.6), was introduced into some labs and grade-schools. This system had a plasma panel display that was used to intercept and interpret the users touch inputs. Since then to the end of the 20th century, the use of the touch screens was very narrowed and used in only a few areas, e.g. in laboratories. The first commercial use of touch screens was probably in calculators and in some ATM machines around the mid-1980s. These however did not need any sophisticated ways of interacting with them, but did ease the speed of which the user could enter specific inputs without looking at the screen. Around the year 1985 there had been many attempts to support multi touch inputs, and

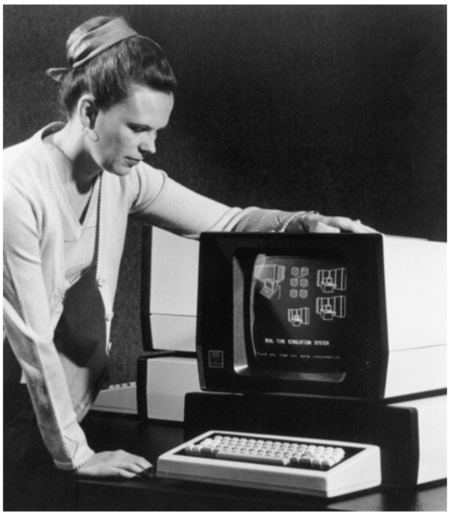


Figure 4.6: The PLATO IV (source: www.bloomberg.com)

a product that did just this was the Sensor Cube (later Sensor Frame, see fig. 4.7a). This had also been researched by Bob Boie who had developed a capacitive multi-touch screen in Bell Labs. A person who took human gestures into the realm of touch was Myron Krueger. He used a video camera to capture gesture and position of hands and then translated these pictures to make the corresponding action to a given object [16].

One of the first mobile phones that used touch technology was *the Simon* (see fig. 4.7b) that had a screen which supported both finger and stylus input. This phone was developed by IBM and Bell South in 1993, and it was around this time that researchers at MIT started to study the possibilities about sensing pressure and vectors with placing the screen on strain gauges.

In 1999, the screens had been developed into not only being able to interpret gestures, but to also sense which direction a touch (swipe) went to, thus being able to have certain options or functions depending on where a touch began and ended. The PortfolioWall (see fig 4.8) used this kind of technique to present images and videos on a wall screen. A menu would appear if the user holds a finger steady on the screen for a while and then being able to slide the finger to the wanted action.

Buxton ends the article by revealing that most of the touch techniques that are being used today was developed around 20 years ago, meaning that technologies that were developed only ten years ago could potentially be the ones that will be used in ten years from now.

(a) The Sensor Frame (source: www.billbuxton.com/multitouchOverview.html).

(b) The Simon Phone (source: www.finestdaily.com).

Figure 4.7: The Sensor Frame and the Simon Phone.

Figure 4.8: The PortfolioWall in use (source: archive.cardesignnews.com).

4.2.2 Problems with Touch Technology

There are a lot of talk about the so called "fat finger problem" [17] when it comes to touch technology, but an article by Baudisch and Holz is claiming that this is not the case [18]. The fat finger problem says that a person's finger may occlude the targeting area and therefore hindering or lowering the precision and accuracy. In the article Baudisch and Holz discuss about the different perceptions that users have about touch technology. For instance, some people believe that the top of the fingertip is where the *"touch"* is being registered, while some believe that it is right at the center of the finger. These beliefs might in some cases be more right or wrong, but in most cases they are usually both true. This comes from the fact that the implementation of e.g. a button is surrounded with an offset to compensate for this. This means that a button could be touched X number of pixel outside it and still be registered as a successful touch on the button. However, in the article they have conducted a study where users are asked to touch a target area a number of times with various finger angles as well as different “roll”-angles (how twisted the finger is) to see how much difference it does towards the actual registered touch point. The result showed that users had very different results of where they touch with the different angles, but the accuracy of the target area was more or less that same overall. They argue that the fat finger problem is more due to different personalities and their perceptions of how the touch screen interprets the touch.

4.3 In-vehicle Touchpad Interaction

The massive use of touch technology has in the last years been integrated into cars. Some car brands have gotten further than others, but the technology is still in its cradle regarding in-vehicle usage.

4.3.1 Competitors usage of touch

In 2010 Audi presented a touchpad for their MMI Touch infotainment system to the 2011 A7 and A8 (see fig 4.9a). This touchpad uses capacitive sensors that detects the user’s finger interaction and will give suggestions to an unfinished word or number. With this technology they were able to decrease the distraction that the driver experienced when looking on an alphanumerical keyboard on the center stack display, and therefore improving the safety. According to the article *“Touch pads help industry fight driver distraction”* written by David Sedgwick in 2012 [5], the company TRW Automobile Holdings Corp., which were the ones that produced the system for Audi, made a research that showed that the usage of touchpad input reduced drifting out of lane with 78 percent in comparison to traditional alphanumeric input.

Mercedes has had a rotary controller which control the infotainment unit in their cars, but in 2014 they presented an option to instead have an innovative touchpad that can recognize swiping and pinching gestures in their fourth-generation C-Class cars [6] [19] (see fig. 4.9b).

4.3.2 Types of Interactions in Vehicles

A paper that is interesting for the thesis is *“Development and Evaluation of a Multimodal Touchpad for Advanced In-Vehicle Systems”* [20] where the two authors conducted an experiment with various types of interactions with the Center Stack Display (CSD). The experiment tested five different setups of the interior to find out which would lower the driver’s distraction and time of task completion the most. One test with touchpad interaction and visual feedback, a second test with a touchpad with visual and auditory feedback, a third test with a touchpad with visual and tactile feedback, a fourth test with touchpad with visual, tactile and auditory feedback, and the last test was conducted with an ordinary rotary push-button switch. Their conclusion was that the touchpad is a plausible way of improving how the user interacts with the in-vehicle system and therefore lowering the distraction for the driver, towards using a rotary push-button

(a) Audi's touchpad system in A8 (source: autoworldnotes.blogspot.com).

(b) Mercedes touch based system (source: http://www.mbusa.com/).

Figure 4.9: Pictures of touch based control of the infotainment system in Audi and Mercedes' cars.

switch. However, the best improvement was when the touchpad had visual feedback combined with either auditory or tactile feedback, and was less improved if only visual feedback was given. This could be seen as a downside to the thesis since auditory feedback will not be implemented, but one has to keep in mind that the experiment was tested towards the CSD, and not the DIM as the thesis intend to.

4.3.3 Exploring Interaction with the Steering Wheel

In the article *Exploring the Back of the Steering Wheel: Text Input with Hands on the Wheel and Eyes on the Road* [21], they use another approach to lower driver distraction by using the back of the steering wheel to control the user inputs. In the article they discuss the usage of speech recognition and input which is not yet perfected and thus, not the best solution to solve the problem. Their goals were to have the driver's both hands on the steering wheel at all times and also to be able to see the input from the user without taking the eyes from the road. This was done by placing two touch sensitive sensors on both sides of the steering wheel which had three different zones with six characters in each and a head up display where the input was visible. The idea of using touch sensitive sensors was however scrapped due to troubles of registering which finger was actually touching a zone at a specific time. Instead they constructed three buttons on each side of the steering wheel which each would traverse through six characters. If two buttons was pressed at the same time it was interpreted as a deletion. From their user studies they could confirm that the system did improve the goals that they had; that the user did not have to let go of the steering wheel when typing and not to let the eyes of the road as much as traditional systems with good results.

4.4 Interaction Design

The field of interaction design is defined in many different ways by many different people, this thesis however follows Preece et. al. [22] description, that Interaction Design is:

> *"...designing interactive products to support the way people communicate and interact in their everyday and working lives. Put in another way, it is about creating user experiences that enhance and augment the way people work, communicate and interact."*

Preece et. al. further recognizes the different terms that are used to highlight different aspects of the design and design process, including user interface design, software design, user centered design, product design, web design, experience design, and interactive system design. Whereby the term interaction design has become an accepted umbrella-term for them all. While one aim is to reduce the negative aspects of the user experience, the obvious counterpart is to enhance the positive ones, and example is to tone down the frustration of a set of actions, and emphasize the enjoyment and rewards one could achieve.

> *"Designing spaces for human communication and interaction..."* - *"...aspects of computing that are focused on people, rather than machinery"* [23].
>
> *"Interactions design is about the why as well as the how of our daily interactions using computers"* [24].

These are two earlier interpretations of Interaction Design that Preece et. al. also cite, which this thesis also consider to be relevant even though they differ in platforms and what they examine.

4.4.1 Usability

In the book *Usability Engineering* by Jakob Nielsen [25] he presents usability as such:

> *"Usability is not a single, one dimensional property of a user interface. Usability has multiple components and is traditionally associated with these five attributes: Learnability, Efficiency, Memorability, Errors and Satisfaction."*

And according to the ISO standards the term *usability* is defined as followed:

> *"(Usability is) the extent to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, effi-*

> *ciency and satisfaction in a specified context of use."* ISO 9241-210 [26]

The thesis has from these studies chosen to interpret the terms *effectiveness*, *efficency*, and *satisfaction* in the following way:

- Effectiveness: the accuracy and completeness with which specified users can achieve specified goals in particular environments.
- Efficiency: the resources expended in relation to the accuracy and completeness of goals achieved.
- Satisfaction: the comfort and acceptability of the work system to its users and other people affected by its use.

4.4.2 User Experience

User experience, also known as 'UX', is one of the cornerstones of the new way we look at design and new solutions. UX focuses on having a deeper understanding of the users by looking at the different attributes: what they need, what they put value into, what their abilities are and their limitations. When UX is practiced correctly, one can improve the quality of the interaction and perception that the user has with your product [27].

The Nielsen Norman Group, Jakob Nielsen and Don Norman [28] define user experience as following:

> *"User experience encompasses all aspects of the end-user's interaction with the company, its services, and its products."*

This is the ISO-definition of the term:

> *"A person's perceptions and responses resulting from the use and/or anticipated use of a product, system or service. User experience includes all the users' emotions, beliefs, preferences, perceptions, physical and psychological responses, behaviours and accomplishments that occur before, during and after use."* ISO 9241-210 [26]

The thesis finds that the ISO-definition is more descriptive than the one of Nielsen and Norman, even though they almost represent the same thing. It is learned that every single interaction that the user has with the product or service builds on the UX which truly makes it a large, however still conceivable, concept.

4.4.3 Affordance

Jerome James Gibson formulated the expression *affordance* [29], which points towards what an object or environment *affords* to do. This means for instance that a chair affords a person the ability to be seated on or to place something on it. However, there are a number of affordances that are different from person to person, like for instance a child may not be able to reach at the top of the refrigerator's top shelf while an adult can (usually) reach it fairly easy. The refrigerator affords something different for a child than an adult. While affordances could be seen as options or actions that could be carried out on an object or environment, William Gaver [30] divided the term affordance into three subcategories; *false*, *hidden* or *perceptible*. A false affordance is e.g. a button that does nothing, or an icon that when pushed will not do anything. A hidden affordance is an option or action that is not visible, perceptible or obvious for the user, e.g. a key could be used for opening a bottle, or a sledge hammer could be used as a broom. A perceptible affordance is simply an affordance that the user instantly can see and understands how to interact with. Affordances are all around us every day in every environment or object that we use, but some of them are hidden which means that they have to be learnt, while some of them are false. These are usually quickly learnt that they do nothing. The way that affordances affect a user is commonly not thought of if they have been learnt. However, when a user is presented to a new object or environment the affordances could be easy to learn depending on if they are false, hidden or perceptible. The thesis work will have to take into consideration the way that actions and options are being presented, making the affordance perceptible and not false nor hidden.

4.4.4 Look and Feel

One of the most important things in designing a development solution, is to customize the look and feel of the application [31]. It can be stated that the look and feel is how the designer defines the application to be presented to the user. There are many guides on how to create a certain look and feel, one example is the chapter Customizing Look and Feel in Application Express 4 Recipes [31]. However, this thesis feels as though there is no correct guide for every project. The look and feel process needs to be designed in a way that it suits the requirements and feelings that the product is set to have. In this project, it was vital to study earlier Volvo designs and attempt to understand what message they convey.

4.5 Programming

The thesis used only a few programming languages to develop the implementation of the system. These are described in the following sub-sections.

4.5.1 Qt

Qt is a cross-platform application framework that was created in 1991 [32] which has easy-to-use elements for creating graphical user interfaces (GUI). The most commonly used programming language in Qt is C++ but has however several macros that could be used for other programming languages. Qt is the main platform that was used during this thesis and has, due to its long lifetime, a wide forum based community where one easily can search for tips and help.

In the Qt-platform there is a UI creation kit language which was developed by Nokia called QML (Qt Meta Language or Qt Modeling Language), and is quite similar to JavaScript. QML is great to create fluid animations (60 FPS), and is often used in mobile applications. The QML has sophisticated graphical items, like rectangles, buttons, images, states and transitions etc.

4.5.2 C++

C++ is an object-oriented programming language based on the programming language C, which was developed 1979 by Bjarne Stroustrup [33] and is widely used in computer game development and communication. This language was used for interpreting the signals from the hardware and sending them to the QML-code.

5

Method

The thesis work was executed by the help of various methods that were studied in the master programme Interaction Design and Technologies and its courses. This chapter will present these methods in a chronological order of which they were used during the thesis. Further methodology lies in software development and testing. To make the process more seamless the project was divided into three phases that each had a different structure of methods. These phases were: *Research*, *Development*, and *Evaluation*.

5.1 Research Phase

The opening phase consisted of initial learning and further survey of the field of study, which was assembled in four main aspects: *In-vehicle Interaction*, *Touchpad and Screen Interaction*, *In-vehicle Touchpad Interaction* and *Interaction Design*. The theoretical segment is already accounted for in the *Theory chapter* earlier in this report. Upon achieving the required knowledge, the next step in this phase was to frame the current situation by stating what specific problems that had to be solved by the thesis. These were then ideated around to find suitable solutions, finally these solutions were evaluated and discussed with end users.

5.1.1 Framing the Scope of the Thesis

The literature survey was important for the thesis to reach a level of understanding of how the current situation and the history of the car industry looked like. Thereafter the next step was to frame the problem. The thesis members used the *Try It Yourself*-method, which is quite self-explanatory, this method was used to ease the understanding of how the current technology works, but also to identify the difficulties and questions that may come up during a test with other users. The thesis tested both an ordinary S/W system of the DIM at Volvo, but also tried the hardware that was to be delivered and used in the thesis by ALPS Electric at their office. After the visit at ALPS Electric, a discussion with Volvo was initiated of exactly what could be plausible to complete during the thesis work. The discussion was very productive as it gave both Volvo an understanding of the thesis' thoughts and ideas of what it could include, as well as it gave the team members and understanding of exactly what Volvo was expecting from the thesis.

The discussions revolved around how the thesis could utilize the hardware that was to be delivered, and how to best satisfy the goals and needs of Volvo. As mentioned in the background chapter, one of the most important goals were to decrease the linguistic barrier that would occur when Volvo moves to having a large CSD touch display while keeping the tangible buttons on the steering wheel.

A simple way of gathering different tasks, actions and interactions that a user do while, in this case, interacting with the DIM and HUD and its mechanics are with *Activity Analysis* [34] and *Behaviour Mapping* [35]. With these methods one could map and list how, what and when a user performs different actions and tasks. For instance, the user might glance at the dashboard module and operate some of its components by pressing button X on the steering wheel, completing the specific task in Y seconds while moving the right arm from position A to position B.

An extra complement to these methods is to use *Cognitive Task Analysis* [36] which is a good way to see which kind of information and perceptual needs a user has and to find out where the user sometimes fail and why. When a user has performed a number of given tasks which are observed and analysed, it is a good time to interview them about, e.g. what they like to be able to do with the DIM when driving. One other possible method that could be used is *Extreme User Interviews* [37], where users that have more or less no earlier experience in the field or, users that are considered to be experts in the field will be interviewed to see differences between them. This method was widely used because due to the confidentiality of the thesis, Volvo employees were the only target group.

5.2 Ideation

After the initial phase where framing some of the problems were framed, an ideation part was carried out. Since the hardware prototype and the technology itself were given from the start, the main task for the thesis group was to ideate around different functions and design aspects. The functions and design choices that were made had to fulfill the use cases while solving the problems. These had to be implementable and achievable with the given hardware and within the available time given for the thesis work.

5.2.1 Workshop

As the hardware from ALPS Electric would take some time to be delivered to the thesis, a workshop was arranged with thesis members and seven employees at Volvo to get everyone's ideas and thoughts of what the system could include and how this could be implemented. When the participants were invited to the workshop they were given information regarding what the workshop would cover and consist of. This was necessary to enable the participants to prepare ideas and consider problems that they could think of.

When the workshop commenced, the thesis members explained the scope of the thesis and what kind of hardware that was available. Then everyone got to say what ideas they had and problems they could think of, in a turn based fashion, whereby a *brainstorming* session began [38]. The compiled comments and ideas were put into *KJ diagrams* [39] and turned into *use cases* [40]. As the workshop was held with a variety of different employees at Volvo (designers, interaction designers, project manager, etc.) the thesis could get a good overview of more use cases and needs from a rather broad spectrum. Worth noting is that some of the participants were expert users and developers in DIM-area, and this variety of participants gave the thesis a good chance to ask questions of things that were unclear or needed deeper explanation. The participants also addressed Volvo's current systems and ongoing projects. As the thesis members got to know a lot of how the DIM and HUD worked in Volvo's current systems, the thesis decided to just focus on the DIM and not the HUD.

These are the most relevant ideas and areas that were covered during the workshop:

- The ability to have both touch and tactile functionality for navigation in the system.
- To have volume control in all areas of the system.
- Being able to quickly search in longer lists with the character recognition.
- Trying to replicate the interaction and architecture of the CSD.
- Simplify the functionality from CSD to the DIM.
- Use the tachometer display area as accommodation for the solution.

The workshop was successful in giving the thesis a good start as well it gave the thesis members a grasp of the scope and depth of what the work would revolve and be about. DIM-interaction has been a difficult nut to crack for some time, and the different interfaces that have been used in the past together with the tangible buttons have not had the rich functionality depth that can be desired. Plans and designs were developed to really facilitate and draw benefit from the three main methods of interaction that the hardware would enable: touch gestures, tactile interaction and character recognition.

These are the use cases that were elicited from the workshop along with the gathered theories:

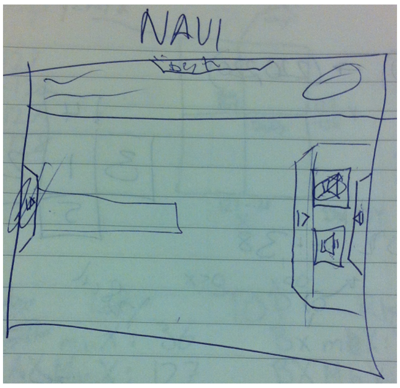
Being able to...

- Answer a phone call.

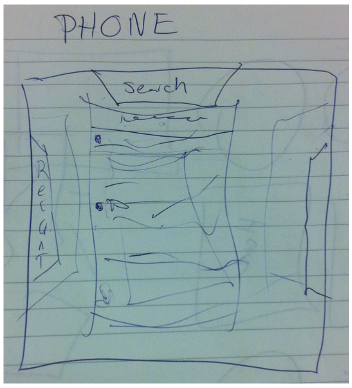
- Set the a recent address as the new destination.
- Select track “X” from your playlist “Y”.
- Ignore an incoming phone call.
- Enter and select a new destination with the help of character input.
- Call latest missed phone call.
- Search for and call contact X with the the help of character input.
- Select the next track in the same playlist.

Together with the thesis’s supervisor at Volvo, sketches and paper prototypes were created, to visualize the different solutions (see fig. 5.1). Specific interactions were designed with the hardware’s capabilities in mind, that would allow the linguistic barrier (the different ways of interacting with DIM and CSD) to be decreased while still keeping the user-to-interface relationship gentle enough to be used while operating a vehicle on the road.

In the workshop, there was a discussion on whether the solution could be placed in the display area that is allocated for the tachometer, which in the next stages was taken further. Plans were to integrate the prototype development into a screen dump of an actual DIM.



(a) An idea of how the Navi-application could look like. To the right in the picture is an example of how the volume control could look like.



(b) An idea of how the Phone-application could look like. To the left, top, and right are the unique tabs for the Phone-application; Recent-tab, Search-tab, and Favorite-tab.

Figure 5.1: Early sketches that were designed to display how the interface could look like.

5.3 Development Phase

As the *Research phase* was completed and the system was delivered to the thesis members, a new phase started with getting the hardware systems up and running. The programming was done in Qt and the languages that were used in the thesis were C++ and QML (Qt Meta Language or Qt Modeling Language). The actual development phase of the prototype was based on the formed use cases and concepts that were created and put forth during the *Research phase.* Some of the use cases that were created from the start could however later be scrapped due to soft-, hardware and time limitations. It should also be noted that due to these limitations, new use cases came up along the actual development phase.

Initially methods like *Experience Prototyping* [41], *Workshops*, *Brainstorming* [38], *Paper prototyping* and *sketches* were used to get a clearer view of what the final product may consist of, with a small cost in both time and resources. The *Paper prototyping* and *sketching* methods were used iteratively during the whole development to quickly explain and bring new ideas to the table. *Brainstorming* was going hand in hand with the paper prototyping and sketching. When the ideas were clear enough and the prototype system was set up with the router, it was time to start implementing. Throughout the whole thesis an *Agile* form of programming development was used to try to keep the thesis members work as efficient as possible.

5.3.1 Agile Software Development

Agile Software Development is a framework with methods that aim towards effective development processes. The framework has numerous key values, which can be found in the *"Agile Manifesto"* [42]: Agile approaches are not focused on the processes nor the tools that are used, rather, it focuses on the team that develops the software [43]. It is of importance to have motivated team members who are given trust and flexibility in what they do, to have an effective interpersonal communication is therefore highly valued. Additionally, agile methods enable the software development teams to work closely with the customers with frequent feedback on the process, in order to adapt to their needs and ultimately reach a satisfactory solution [43].

The "Agile teams" work in *sprints* while continuously delivering working software to the customers. These sprints are short intervals that typically range from 1-4 weeks [44]. By sprinting, the development teams are facilitated with means to easier respond to changes in the working environment and customer needs. While the primary measure of progress is *working software*, *documentation* is seen as means for communication and to support the development of good software [43]. Non-agile approaches typically include user interface-documentation which can range from 5 to 200 pages of information, compared to agile methods where no such extended documentations exist. Rather, agile development teams usually complete basic analysis prior to coding, and customer needs are elicited from questions that are raised as the project moves forward [45]. Ultimately, because of the nature of agile software development (with short iterations, the focus on interpersonal communication and close connection to the customer) a co-located team is preferred here to a higher extent than in traditional approaches [46].

Scrum

The *Scrum method* is one approach of agile development. Scrum is, as believed by the founders, a good way of building small pieces of a product at a time that encourages creativity and enables the team to easily respond to changes in the working environment [47]. Methods used in Scrum are developed to support team members and give advantages to their best traits and characteristics, in order to solve demanding tasks collectively.

The three core roles of Scrum are as follows [47]:

1. *Product Owners* determine what needs to be built in the next sprint.
2. *Development Teams* build what is needed in the sprint, and then demonstrate what they have built. Based on this demonstration, the Product Owner determines what to build next.
3. *Scrum Masters* ensure this process happens as smoothly as possible, and continually help improve the process, the team and the product being created.

This thesis tried to use Scrum as the development method whenever possible. Sprints was obviously of the shortest kind as a result of how small the time span of the project was, and a reasonable length for these were one week due to meetings with supervisors etc. The roles of Scrum were assumed as: *The Development* team was the two Master Thesis students, whom also partly assumed the role *Scrum Masters*, together with the appointed supervisor from Chalmers. Volvo Cars could be viewed as the *Product Owners*, and the needs from the company was channeled through the appointed supervisor from Volvo along with the Research Project Manager at the department. Short iterations were important to swiftly reach an agreeable outcome.

5.3.2 Initial Development

At the start of the thesis the first thing was to set up the prototype system's connections and being able to interpret its signals so that the actual implementation could start.

The First Step

As the delivered system had no graphical interface, the team members had to create a "dummy" widget of their own to see where a touch was drawn. The widget was very simple and showed the characters that the system found. The hardware would give a percentage of the four most likely characters that it calculated from the touch input (see fig. 5.2). The next step was to learn the E-boxes' signals and functions which translated the touch and tactile input from the touchpad. The thesis spent a lot of time to get a good understanding of how the touch signals was translated. If not, the project could suffer from a small error in a later stage of the thesis work. The given hardware had a coordinate system that was not as simple as the top left corner started with (X min, Y min) and the lower right corner ended with (X max, Y max), but had instead had four quadrants with differently reversed and negative coordinates (see fig. 5.3). This was a problem that took quite some time to get the right transformation to get a logic way of getting the correct coordinates from the touchpad. The created widget helped in both coming up with new ideas of interaction, but also to see the hardware's capabilities and it was later easier debug errors that could arise. This widget was very simple as it only needed to show the touch inputs on a black canvas. Later as the touch input was correctly entered on the widget, and the thesis members also had learnt more about what kind of signals the hardware sent out, the widget was expanded with what characters was found (the prototype gave four characters with different possibility values), a gesture history (which was not fully implemented), and finally the current coordinate that the touch input was registering. This widget was a great help and was kept during all the other iterations.

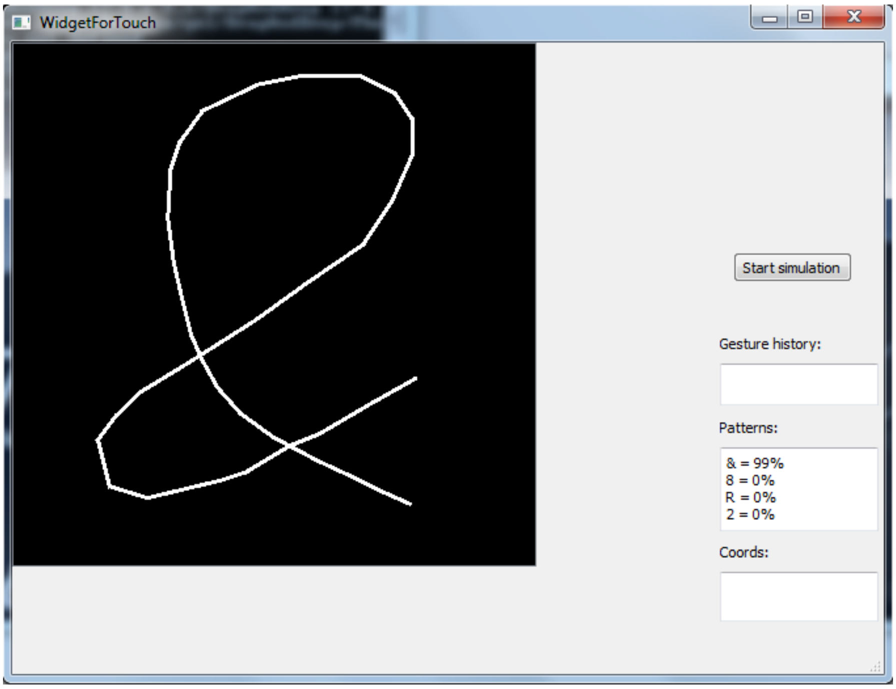


Figure 5.2: The widget that showed the touch input and the four most plausible characters.

When the simple graphical interface was set up the thesis members started to sketch ideas of how the graphical interface for the actual DIM should look like. Since the thesis aimed to use the tachometer-area for the system with the integrated CSD functionality, the interface was made so that the program produced a view of a DIM where the new

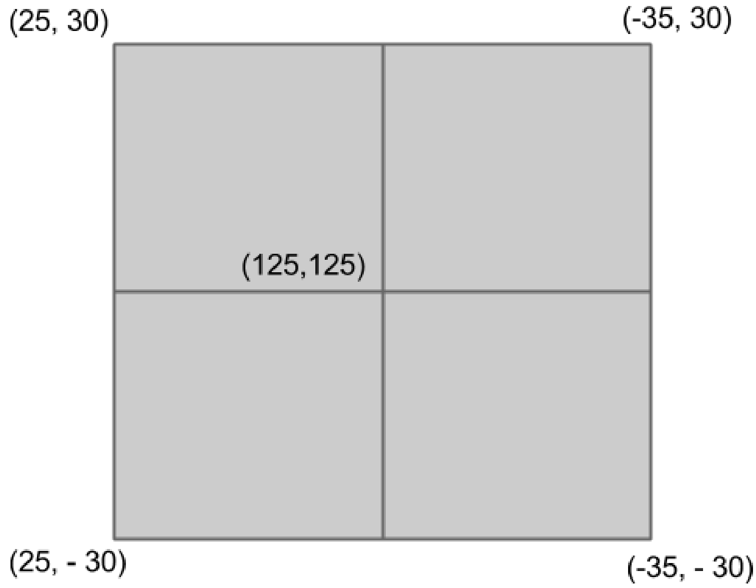


Figure 5.3: The hardware's coordinate system.

system was overlapping the tachometer. In consideration with the similar architecture as the CSD, the graphics and architecture of the new system was done in three major iterations, smaller design iterations was however done during and in between them. All iterations had three main applications; Phone, Navigation and Music, that followed through every iteration phase. The center of the system was called Home-screen, where the most important information from the applications was shown all together. In the initial development a fourth application was also included, the Climate-application. The graphical architecture for the four applications was built in a crossroad-like way with a Home-screen in the middle, and was built rather straightforward in order for the thesis to get a chance to try different ways of interactions and algorithms that could possibly work for it (see fig. 5.4).

Reflections on the Initial Development

In this initial development, the thesis focused more on the way that signals could be used for e.g. swiping between applications and recognizing characters. The graphical architecture was at this point not the main objective since the thesis members still had some hardware issues that needed to be dealt with. The architecture was still somewhat successful and gave a lot of ideas of how it could look like in later iterations. In code the only programming language used in this step was C++ and was used to create the widget that the touch input was drawn upon. Many of the signals from the prototype had to have their own functions and algorithms in order to create a well-structured base for later use.

Figure 5.4: The intial structural layout of the interface, whereby the user would navigate between applications.

The Initial Development's Design

From a design point of view, the initial development was very helpful, both in terms of interaction and aesthetics. The thesis learned the possibilities and limitations that the development platform gave and could so make decisions based on these facts. Swiping between apps or screens was proved to be a valid and feasible way of interaction, which would realize the plans to mimic the interactions in the CSD. One major difference was however that the hardware did not give a high coordinate update-frequency when compared to the CSD. This performance limitation could seem crippling when the thesis had intentions to make the interface interact with direct touches, but when implementing transitions into the prototype, this minor limitation was deemed insignificant. Aesthetically, the initial development gave indication that the platform could be used with a quite compound structure of images and transitions. This finding made way for further development concerning the look and feel of the prototype.

Evaluation of the Initial Development

This initial development was evaluated with the supervisors and one other employee at Volvo. They were introduced to what the thesis had done so far and were then able to operate the current system. When using the system they were asked to *think-aloud* and describe their feelings and impressions of the system. By using this *think-aloud* method [48] the thesis members were able to take notes of what was being said. When everyone had tried the system the participants were questioned in unstructured interviews about the system. Notes were compiled and the pros and cons of the current implementation were evaluated. By examining the results, the thesis could move on to the first iteration.

5.3.3 First Iteration

From the evaluation of the initial development the thesis decided to implement three applications into the prototype system; Phone, Navigation and Music. This limitation was to ensure that the time-span would suffice and that the prototype could be functional enough when the evaluation phase started. To implement a Climate-application was also discussed quite far into the work, but was discarded upon the realization that it would require too much time from the development.

The initial development focused more on the graphical architecture and used QML to create a bridge between the input signals and the graphical interface and its components.

The Second Step

In this implementation the user could drag out each of the three tabs and take a *"peek"* of what was currently going on at that specific application by gently sliding a finger from that tab's origin and inwards. If the user let go of the tab the system would return to the Home-screen (see fig. 5.5), but if enough of the tab was dragged out towards the middle, that application would lay itself over the Home-screen and become active.

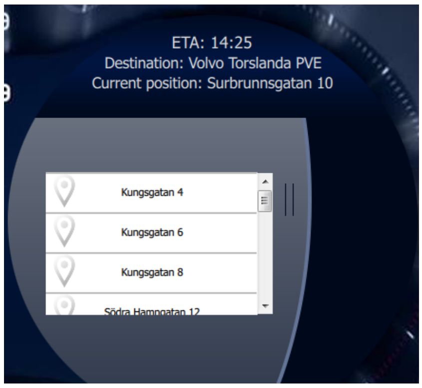
Figure 5.5: The first iteration's design of the Home-screen.

All three applications had their own unique *"base state"* in which they would land in if activated. They then had two unique tabs, one to the left and one to the right of the base state.

When the Phone-application was dragged out it would show the so called *"Phonebook"* where one could search for any contact in the list. In the Phonebook-app a tab called *"Favorites"* was to the left and a second tab called *"Recent"* to the right. In the Favorites-tab only the selected favorite contacts was available and in the Recent-tab the recent and missed calls was displayed, both of them had lists to display the contacts. If the user would drag out the Favorites-tab, the system would lay the Phonebook- and Recent-tab to the right of it. If the user would instead drag out the Recent-tab, the other two tabs would lay themselves to the left of it. This however caused a problem due to the fact that there was not much room for the tabs to appear on the application, and with so much information and texts that needed to be displayed at once, this was later redesigned.

When the Navi-application was dragged out, it would show a tab with a map (see fig. 5.6a), showing the current geographical position and the route for the set destination. The left tab held the favorites and recent set destinations (see fig. 5.6b), and the right tab lead to a search mode of destinations.

(a) The main view of the Navigation-application.



(b) The Favourite and Recent-tab in the Navigation-application.

Figure 5.6: The design from the first iteration of the Navigation-application.

When the Music-application was dragged out, it would first show a tab with the current selected playlist's or artist's tracks. The left tab was where the user could search and select playlists, and the right tab had a search list for all artists and playlists.

Reflections on the First Iteration

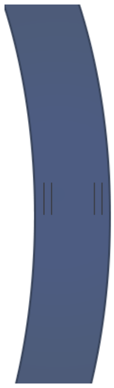
It was in this first iteration that the thesis was given an upgraded hardware with tactile functionality as well as touch input (see fig. 5.7). These input signals were put into real use and a lot of different ideas of how to interact with the system were tried out. The system was then implemented with both swipe and tactile functionality to switch between views. Different ways of interacting with items in e.g. lists and search-boxes was tested with both swipe and tactile input. Both seemed to be working well with list elements, especially swipe when longer lists were handled. However, the thesis had not yet reached a fully functional way of separating the distinction between gestures that was meant as a swipe/tactile input or a character input. At the time the physical Home-button, that would take the user back from the current tab and potentially directly to the Home-screen, was not in the current prototype available for the thesis, and was therefore simulated with a press on the computer's Space-button on which the system was running.

Figure 5.7: The newly shipped upgraded hardware that was used throughout the rest of the thesis.

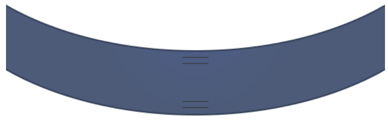
The First Iteration's Design

In this first iteration, an extensive amount of design was improved. QML enabled the thesis to work with different "states" that in terms of design can be quite complex. Portable Network Graphics or PNG-image files were created and assembled that was intended to look and feel like a distributable Volvo product. This task was not supported with a theoretical background on how Volvo's design department operates and undertakes design production. Rather, the thesis sought to create an interface that suited well in the DIM while still being comparable to the CSD-based SPA-design. The color scheme that was chosen was heavily based on the acquired image of a DIM prototype that was taken from the Volvo Car Group Concept Estate that was unveiled at the Geneva Motor show in February 2014 [49]. Fonts and size were also inspired by the concept, and were designed to be big enough for reading while driving. When designing the "pullers" that are the indicators for which direction the user should swipe to open apps, it was important to keep the affordance perceptible. This was done by designing two vertical (or horizontal) lines that would imply the affordance of that the component is movable (see fig. 5.8).

The design had now moved completely into the area that is allocated for the tachometer. This was implemented in a way that the interface was activated when the user touched the touchpad. When the user was not interacting with the touchpad, the display would go back to showing the tachometer.



(a) The horizontal puller.



(b) The vertical puller.

Figure 5.8: The pullers that were created and used in the prototype.

Evaluation of the First Iteration

The first iteration was evaluated in a similar way to the initial development. However, this evaluation added more focus on the design of the system. Test subjects were asked questions regarding interactions, color schemes and affordance. Before moving onto the next iteration, the thesis was determined to improve the design and usability, and to fully utilize the hardware's strengths.

5.3.4 Second Iteration

As the first iteration did not support all the necessary room for all the information that an application's tabs needed, the applications' architecture was redesigned. Applications now started on a specific tab and then have the other two unique tabs on the opposite direction as the application was dragged into the middle. If for instance the Phone-application was dragged into the middle, the starting tab would be a list of favorites. On the right side of the application was a tab back to the Home-screen was shown, and on the left side of the application there was a tab which would lead to the Recent-tab (see fig. 5.9). This tab would show a list of the most recent calls. To the right of it would had a tab which lead back to the first Favorite-tab, and on the left of that tab it would lead to the Search-tab where one could search for all contacts in one's phonebook.

This tab had to its right two tabs, and if the user dragged from the right to the left on the touchpad they would get back to the Recent-tab.

Figure 5.9: The old design of the Phone-page Recent-application.

This architecture would solve the problem with an applications tab not having enough room for the information. However, when shorter user test were conducted on this system and layout, it quickly came clear that it was a tedious work to actually get back to the Home-screen if a user was at the end of an application. In this iteration was the interacting with list and search-boxes was solved and the iteration created different functions and algorithms for handling if the user was meaning to move around between the applications or entering a character.

The Second Iteration's Design

From a design point of view, the system was updated with developed image files that were suitable to the interface solution (see fig. 5.10). These images were adjusted to being able to use more of the display area, and to better highlight the important information. The overall Look and feel of the interface was however not changed much.

Evaluation of the Second Iteration

The evaluation of the second iteration was greatly assisted by the appointed supervisor at Volvo. With valuable insight in the layout architecture, he aided the thesis to take beneficial decisions regarding how the system would excel in terms of the interaction design. The supervisor was given a longer stretch of time to examine, evaluate and formulate thoughts and ideas of improvement to the implementation. This due to the

Figure 5.10: The second iteration's Home-screen.

fact that time was running out and the thesis knew that only one final iteration would be possible to perform before the user tests. It was in this evaluation that the thesis members came up with the title of the thesis and name for the prototype; *"SteerPad"*.

5.3.5 The Third and Final Iteration

The third and final iteration was used during the user tests and will be further discussed in the *Result chapter*. This is due to the fact that the thesis meant to deliver an implementation along with answering the research question, it is seen as a result of the thesis. The final implementation of the system was not changed after the user tests even though ideas came up during them. The thesis did however write down every new problem and bug that was found during the user tests, along with appropriate comments from the testers that pointed towards problems and solutions.

Known Bugs in the Final Implementation

As the delivered touchpad system was a prototype which had no physical Home- or Back-button which was indicated at the beginning of the thesis work, some of the solutions were affected by this. The Home-button was initially simulated by pressing a keyboard button and was in the user tests configured to be triggered by pressing a button on a mouse which was put in the steering wheel. A few bugs and errors still remained in the used implementation in the user tests. One of the bugs was for instance that some graphical animations lingered on when a user was in a list and switching between elements, the highlight around the currently selected element was not updated correctly. Due to time issues these were overlooked as they did not compromise the result of the user tests. Other known problems had to do with the hardware. The tactile functionalities did not work unless pressed in a certain quadrant in the hardware, and would not trigger the right action. Furthermore, the prototype could sometimes lag, because of the complex nature of the connection between computer and hardware (see fig. 5.11).

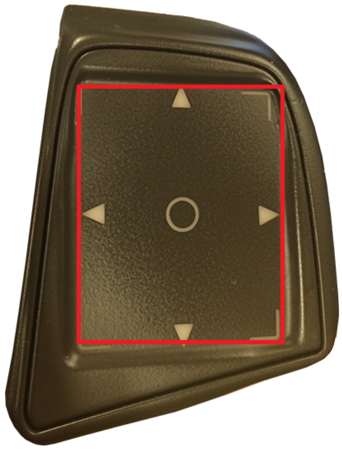


Figure 5.11: The red area visualize the quadrant where the input signals are correctly interpreted.

5.4 Evaluation Phase

This section addresses the main areas and techniques that was used, related and carried out during the final evaluation of the user tests.

5.4.1 User Tests

When all the parts of the prototype were implemented to the extent that they were ready to be tested, iterations of evaluations on segments and functions took place in parallel with the development. At this point, the next step was to plan user test to evaluate the prototype. A limitation was that testing had to be made in a lab environment and not in a real car on the road, this was due to several factors. First of all, the hardware demanded a quite intricate installation process that would be very time consuming to do in a car. Secondly, the hardware needed router access, which also would be a large inconvenience to install. Furthermore, installing and using the chosen eye tracking system, would also include the use of several laptops and on-the-road calibration, which the thesis deemed unreasonably excessive. Therefore the tests were to be carried out in a simulated driving environment, namely Volvo's HMI Usability Lab [50] (see fig. 5.12).

This lab offers a great range of scenarios and testing capabilities that suited well to thesis' use cases. Eye-tracking was the most important parameter, being a necessity when testing against NHTSA's guidelines whereby the lab offered two different systems for eye-tracking. One was Smart Eye [51], and the second system was Ergoneers [52]. The thesis decided to do the user tests with the Ergoneers *Dikablis Glasses* eye-tracking system, with the reasoning that the laboratory experts recommended it due to a higher pupil detection rate.

Figure 5.12: Volvo's HMI-lab (image from video). (source http://www.completemedia.se/)

The SPA System

The other criteria that the thesis wished to test the prototype against, apart from NHTSA, were an existing system that was implemented in present Volvo cars. A discussion was ongoing with supervisors and employees about which of the Volvo systems the prototype would be tested against. Two main requirements were decided on:

1. *The system should be tested against an already released product.*
2. *The released system should be able to be placed and tested against in the HMI-lab.*

With these requirements the discussion moved away from the interesting idea to test the prototype against another ongoing project's prototype. A decision was made to test the system against a CSD-based SPA-system (Scalable Product Architecture) [1]. The thesis wanted to test against a DIM-based SPA-system, but as the HMI-lab did not have any simulation for it, the CSD-based SPA-system on an iPad had to suffice. SPA is a new architecture that Volvo released in which the driver is the core of the Volvo Car, extended by a 360 degree system of technology that puts her in contact with the surrounding world. Some key matters are presented with SPA. Embracing the driver is a motto, where safety is the key factor and is constantly being enhanced, an example is the more extensive use of boron steel. Smart automobile features are also included into the architecture such as: *Crash Avoidance and detection*, *Seeing around the corner*, *Steer assist*, etc. However, the one this thesis has focused on is the notion to always be in touch with the world. Volvo acknowledges the difficulties that connectivity brings when applying it to the driver's seat, from a safety perspective, and a large touch display acting as CSD has been carefully developed. When comparing the systems in the user tests, an iPad was placed where the CSD usually is in the car. This display is what the thesis chose to compare the prototype against.

The SPA Display

A multifunctional system (see fig. 2.1 in earlier chapter) has been developed by Volvo and implemented in the form of a large touch display in the center stack of Volvo cars. This interface substitutes all functions that were available earlier, and extends these with new possibilities that touch displays offer. The interface has three main tabs that are swiped between in a horizontal fashion. One for driving assistance, one for four main apps (Navigation, Music, Phone and Climate) and one for further applications. These apps are all managed by touch interaction. It was an early decision to restrict the testing comparison to the applications: Navigation, Music and Phone.

5.4.2 Inviting users

As the thesis project was classified, only people from Volvo could attend the user tests, but when inviting users to the test study, the thesis tried to get a good spread of age from the personnel available. The NHTSA guidelines recommend that each group of test participants used for testing, there should be an even spread in the age groups: 18-24, 25-39, 40-54, and 55+ [7]. The thesis tried to sort the test users into three age groups instead of four as the guidelines recommend, this due to the fact that thesis was told that the Volvo employees over 45 was said to not usually participate in simulation tests. The first group was people between the ages of 18 to 24, a second group of people between the ages 25 to 35, and the third and last group of people between the ages of 35+. It should also be noted that the thesis tried to invite so that all the three groups was half male and half female users. This however was not achieved even though sending several requests to female employees. The proposition to get three different age groups was also somewhat not achieved as the thesis had trouble to get people in the first age group, people of the ages 18 to 24, to attend the user test (see table 5.1).

	Gender	Age	Work	Driving license	For X years
TP1	Male	42	Software Asset Manager	Yes	18
TP2	Male	56	Cost Estimator	Yes	38
TP3	Male	44	IT Strategy Manager	Yes	26
TP4	Male	46	Purchasing Manager	Yes	27
TP5	Female	28	Supplier Quality Management Engineer	Yes	11
TP6	Male	49	Research Project Manager	Yes	31
TP7	Male	61	Controller	Yes	44
TP8	Male	33	Purchaser	Yes	15
TP9	Male	38	Purchaser	Yes	21
TP10	Male	32	Senior Accountant	Yes	14
TP11	Male	31	Investor Relations Officer	Yes	13
TP12	Female	37	Interaction Designer	Yes	19

Table 5.1: Table of attending participants with their personal information.

As seen, only 2 out of the 12 participants were female, the average age was 41,14 within the range of 28 - 61 years old, the median age was 55, and all of the participants have had a driving license for over 11 years or more.

The way that the tests were carried out was as following. The user was introduced to what the thesis work was about and what kind of system that had been implemented. Known bugs and errors were also mentioned so that no confusion and irritation would come up during the test if they occurred. They were also told about how the testing should be performed, and if they agreed on being filmed and recorded when doing the tasks during the test. The way it was performed was that the user was placed in the driver seat along with one of the thesis members in the passenger seat, arbitrary starting with one of the systems, CSD (SPA) or SteerPad, first. The other thesis member would sit behind the car to take notes and managing the Dikabils systems. The user would then be introduced to the system by operating the system themselves. When they felt comfortable enough with the system, they would be guided to do the use cases set up for the specific system standing still. The thesis member sitting in the passenger seat would read a scenario from a manuscript during the tests. If they were comfortable with that they would then do the same tasks again, but this time driving in the simulator where a simulated car was in front of the user. The user was asked to keep a reasonable distance to the car in front during the tasks. When they and the thesis members felt that the user knew the system well enough would the actual test begin with the eye-tracking system. The NHTSA guidelines specify this to be of utmost importance as the user should not be tested on a task that they are not familiarized with. When the calibration of the eye-tracking system was completed, the recording and data collection would begin, and the user would do the same use cases again. This time however, the thesis member sitting next to the user would say the task but the user was not allowed to start until the thesis member sitting behind the car said "Start". This was due to the fact that the Dikabils system had to be given a unique keyboard input for each task. When the thesis member pressed the assigned letter on the keyboard the system would mark the time and task in the recorded video. During the test the user was again asked to keep a reasonable distance to the car in front of them. When the user was finished with a task the same key had to pressed again to end the marking of that task. If a user would make a mistake during the actual test, the user would simply do that task once again until he/she completed the task with no errors. As the tasks were completed, the user would then be asked to rate that specific systems' different parts with four questions on each on a 1 to 5 rating scale. After the ranking was completed the same procedure would be carried out with the other system. Finally, when the user had completed the testing of both systems, they would be interviewed and asked more general questions about the systems. A question that was asked for instance was about the pros and cons between the two systems, where the user answered in a Think-aloud kind-of-way (see Appendix X for the entire questionnaire). Each test was given 1,5 hour of time, but took approximately only 1 hour to perform. Between each participant there was a 15 minutes break so that all the systems could be reset so that everyone had the same starting point.

5.5 Data Evaluation

After all the tests had been carried out, the data from the eye-tracking system would be processed. When processed, the Dikablis program would give a percentage of how much of the pupil detection had been during the test. The lowest percentage that was used was 91 percent, but sometimes the percentage could be lower than that and after-calibration had to be done on that specific recording session. The thesis results come from the evaluation based on the NHTSA regulations, which presents three different criteria. The first criteria demands that 87.5 percent of all the participants must have an individual percentages of less than 15 percent of the total glances that are 2 seconds or below to pass. The second criteria demand that 87.5 percent of all the participants must have a mean value of 2 seconds depending on all the glances they did. The third and last criteria demand that 87.5 percent of all the participants finish a task in 12 seconds or below. The eye-tracking data would serve to help the thesis' questions about the safety and task completion time. The evaluation is secondly based on the statistical and qualitative answers that the test users gave after they had tested both the systems, and also the recordings that were filmed during the tests. These would serve to answer the thesis' questions about the usability and user experience. The way that the eye-tracking data and the statistical data from the questionnaires were analyzed was by setting up spreadsheets for the different users and questions. The eye-tracking data would be interpreted to see whether or not the three criteria were met or not by using mathematical calculations in the spreadsheets. The statistical data from the questionnaires was interpreted in the same manner, however, here the data had to be set up in a way so that both individual and general data could be analyzed. This was done by summarizing all the ranking scores for both system for a user and then compare which system had the highest individual ranking score. Then the general data was calculated by combining all users' ranking scores on each question and calculating the mean value of each question. The recordings helped the thesis to do a *Cognitive Task Analysis* to see when and where certain errors were made and also in to see how the user was interacting with the system (e.g. which finger the user was using the SteerPad system with).

6

Result

IN THIS CHAPTER THE FINAL ITERATION of the development and design will be described, which is also the prototype that this thesis delivers to Volvo. This chapter also presents the compilation of results that came from the user tests in an extensive and thorough manner.

6.1 The Final Implementation

For the third and final iteration a few new ideas of how to solve the orientation issue were designed. The main goal was to quickly get to each application and its unique features, so the thesis went back to the second iteration's ideas and redesigned the interface to an updated crossroad-layout. The changes were made so that the three applications, except the Music-application, had only one tab. The Music-application came to have two tabs, one with the current playlist's tracks and one with all the playlists. All of these four tabs were however implemented in a similar list-management manner 6.1.

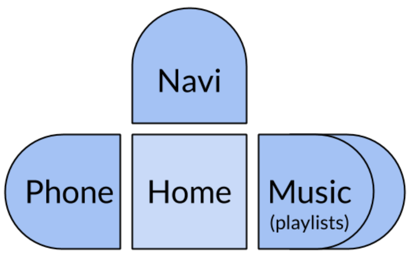


Figure 6.1: The final iteration's architectural layout.

Each application had three different states; first an *Inactive-state* where the user could swipe or press their way back to the Home-page. By pressing in the middle of the touchpad the user would enter the second state, the *Active-state* (see fig. 6.2).

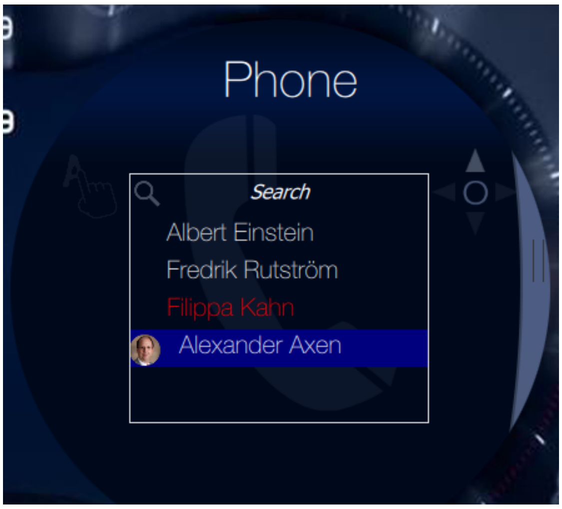
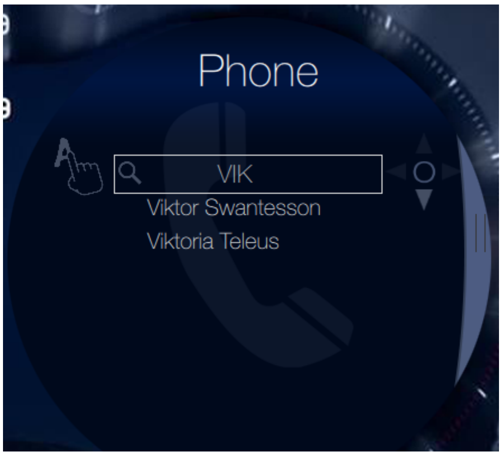


Figure 6.2: The Phone-application's Active-state where the user can overview and interact with the recent calls list.

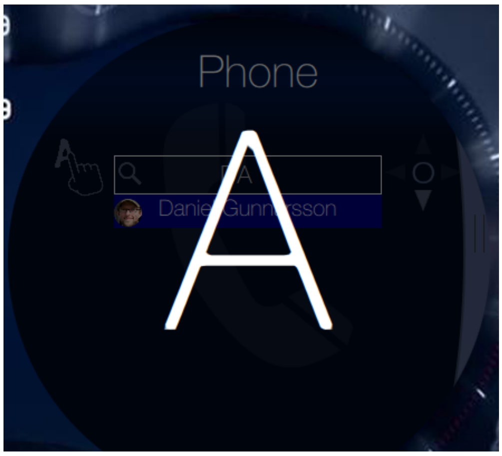
In this state the user entered a unique list for each application. If e.g. the Navi-application was activated the user would enter the recent destination list. If the user then would either swipe or click their way through the list they could select the currently highlighted item by pressing in the middle of the touchpad. If they navigated the selection highlight up to the top of the list, they would be able to active the application's search function. When the user then actively pressed in the middle of the touchpad, they would enter the *Search-state* for that specific application. In this state they could enter characters by the use of the pattern recognition on the touchpad. The entered characters would instantly update the list according to the input. The characters that was found would be displayed as big letters over the list for a short amount of time so that the user easier could see which character that the system had found (see fig. 6.3a and fig 6.3b).

In the Phone-application a clicked name would bring an overlay over the list with that persons profile picture and the option to either call or message the person. As the messaging functionality was not implemented nothing would happen if the user clicked or swiped that option. In the Navigation-application a selection of destination would display an overlay text with the newly set destination and the system would then bring the user back to the Home-page (see fig. 6.4).

In the Music-application's Current-playlist-tab, a selected song would be played as the new song. After the user had selected a new song, the system would return to the Inactive-state of that tab. In the Music-application's Available-playlist-tab, a selection of a playlist would take the user back the Active-state of the Current-playlist-tab with the newly selected playlist's tracks.



(a) The Phone-application's Search-function which will display the contacts depending on the character input.



(b) When writing a character in Search-mode, the system will print the character over the page for a short amount of time.

Figure 6.3: The Search-state of the Phone-application.

Figure 6.4: The screen that comes up giving feedback to the user that the clicked destination has been set.

In this third and final iteration, all functions and algorithms was either improved or created to make a better user experience. One of these improvements was sound feedback when navigating through lists. A "clicking" sound was played every time the user switched between active elements in the list. Design of the audio file took place in a music software called Ableton, in which the thesis sought to create a subtle yet effective sound. A comprehensive software guide was used to learn and understand how to create a satisfactory sound [53].

6.2 The User Tests Result

In the following section all the data from the user tests will be presented. Take note that the SteerPad system will have eight tasks and the CSD (SPA) system will only be presented on six tasks. This was due to the fact that the thesis added two tasks for the SteerPad, one for answering an incoming phone call and one for dismissing an incoming phone call. This could not be done with the CSD (SPA) system as this software was on an iPad and the thesis could not simulate phone calls.

6.2.1 Eye-tracking Data

The tasks are shown one at a time with the three NHTSA criteria called accepted criteria (AC).

Eye glance acceptance criteria as stated earlier in the Theory chapter:

- *AC1: For at least 21 of 24 test participants, no more than 15 percent (rounded up) of the total number of eye glances away from the forward road scene should have durations of greater than 2.0 seconds while performing the testable task one time.*
- *AC2: For at least 21 of 24 test participants, the mean duration of all eye glances away from the forward road scene should be less than or equal to 2.0 seconds while performing the testable task one time.*
- *AC3: For at least 21 of 24 test participants, the sum of the duration of all eye glances away from the forward road scene is less than or equal to 12.0 seconds while performing the testable task one time.*

The following tables show the criteria percentage from all the users compiled according to the NHTSA guideline (see Appendix X for more detailed data).

Accepted Criteria	CSD (SPA)	SteerPad
AC1	-	91,67%
AC2	-	91,67%
AC3	-	91,67%

Table 6.1: Task 1 - Answering an incoming call (SteerPad only).

Table 6.1 show the results of the task of answering an incoming phone call. The SteerPad system passed all three NHTSA criteria with an average percentage on all users of 91,67%, while the CSD (SPA) system was not tested in this task.

Accepted Criteria	CSD (SPA)	SteerPad
AC1	33%	50%
AC2	91,67%	100%
AC3	91,67%	100%

Table 6.2: Task 2 - Select recent address X.

Table 6.2 show the results from the task where the user was asked to select a specific recent address. Both the CSD (SPA) and SteerPad systems failed on the first criteria (AC1), but passed the second (AC2) and third criteria (AC3). Note that SteerPad system has a higher percentage on every criterion.

Accepted Criteria	CSD (SPA)	SteerPad
AC1	75%	75%
AC2	83,33%	100%
AC3	100%	100%

Table 6.3: Task 3 - Select track X from playlist Y.

Table 6.3 show the results from the task where the user was asked to select a certain track, in the current playlist. The CSD (SPA) system failed on the first two criteria, but was close to pass the second criteria. The SteerPad system failed on the first criteria, but had a full score on the second and third criteria. Note that the SteerPad system has a higher percentage on the second and third criteria.

Accepted Criteria	CSD (SPA)	SteerPad
AC1	-	100%
AC2	-	100%
AC3	-	100%

Table 6.4: Task 4 - Ignore incoming phone call (SteerPad only).

Table 6.4 show the results from the task where the user was asked to ignore an incoming phone call by dismissing it. The SteerPad system had full score on the three criteria. The CSD (SPA) system was not tested in this task.

Accepted Criteria	CSD (SPA)	SteerPad
AC1	33%	83,33%
AC2	91,67%	100%
AC3	66,67%	50%

Table 6.5: Task 5 - Search for and select destination X.

Table 6.5 show the results from the task where the user was asked to search for and select a new destination. The CSD (SPA) and SteerPad systems failed on the first and third criteria but passed on the second criteria. This task was the worst for the SteerPad system as it failed on two criteria. Note that the SteerPad system has a higher percentage on the first and second criteria.

Accepted Criteria	CSD (SPA)	SteerPad
AC1	25%	91,67%
AC2	83,33%	100%
AC3	91,67%	100%

Table 6.6: Task 6 - Call the last missed phone call.

Table 6.6 show the results from the task where the user was asked to call the last missed phone call. The CSD (SPA) system failed on the first two criteria but passed on the third criteria. The SteerPad system passed on every criterion. Note that SteerPad system has a higher percentage on every criterion.

Accepted Criteria	CSD (SPA)	SteerPad
AC1	16,67%	91,67%
AC2	100%	100%
AC3	66,67%	66,67%

Table 6.7: Task 7 - Search and call person X.

Table 6.7 show the results from the task where the user was asked to search for and call a certain person. The CSD (SPA) system failed on the first and third criteria but passed on the second criteria. The SteerPad system passed on the first and second criteria but failed on the third criteria. Note that SteerPad system has a much higher percentage on the first criteria.

Accepted Criteria	CSD (SPA)	SteerPad
AC1	58,33%	66,67%
AC2	91,67%	100%
AC3	91,67%	100%

Table 6.8: Task 8 - Select previous track X.

Table 6.8 show the results from the task where the user was asked to select the previous track in the current playlist. The CSD (SPA) and SteerPad systems failed on the first criteria but passed on the second and third criteria. Note that SteerPad system has a higher percentage on every criteria.

In the following table 6.9, a summation of all the passed criteria for the both system is displayed.

Accepted Criteria	CSD (SPA)	SteerPad
AC1	0 / 6	5 / 8
AC2	4 / 6	8 / 8
AC3	4 / 6	7 / 8

Table 6.9: A summation of all the tasks' with passed criteria.

Table 6.9 illustrates a great favor for the SteerPad system. The SteerPad system passed 20 out of 24 (83,33%) available NHTSA criteria whilst the CSD (SPA) system only passed 8 out of 16 (50%) available NHTSA criteria. Note that the CSD (SPA) system did not pass any of the tasks on the first criteria, where 87,5% of the participants had to have no higher than 15% of their total glances to exceed 2 seconds, whilst the SteerPad system passed 5 out of 8 of the tasks.

6.2.2 Questionnaire - Statistical Data

The statistical data from the questionnaires has been compiled and is presented in the following section.

The questions prompted the user to rate the three different applications in the CSD (SPA) and SteerPad systems from 1 to 5, 5 being agreeing the most. The ratings from all the users were summed up and divided with the total number of users to get a mean value. The mean value is presented in the following tables with the questions for each application (see Appendix X for more detailed data):

NAVI	I find the system easy to learn:	I find the system efficient to use:	I experience that the system is safe to use while driving:	I find text and icons understandable:
CSD (SPA) mean:	3,83	3,08	2,33	3,83
SteerPad mean:	4,25	4,33	4	3,91

Table 6.10: Displaying the mean values on the Navigation-applications for the CSD (SPA) and SteerPad systems.

Table 6.10 regarding the Navigation-application, show that the SteerPad system has a higher mean value on each of the four questions. Note that the mean value on the third question regarding safety is much higher rated on the SteerPad system.

MUSIC	I find the system easy to learn:	I find the system efficient to use:	I experience that the system is safe to use while driving:	I find text and icons understandable:
CSD (SPA) mean:	4,5	4,08	3,58	4,41
SteerPad mean:	4,25	4,08	3,83	4,25

Table 6.11: Displaying the mean values on the Music-application for the CSD (SPA) and SteerPad systems.

Table 6.11 regarding the Music-application, show that the CSD (SPA) system has a higher rating on two of the questions and the SteerPad system only has a higher rating on one question. The mean value on the second question regarding efficiency was even between the two systems. Note that the SteerPad system still has a higher rating on the third question regarding safety.

PHONE	I find the system easy to learn:	I find the system efficient to use:	I experience that the system is safe to use while driving:	I find text and icons understandable:
CSD (SPA) mean:	4,08	3,66	2,83	4,08
SteerPad mean:	4,41	4,58	4,33	4,08

Table 6.12: Displaying the mean values on the Phone-application for the CSD (SPA) and SteerPad systems.

Table 6.12 regarding the Phone-application, show that the SteerPad system has a higher rating on the first three questions. The rating on the fourth question regarding design was even between the two systems. Note that the rating on the third question regarding safety is much higher on the SteerPad system.

Below is table 6.13, where the each participant's rating has been summed up to see the individual preference between the two systems.

	Navigation	Music	Phone
CSD (SPA):	1	5 (1 even)	1 (2 even)
SteerPad:	11	6 (1 even)	9 (2 even)

Table 6.13: Displaying the two systems three different applications and the number of users that had a ranked that application higher.

Of the 12 test users, based on their individual ranking scores on the different applications of the two systems, 9 of the test users had a higher score on the thesis' SteerPad system. Only 1 of the test users had a higher score on the CSD (SPA) system, and 2 of the test users had an even score between the two systems (see Appendix X for more detailed data).

6.2.3 Questionnaire - Qualitative Data

From the qualitative questions in the questionnaires, the following results could be compiled.

Which system felt safer to use while driving?

10 out of the 12 users said that SteerPad was safer, while 2 said that CSD (SPA) felt safer to use while driving.

Why?
From the 10 that said SteerPad in the previous question, 5 of them said that it was due to being able to keep both their hands on the steering wheel. The other 5 gave no explanation. The 2 that answered CSD (SPA), said that it was due to the fact that the screen was bigger and therefore easier to get an overview of the system.

Do you feel that the SteerPad (the system in the steering wheel) is enjoyable to use?
12 out of 12 users answered “Yes”.

Are there any specific parts of our SteerPad that you feel are innovative or interesting?
4 of the users said that the character recognition was interesting and worthwhile exploring, 2 said that they liked the swipe-functionality.

Do you have any suggestions of how the SteerPad could be improved?
4 of the users said that they would like the touchpad to be more ergonomic and have some sort of surface that distinguishes where the finger is. 3 users said that they would like to add voice control to the system. 2 users said that the Home-button should be developed. 2 users would like to have some of the information, e.g. the character input, displayed in the HUD for more security. 3 users also said that some sort of quick-search would be good, e.g. if the user is in the Phone-application and wrote a “P” on the touchpad, then all the people with “P” would show.

If you compare the two systems, SPA and SteerPad, which components are better or worse?
6 of the users said that short commands and tasks were better in SteerPad since it was closer and had a good search-function. 3 of the users said that the visual layout and design was better in CSD (SPA) since it is bigger and therefore easier to see.

Do you have any feedback regarding the SteerPad system?
2 of the users said that the SteerPad’s touch area should be design so that is will be more ergonomic. 1 user said that it was confusing with having both swipe and tactile functionality. 1 user said however that it was good to have both swipe and tactile functionality. 2 users said that they did not like that they had to press the touchpad to enter a list and would instead like to directly be able to manipulate the list. 1 user said that the touchpad was a little bit small and therefore harder to use.

6.2.4 The Video Recording Results

From the recordings and observations (see fig. 6.5) a *Cognitive Task Analysis* was made on the SteerPad system. It was found that 8 out of 12 users used their thumb to interact and write characters to the system. The other 4 users used their index finger to interact and enter characters to the system. The 4 users were mainly using their index finger for entering characters, but when navigating through the system they used their thumb. The recordings also showed that the main issues when a user was making a mistake was usually due to the fact that they did not let go of the hardware when entering a new state or that they were too quick with entering characters. As the implementation of the system limits the user to only enter one type of input at a time, it is necessary to let go of the touchpad between different inputs. The meaning of *type input* in this case means that the user cannot do tactile interaction and then directly do swiping interaction to the system and vice versa.

Figure 6.5: One of the test users using the SteerPad system in action in the simulator.

7

Discussion

When examining the process and the results of this thesis, one might believe that the project was a success and that the outcome is unambiguously pointing out which direction this technology and development should take. The underlying facts and conclusions are however quite hard to elicit, and need to be put to light to fully understand the advantages that are presented. This chapter will present the discussion that this thesis has carried throughout the project.

7.1 Result Discussion

The results are discussed from two aspects, one in the NHTSA regulations point-of-view and one regarding the test users' questionnaire answers.

7.1.1 NHTSA Result

User testing of the prototype did in the end prove to be a lengthy process, but rewarding nonetheless. Analyzing the results on the statistical data from the eye-tracking recordings regarding the NHTSA regulations, show that SteerPad passed 20 out of 24 criteria and the CSD (SPA) only passed 8 out of 18 criteria. This was a much higher than expected outcome for the SteerPad as these regulations are, according to the supervisors at Volvo, hard to live up to. On that basis, the thesis is very content with these results.

The three different criteria have during the thesis been divided into levels of importance. The first criteria (AC1), where 87,5% of the participants has to have no more than 15% of their glances to exceed 2 seconds, is considered by the thesis members to be the *second most important* one. To keep the eyes on the road is absolutely crucial for the driver, and it is therefore important that the glances do not exceed 2 seconds. To be able to make shorter glances and still completing a task is essential when designing an in-vehicle interactive system.

The second criteria (AC2), where one calculates the mean duration of all the glances which should not exceed 2 seconds, is quite similar to the first one. This criteria is however seen by the thesis to be *even more important* than the first one. The reasoning behind this is that even though a user may pass the first criteria, he/she could still have glances that greatly exceed 2 seconds which make no impact on the first criteria, but evidently would deem the second criteria to fail. That a driver looks away from the road for e.g. 5 seconds, could certainly be seen as far more dangerous than a few glances that are just over 2 seconds.

The third criteria (AC3), where one adds up all the glances from the driver and the summation should not exceed 12 seconds, is of course important. However, the thesis members argue that it is more important that the first two criteria are met than that the driver is completing a task in less than 12 total seconds.

As the SteerPad system passed 5 / 8 possible tasks of the first criteria, 8 / 8 of the second criteria, and 7 / 8 of the third criteria, the thesis members see this as a tremendous success.

7.1.2 Questionaire Result

The statistical data from the questionnaires showed better general and individual results for the SteerPad system compared to the CSD (SPA) system. A total of 9 users had a higher individual rating on the SteerPad system. Only 1 user rated CSD (SPA) higher, and 2 users had an even rating between the two systems. Furthermore, the SteerPad had a higher rating on the three different applications (Music, Navigation, and Phone) in 8 out 12 possible questions, and on all three different applications the SteerPad had a higher rating on the question regarding safety. 2 of the 12 questions had the same mean value, one regarding the design and one regarding the efficiency of the system.

The 2 questions in which the CSD (SPA) was rated higher than SteerPad was regarding how easy it is to learn the systems, and the other was regarding the design of the systems. The thesis members believes that the reason why the "Easy to learn"-question was rated higher on the CSD (SPA) system was partly because it has a very straightforward way of changing tracks, which was what the tasks regarding the Music-applications was about. It only requires one click by the user to change the track when in the Music-application of CSD (SPA), when it takes one click, then clicking/scrolling to find the right track in the SteerPad system. Regarding the question about the design, it should be noted that the SteerPad system did not add art albums on their playlist's and tracks as the CSD (SPA) did. This was due to the small display area that was available for the system and also because of time limitation.

As the questionnaire covered questions regarding usability, user experience, safety and design, which were stated goals and objectives in the project, this positive result is certainly proof of success for the thesis.

From the qualitative answers in the questionnaires, the users had a positive attitude towards the SteerPad system with only a few complaints. Some of the complaints addressed the SteerPad's physical design and placement, which made some of the users hold the steering wheel in an unnatural way while driving and using the system. A few of the users that complained about this did not change the way they held the steering wheel. Hence, the angle of the finger made it harder for them to perform a gesture and/or write a character that was interpreted correctly by the system. The placement and physical design of the system could not be altered by the thesis as this was the given system that the thesis got from the sub-supplier. As to the complaints regarding that the graphical design was better and bigger in the CSD (SPA), this opinion is understandable and to some extent shared by the thesis members. The small amount of resources that could, and has been put on design, could still not be able to match a product that is marketed. The graphical design of SteerPad could certainly be improved in some areas, but as time ran out the thesis had to stop when the user tests began. The thesis members are still pleased and satisfied with the current design that was achieved on this time period.

The questionnaire implies, from both the statistical and qualitative answers, that the thesis' goal and objective to increase the safety when driving has been achieved. Even though the short amount of time that the thesis had to implement and develop the system, the user tests shows that the SteerPad system has great potential in increasing the user experience, lowering the driver distraction and thereby increasing the safety. With further development this system could surely help improving the driving experience even more.

With regard to test participants being company employees, one might argue that the questionnaire was answered with a lighter state of mind, where the test user wanted to be kind and helpful. However, it can also be argued that a company employee wishes the best out of every project, and thereby would give stronger feedback in order to give better constructive feedback. Because this was impractical to measure, it was assumed that all test participants were stating their true perceptions and opinions.

7.2 Implementation and Design

The finished prototype that was produced is a product that the thesis is very satisfied with. In terms of interaction design, there is a shared opinion by the test users and the thesis that the final product is enjoyable and effective to use. Usability was a strong consideration throughout the design process, and was reflected upon during the iterations. The effectiveness was proved in the user tests, in which the users completed all use cases with great accuracy. On the subject of efficiency, the prototype requires very little from the user to reach effectiveness. To complete tasks, the user simply needs to direct focus and interact with the finger of choice. Satisfaction is also a usability trait, which the prototype seems to provide, as the users were very satisfied with the level of comfort and workload that the system requires.

When evaluating if the system provides perceptible affordance, the systems graphical elements are critical. The thesis has come to a conclusion that there are two main parts where affordance is most crucial; swiping between apps with the sliders/pullers and when interacting with the list structures. From the user study, it became obvious that these elements had a level of perceptible affordance, but that the list structures have room for improvement. One might argue that the *volume up and down* functionalities are of hidden affordance. This is because there is no apparent indicator that pressing in the top or bottom right corner will adjust the volume. However, the thesis finds the solution suitable and recommends that a physical appearance should be designed to make the affordance perceptible.

The look and feel of the system, namely the designed presentation of the application towards the user, is something that the thesis is also quite satisfied with. By studying Volvo's previous systems and current concepts, a suitable and pleasing solution has been reached.

When designing user experience (UX) it can be difficult to evaluate whether the system provides a good or bad experience. The designer needs to understand all the perceptions and responses that the user has from the result of using the system. These include; emotions, beliefs, preferences, perceptions, physical and psychological responses, behaviors and accomplishments. However, when examining the user tests one can clearly see that most of the users had a good experience while interacting with the prototype.

Messaging functionalities were designed but not implemented. There are many reasons for this decision. When studying the NHTSA guidelines it was learnt that *"manual text entry by the driver for the purpose of text-based messaging"* is not recommended and should therefore be excluded from the system, unless further studies and implementations are found to meet the regulations.

The usability paradox that was discussed in the *Theory chapter* depict the driving risk that emerges when the user actually will spend more time with a more superior system than with a poor one. When investigating the user test result, it is clear that the users felt that the prototype was enjoyable to use. Notwithstanding, the test results also point out that the prototype almost passed all the NHTSA criteria, which certainly is proof that the paradox is not noticeably present in the thesis' solution.

7.3 Answering the Research Question

Studies that were conducted at the beginning of the thesis came to see a gap that existed between automobile safety and in-vehicle infotainment. The thesis sought knowledge on how to decrease this gap by developing and testing the so called SteerPad system. With a touchpad that was installed onto the right side of the steering wheel, the thesis designed and developed an environment to assess this gap. The thesis came to have the following research question:

> *How can a touchpad that is integrated in the steering wheel that controls the DIM functionality, fulfil the requirements from the regulations defined by NHTSA for safety issues, while also providing a positive user experience?*

The research question was decomposed into three parts:

1. Can a touchpad enhance the usability and user experience of an in-vehicle infotainment system?
    - Meaning that to research whether the time of completion of tasks could be lowered or in some way improved, and also if the satisfaction from the user is heightened.
2. Will a touchpad integrated in the steering wheel decrease the so called linguistic barrier between the current infotainment systems, while also meeting the requirements from the regulations?
    - Because DIM and CSD would now both be controlled by touch based interaction, an understanding on how to control the systems and their architectures in concert is vital.
3. And finally what kind of potential can a touchpad bring to today's car system?
    - Potential in this sense means that this could be something worth investigating further and invest in for Volvo.

To answer the first (1) of these sub questions, the usability and experience have according to the results from the user tests indeed been enhanced and improved. The SteerPad system has been shown to be effective and enjoyable to use, both from statistical and qualitative answers during the user tests. In regards to driver distraction that was mentioned in the *Theory Chapter*, the distraction during the test could be said to be both binary and continuous. This due to the fact that even though the SteerPad system demands fairly short glances it could be seen as more continuous, but is still binary in some sense as test users were fairly new to the system. Hence, if they were given more time to get to know the system, the expected result would surely require even shorter glances.

The second sub question (2), is harder to answer than the first one. Even though the thesis have seen patterns of shorter *Time of Completion* on cases where the user started with SteerPad system and then used the CSD (SPA) system, it is hard to definitely state that the linguistic barrier between the systems have been decreased. However, the results clearly show that the SteerPad system is able to pass most of the NHTSA regulation criteria where the CSD (SPA) system only passed a few of these.

The third sub question (3), the answer is based on both the questionnaire answers and the data from the eye-tracking data, and is the thesis interpretation that the system has enormous potential to be worth investigating further and investing for Volvo.

To sum up all of these sub questions to answer the main research question, the thesis is arguing that the eye-tracking and questionnaires results, show that it does meet the requirements in a usability and user experience point-of-view, and to most extent the regulations regarding safety set by NHTSA. The thesis has thereby taken a step towards decreasing the gap that was acknowledged in the beginning of the thesis.

7.4 Thesis' Methodology and Outcome

If the thesis had to be done all over again, the time plan and methodology would be quite similar. Of course some methods could have been carried out in a different way and some methods would have been added. However, as the members now know more about the regulations and have more experience in development, it would certainly be a more rapid process to implement the system as well as conducting user tests.

As the start of the development phase, much time was given to understand and implement the E-box's signals. A lot of that time could have been put to better use. If the thesis would have been able to start implementing the actual system and design earlier, considerable more sophisticated functions and bug fixes could have been implemented, therefore leading to an even better system. Furthermore, the design could have been assessed and developed more, in terms of aesthetics and affordance.

Using the tachometers allocated display area for the prototype proved to be a clutch decision. The thesis is very satisfied with how that solution turned out and feels that this direction has a very strong base of arguments for usage. One of the strongest reasons, the thesis feels, is that it allows for the system to be less cluttered, that the interface is only displayed when the user is interacting with it.

Looking back on the user tests the thesis members only regret is that they were not able to invite more participants. Especially with not being able to invite more female participants even though several attempts were made to contact female employees to attend. Regarding the user tests, one thing that could have been improved was that more data could have been collected such as; wobble, what mistakes that were common, and how/when the user did them. Due to the time limitation these were not collected, but if collected they could potentially lead to more findings and therefore making it easier to improve the SteerPad system. Other than this the thesis members feel that they conducted well-planned user tests that had a good introduction, use case scenarios, and questionnaires.

During the thesis, the members' has improved their knowledge in areas such as; coding (e.g. C++, QML), design, and user testing.

The members have learnt much about their own and each other's strengths and weaknesses during this time. They have also been given a great insight in how a real project is carried out in a big company.

7.5 Future Work

The SteerPad system is far from being fully functional. There are many known bugs that have to be dealt with. But after all there are many interesting areas of use, and functions that could be included in the system.

7.5.1 Bugs that has to be Fixed

As stated in the *Method Chapter*, there are a number of bugs and hardware issues that are known to the thesis and has to be fixed. For instance, a graphical animation issue regarding the currently highlighted element in a list, where it would sometimes linger and caused some confusion during user tests. A hardware issue that has to be dealt with is the physical Home-button that has to be added to the steering wheel. This would certainly add to the user experience and driver safety, as the thesis used a computer mouse to simulate the Home-button. This mouse was far from being in an optimal position in the steering wheel during the user tests. Another problem with the hardware was that the tactile functionalities did not work unless pressed in a certain quadrant on the touchpad. Lastly, the prototype could sometimes lag, causing the system to either crash or perform stacked actions after some time.

7.5.2 SteerPad - Thoughts and Ideas

The results from the user tests showed how the user is interacting with the current SteerPad implementation but also how the user could, and would like to interact with the system. The thesis believes that the system should utilize its most advantageous aspects; to keep things quickly reachable and easy to use. It is the thesis strongest opinion that the system should be kept as simple as possible to ensure the safety, while withholding the high level of user experience. The current system gives the user a fair amount of information and options while driving. The thesis does not recommend furthering adding of complex applications to the system. If so it should be tested and designed in a way that does not compromise the driver safety.

The architectural layout of the system could certainly be designed in another way than the current implementation. The thesis tried to replicate as much as possible from the CSD (SPA)'s architecture, but in the aftermath this is perhaps not the best way to implement a system that is located in the DIM. In the user tests, a lot of the participants had concerns about the extra interaction layer that one has to click to activate a list. If more work were put on distinguishing between gesture and character inputs, users could easier be able to interact with the system. Then a user could be able to *quick-search* in a list by typing a character, and then be directed to the according part of the system or current list. This would also need a more sophisticated character recognition library that can interpret multiple characters in a row.

The thesis members could clearly see a level of hardship with the current implementation of SteerPad when entering longer text input. This could be due to the fact that the current character library does not support the input of more than one character at a time. ALPS Electric has affirmed that this functionality is possible to add to the system, and it is the thesis' opinion that this should be done. This could certainly improve the user experience but should be further studied to see if any negative aspects will join this enhancement.

One of the answers to the questions from the user tests regarding how to improve the SteerPad system was that the system could benefit from using the HUD as an extra display. This was discussed in the early stages of the thesis, as well as when working with the system. It was also a consideration to use the HUD in the early stage of the thesis, but since the usage of the HUD would have taken far too much time to implement and connect with the DIM-display it was not prioritized in this thesis. However, it is the thesis members' strong opinion that the SteerPad system should in fact be connected with the HUD. This display could for instance be used to show the current highlighted item in a list or other types of selection areas. A character that the system interpreted when using the character recognition could also be displayed in the HUD.

If the SteerPad system also where combined with controlling not only the DIM (and/or HUD), but also the CSD for simple interaction, the user experience could perhaps be increased. This of course needs further studies to see its potential.

The design of the SteerPad system could also be improved, and an idea that the thesis had, that goes along with Volvo's new system SPA, is that the functionality and applications could be personalized. This would give further enjoyment to the user as e.g. some likes to listen to music while driving, when some people never listen to music while driving.

8

Conclusions

THE RESULT OF THIS THESIS PROJECT has been divided into two different parts. One result of the thesis is the implementation and design of the interactive prototype system, called SteerPad. This system is operated by a small touchpad on the right hand side of the steering wheel, and is implemented to control the automobile's DIM. The other outcome is the analysis of the data that has been compiled from pervasive user tests of the prototype. Eye-tracking data has been tested against safety regulations, and statistical as well as qualitative data from questionnaires has been analyzed in terms of user experience, usability, and potential.

Software development and design has been created from an interaction point-of-view. The prototype is framed by certain methodology to enhance usability, user experience and safety. Regarding the safety-issue that lie with developing *in-vehicle information systems*, the thesis has followed the NHTSA regulation guidelines. These regulations present three criteria that are strongly recommended to be followed in the car industry.

User tests were conducted on the SteerPad system to see what possibilities and potential that lies with this technology. An astounding 20 out of 24 use case with NHTSA criteria were fulfilled, which greatly reveals the potential that this system has. The thesis wanted to test the system against another DIM-system, but due to lack of simulation software in the HMI-lab at Volvo, a CSD with a SPA-system implementation had to suffice. The thesis system achieved a higher user rating score in almost every aspect, that is; *eye-tracking*, *statistical* and *qualitative* data.

The touchpad facilitates three main means of interaction; *swipes*, *tactile interaction* and *character recognition*. Two of these are well researched, but the *character recognition* is an interaction that just until recently has been integrated into cars. The SteerPad interface has three main applications that have been implemented; Navigation, Phone, and Music. All of these three applications are created in a list-hierarchical fashion. Character recognition has enabled the thesis to lower long and tedious text inputs. With this, in combination of swipes and tactile interaction, the thesis has been able to create a user friendly system.

This thesis has sought to assess the gap that exists between vehicle safety and infotainment. Evaluations of the system point towards that the system to some extent is moving in the right direction and has the possibility to decrease the gap. From these conclusions, this thesis is confident that the technology has been proved to be a valuable source, and feels that it ought to be conducted further studies in this area. However, it is important to keep the level of complexity down so that driver distraction can be minimized, yet still increasing, or at least maintaining the level of user experience.

If this project was to be taken further, there are a number of recommendations and thoughts that have emerged throughout the development and evaluation of the thesis. The use of a Head Up Display is of utmost relevance, due to several reasons. By a shared use of both the DIM and a HUD, an interface can potentially reach a level of safety that is even higher than the current system. If displaying the most important information in the HUD, the user can focus much more on the road while still interacting with the system. An example that is reasonable to consider is active elements; e.g. where the active element would be displayed on the HUD along with its adjacent elements, where the middle (active) one would be displayed larger. Another example is to use the HUD for interface feedback and other notifications, e.g. characters that are written.

The current hardware setup is a well-functioning one, but leaves some things to desire. First and foremost, the setup needs to be sorted in a different way than through WiFi connection, which is unfeasible in a vehicle environment. Secondly, it should be considered to design the touchpad in a more haptic and ergonomic way, and also to include suitable icons and tangible details that allow a more perceptible affordance. The implementation should also enclose the quadrant in which the user can press, so that no miss clicks will happen.

To summarize this thesis, it has been shown that the SteerPad system is a valuable source of research. As in many projects, there are many interesting areas in the thesis that needs further research and studies. But the SteerPad system has proven to be enjoyable, and to some extent a safer system to use than others.

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A

Eye-tracking Data

This appendix show all the raw data of the eye-tracking results on all eight use cases regarding the SteerPad system. The first row display all test participants. The following rows that starts with a number show the number of glances that each participant did and how long they were. The last four rows of each table means the following:

”>2s” shows the number of glances that were exceeding the limit of 2.0 seconds. ”%>2s” shows the percentage of all the total glances that a participant did. It should not exceed 85%. ”Mean” shows the mean value of the participants total glances. It should not exceed 2.0 seconds. ”Sum” shows the total time of all the glances a participant did. It should not exceed 12.0 seconds.

Glances	TP1	TP2	TP3	TP4	TP5	TP6	TP7	TP8	TP9	TP10	TP11	TP12
1	1	0,68	1	0,9	0,6	0,3	2,08	1,2	0,2	0,12	0,84	0,52
2		0,88	0,6	0,2		1,1		0,7	0,5	0,28	0,56	0,12
3		0,52				0,3		0,4	0,2			0,68
4								1,5				
5								0,8				
>2s	0	0	0	0	0	0	1	0	0	0	0	0
%>2s	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%
Medel:	1	0,6933	0,8	0,5	0,6	0,6	2,08	0,9	0,3	0,2	0,7	0,44
Summa:	1	2,08	1,6	1,1	0,6	1,7	2,08	4,6	1	0,4	1,4	1,32

Figure A.1: Displaying all the glances and the total time of each glance on task 1.

Glances	TP1	TP2	TP3	TP4	TP5	TP6	TP7	TP8	TP9	TP10	TP11	TP12
1	0,2	0,8	0,5	0,36	1,4	1	0,7	0,3	0,8	0,32	1,52	0,28
2	1	1,3	0,9	2,32	0,9	1	2,6	2,4	0,56	0,12	0,4	0,12
3	0,9	1	0,8	0,52		0,6		0,5	0,68	0,6	0,6	0,52
4	2,4	1,8	0,7	0,8		0,5		0,3	0,44	0,4	0,56	0,16
5		1,1	0,9	2,04				4,4	0,2	0,2	2,16	0,88
6		1,1	0,9	1,6					0,48	2,52	0,52	0,16
7		1,2	1,4						0,96			0,4
8		0,4	0,9						0,48			0,2
9		0,4	0,8									
>2s	1	0	0	2	0	0	1	2	0	1	1	0
%>2s	25%	0%	0%	33,33%	0%	0%	50%	40%	0%	16,67%	16,67%	0%
Mean:	1,1	1	0,9	1,2733	1,2	0,8	1,7	1,6	0,575	0,6933	0,96	0,34
Sum:	4,5	8,9	7,9	7,64	2,4	3,2	3,3	8	4,6	4,16	5,76	2,72

Figure A.2: Displaying all the glances and the total time of each glance on task 2.

Glances	TP1	TP2	TP3	TP4	TP5	TP6	TP7	TP8	TP9	TP10	TP11	TP12
1	0,2	1,1	0,6	2	1,1	0,4	1,72	2,7	1	0,12	0,44	0,08
2	2,1	0,8	0,8		1,1	0,2	2,44	0,8	0,8	0,88	1,16	0,4
3	4,3	1	1,1		0,4	1,3	0,36	0,4	0,3	1,28	0,96	1,12
4	0,4	1,4	0,6			0,7	1,76		0,3	0,44	1,36	0,52
5		0,4				0,4	2,6				0,92	0,52
6							0,24				2,4	0,88
7												1,24
>2s	2	0	0	0	0	0	1	1	0	0	1	0
%>2s	50%	0%	0%	0%	0%	0%	17%	33%	0%	0%	14%	0%
Mean:	1,8	0,9	0,8	2	0,9	0,6	1,52	1,3	0,6	0,68	1,21	0,68
Sum:	7	4,7	3	2	2,6	2,9	9,12	3,9	2,5	2,72	7,24	4,76

Figure A.3: Displaying all the glances and the total time of each glance on task 3.

Glances	TP1	TP2	TP3	TP4	TP5	TP6	TP7	TP8	TP9	TP10	TP11	TP12
1	1,8	1,6	0,8	0,92	0,5	1,2	1,8	0,6	0,4	0,32	1,4	0,08
2								0,5				0,64
3								0,7				
>2s	0	0	0	0	0	0	0	0	0	0	0	0
%>2s	0%	0%	0%	0,00%	0%	0%	0%	0%	0%	0,00%	0,00%	0%
Mean:	1,8	1,6	0,8	0,92	0,5	1,2	1,8	0,6	0,4	0,32	1,4	0,36
Sum:	1,8	1,6	0,8	0,92	0,5	1,2	1,8	1,8	0,4	0,32	1,4	0,72

Figure A.4: Displaying all the glances and the total time of each glance on task 4.

Glances	TP1	TP2	TP3	TP4	TP5	TP6	TP7	TP8	TP9	TP10	TP11	TP12
1	1,32	0,5	0,4	2,4	0,9	1,5	2,48	1,8	0,7	0,16	0,24	0,84
2	1,6	1,5	0,5	1,52	0,6	1,6	0,84	0,5	0,5	0,52	0,6	0,6
3	1,92	0,6	0,8	3,08	1,1	0,5	1,6	3,2	0,6	0,16	1,28	0,52
4	0,32	1,2	0,8	1,84	0,7	0,6	0,6	1,4	0,2	0,56	1,08	0,84
5		1,1	0,8	2,04	0,7	0,8	0,24	2,5	0,6	0,84	0,36	0,68
6		0,4	0,6	1,16	0,8	1,6	2,2	1,4	0,5	0,36	0,4	2,08
7		0,4	0,8	0,32	0,7	2,1	0,64	0,7	0,4	0,72	0,84	0,84
8		1,3	0,8			0,6	1,28	0,6	0,2	0,12	1,24	1,96
9		2	1,2				0,68	0,6	0,2	0,96	1,24	1
10		1	1,3				2,8	1,2	0,3	0,44	1,36	0,92
11		1,7	0,5				0,12	1,2	1,1		1,88	0,92
12		0,8	0,4				0,16	0,6	0,3		0,56	0,88
13		1,8					0,6	0,7			1,04	0,16
14		0,7					0,56	0,3			2,48	0,16
15		0,4					3	1,9			0,68	0,48
16							0,16	1,2			1,2	
17											0,6	
18											0,4	
19											1,28	
20											0,36	
21											0,96	
22											0,76	
23											1,68	
>2s	0	0	0	3	0	1	4	2	0	0	1	1
%>2s	0%	0%	0%	43%	0%	13%	25%	13%	0%	0%	4%	7%
Mean:	1,29	1	0,7	1,77	0,8	1,2	1,12	1,2	0,5	0,484	0,98	0,8587
Sum:	5,16	15	8,9	12,4	5,5	9,4	18	19	5,6	4,84	22,5	12,88

Figure A.5: Displaying all the glances and the total time of each glance on task 5.

Glances	TP1	TP2	TP3	TP4	TP5	TP6	TP7	TP8	TP9	TP10	TP11	TP12
1	0,3	0,64	0,2	2,3	0,9	1	1,56	0,48	0,76	0,88	1,68	0,2
2	1,4	0,76	0,8	1,2	0,8	0,7	0,52	0,32	0,16	0,56	1,28	0,16
3	2,8	0,44	0,4	1,6	0,6	0,7	0,44	1,32	0,2	0,28	1,36	1,08
4	0,6	1,6	1,1	1,2	0,7	0,7	0,92	0,68	0,4	0,36	0,04	0,44
5	1	2,04	2,2	0,8		1	0,12	2,8	0,4	0,2	0,44	1,08
6	1	1,2	1,4	1,2		0,8	1,28	0,76	0,52	0,64	1,28	0,36
7		0,36	1,4	1		0,9	1,16	0,44	0,96	1,56	0,24	0,4
8			0,6			1,2	0,32	0,84	0,64	1,56	0,88	
9			1,4			0,6			0,48	0,36	0,64	
10						0,5			0,44		1,16	
11											0,56	
>2s	1	1	1	1	0	0	0	1	0	0	0	0
%>2s	17%	14%	11%	14%	0%	0%	0%	13%	0%	0%	0%	0%
Mean:	1,2	1,0057	1,1	1,3	0,8	0,8	0,79	0,96	0,496	0,71	0,87	0,53
Sum:	7,2	7,04	9,6	9,2	3	8	6,32	7,64	4,96	6,4	9,56	3,72

Figure A.6: Displaying all the glances and the total time of each glance on task 6.

Glances	TP1	TP2	TP3	TP4	TP5	TP6	TP7	TP8	TP9	TP10	TP11	TP12
1	0,64	1,48	0,4	0,88	1	1,92	1,5	0,8	0,6	0,44	1,4	1,8
2	1,2	1,6	0,4	3,04	0,8	1,2	0,4	1,1	0,7	0,12	0,28	1,76
3	1,36	0,6	0,8	2,52	0,6	0,6	1,3	1,1	0,6	1,12	0,52	1,24
4	1,2	1,04	0,8	1,68	0,6	1,64	0,7	0,4	0,3	0,36	1,4	1,8
5	0,52	1,76	0,7	0,52	0,9	1,2	0,2	0,6	1,1	1,32	1,64	0,4
6	1,32	0,52	1,5	1,28	1,8	1,16	1	0,5	0,9	1,68	0,4	1,24
7	0,4	0,84	0,6	1,12	0,4	0,8	2,5	0,8	1,6	1,32	0,6	
8	0,6	2,16	0,8	1,64	0,8	0,48	1,4	0,3	0,7	2,44	0,72	
9	1,12	0,6	0,6	0,6	0,7		1	3,3	0,7	1,12	2,12	
10	1,2	0,48	0,6	1,52	1,2		0,3	0,3	0,8		1,92	
11	2,8	1,6			0,5			0,4	0,4			
12	1,4	2,04			0,7				0,4			
13	0,24	1,72							0,4			
14		0,96							0,6			
15		0,28							0,3			
16		0,92							0,3			
17		1,68							0,9			
18		0,92							1			
19									1			
20									0,3			
>2s	1	2	0	2	0	0	1	1	0	1	1	0
%>2s	8%	11%	0%	20%	0%	0%	10%	9%	0%	11%	10%	0%
Mean:	1,0769	1,17778	0,7	1,48	0,8	1,125	1	0,9	0,7	1,1022	1,1	1,3733
Sum:	14	21,2	7,1	14,8	10	9	10	9,5	14	9,92	11	8,24

Figure A.7: Displaying all the glances and the total time of each glance on task 7.

Glances	TP1	TP2	TP3	TP4	TP5	TP6	TP7	TP8	TP9	TP10	TP11	TP12
1	0,8	0,56	1,9	1,36	0,5	1,1	0,96	0,4	0,9	0,76	0,88	0,24
2	1,3	0,68	0,4	2,96	0,2	2,4	1	1	0,6	0,6	0,76	1,36
3	1,4	3,04	0,6	1,56	1,3	0,6	1,12	1,9	0,6	0,44	0,32	0,56
4	0,8	0,68	1,6	0,68	0,3		0,36	4	0,4	0,6	0,52	1,2
5			2,2					0,2	0,3	1,12	1,12	1,48
6								1,3		0,88		0,96
7								1,9				
8								0,6				
>2s	0	1	1	1	0	1	0	1	0	0	0	0
%>2s	0%	25%	25%	25%	0%	33%	0%	13%	0%	0%	0%	0%
Mean:	1,1	1,24	1,4	1,64	0,6	1,4	0,86	1,4	0,6	0,73	0,72	0,97
Sum:	4,3	4,96	6,8	6,56	2,4	4,2	3,44	11	2,8	4,4	3,6	5,8

Figure A.8: Displaying all the glances and the total time of each glance on task 8.

B

User Tests - Script

This appendix presents the script that was used during all of the user tests.

Meet and Greet

1. Explain the scope of the thesis and what we want to achieve with this user study.

    - By putting a touchpad with gesture recognition in the steering wheel, we have replaced the old S/W-buttons and moved some infotainment functionality from the CSD to the DIM. We hope whis will increase both the safety and driving experience. In the test we are conducting today, we will gather information on Eyes on the Road, Task Completion Time and also your general opinion on differences, pros and cons with the different systems.

2. Explain how our system is built and how it is used. Also explain the SPA-iPad and how that system works.

    - The system we have developed is based on touch-technology with the extension of tactile signals, that is buttons, just like in earlier steering wheel implementations that control the DIM. This system also has the functionality to recognize characters that the user inputs on the touchpad, which opens for many interesting possibilities in use and operation of the system.
    - SPA is emulated in an iPad that is placed as a CSD as we have not been able to find a SPA-implementation that fits in the simulator-DIM. This system is also touch-based and has the standard application installed; phone, navigation, music etc. Unfortunately, SPA is not fully functional so there is no feedback when selecting a destination. To clarify: when you select "Save destination" the system will not give this feedback.

- We ask for your understanding that both systems may contain bugs and minor defects that could arise during the tests.

3. Explain how the tests will be carried out and how the test is set up

    - The test will be such; you will sit and drive in the simulator while performing some tasks that we will tell you. We will put an eye tracking device on you will you perform the tasks. You will do all the tasks on each system. Between each system test you will be asked to answer a questionnaire and then do the tasks on the other system. After this you will do a final questionnaire and tell us your general opinion and ideas of the systems.
    - We will also want to say that this test is not meant for you to feel bad if you find a task difficult to complete. We are testing to see whether or not our system is intuitive and easy to understand.
    - Before the "real" test you will be able to test the system and our use cases, this is to let you get to know and understand the systems. This will be done in two phases: One when the vehicle is standing still, and one when while driving. After this you will do the actual test where we will record and take notes of your actions.
    - Please note that this is confidential and we ask you to not disclose any of this information that you will learn today.

4. Please note that this is confidential and we ask you to not disclose any of this information that you will learn today.

    - Touchpad can be slow at times, try not to make fast gestures
    - The touchpads tactile functionality is not sensitive outside of the quadrants borders
    - Always try to be patient and wait for the interface to finish.
    - Implemented a temporary "Home" button
    - Please understand that the "home" button could not be implemented in another way at this time.
    - Touch Pad will sometimes be slow or send incorrect data, please have patience with this.
    - The SPA-iPad is not fully functional, please understand

5. Lastly: May we film you?

SteerPad Use Cases

1. When you get a phone call, please answer that call.

2. We want you to enter Landvetter as the new destination and select it from recent.

3. We want you to enter Landvetter as the new destination and select it from recent.
4. Now please select the track "Vad dom än säger" by Movitz
5. When you get a phone call please dismiss that phone call
6. Now please enter a new destination to Bromma flygplats.
7. Please call up the latest missed call
8. Please call up Charles Hart mobile
9. Finally, please select the next track in the current playlist, "Nah na na".

Questionnaire - Part 1

SPA Use Cases

1. We want you to enter Landvetter as the new destination and select it from recent.
2. Now please select the track "Vad dom än säger" by Movitz
3. Now please enter a new destination to Bromma flygplats.
4. Please call up the latest missed call
5. Please call up Charles Hart mobile
6. Finally, please select the next track in the current playlist, "Nah na na".

Questionnaire - Part 2

Questionnaire - Final Part

End.

Thank you for you participation, we are very grateful that you have put your time to help us with the evaluation of our Thesis Work.

C

User Tests - Questionnaire

This appendix presents the Questionnaire that was used on all test participants

Fomalities

- Please enter your age.
- Male/Female?
- Do you have a drivers license? If yes, since when?

Questionnaire - Part 1 and 2

The participants were asked to rate the tested systems different applications; Navigation, Music and Phone. One each of the application, four questions were asked:

- I find the system easy to learn:
- I find the system efficient to use:
- I experience that the system is safe to use while driving:
- I find text and icons understandable:

These were answered in a scale from 1 (Negative) to 5 (positive). This process was then repeated in the second part of the questionnaire after having tested the other system.

General Questions - Final Part

- If you compare the two systems, SPA and SteerPad, which components are better or worse? Please give your thoughts and ideas on how it was better or how to use a specific part better.

- Do you feel that the SteerPad (the system in the steering wheel) is enjoyable to use? Compare it to your experience with interacting with the DIM
- Are there any specific parts of our SteerPad that you feel are innovative or interesting? Which ones, and why?
- Which system felt safer to use while driving? Why?
- Do you have any feedback regarding the SteerPad system?
- Do you have any suggestions of how the SteerPad could be improved? In terms of: Hardware, Interface, Display-usage, Levels of Interaction
- Additional Comments?