



Touch Drive A touch-based multi-function controller for autonomous driving

Master of Science Thesis

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Cover:

The cover illustrates the tablet interface concept developed in the context of future autonomous cars during this master thesis. Gothenburg, Sweden, 2015

ABSTRACT

The design space of In-Vehicle information systems for autonomous cars is an unexplored area, inviting interaction designers to explore various solutions for delivering an innovative autonomous driving experience. A big challenge is keeping the driver in the loop of the driving task being able to efficiently and safely control the car in a higher level, leaving the tedious operating tasks to be handled by automation. The information system should provide sufficient and proper feedback in order to build thorough understanding of automation's actions, even while the driver is accessing infotainment features.

A design solution is proposed in this thesis, which aims to establish a convenient way for controlling autonomous cars and at the same time enables the user to control tertiary features unrelated with the driving task. A visual tablet interface was implemented, enabling the driver to control the car in tactical level, assigning commands for changing lanes, turning at intersections, overtaking vehicles and changing the speed. The solution also provides a menu for accessing tertiary features related to infotainment control, by maintaining output functions and visual feedback which intend to keep the driver aware of the autonomous driving task. An overlay cover was also built to raise the efficiency and effectiveness of the tactical control by making the interface more intuitive. The goal of this thesis is to evaluate a tablet interface solution in the context of semi-autonomous driving, in terms of usability and user experience examining also human feelings towards automation, namely trust and controllability.

Keywords: automation, semi-autonomous car, tactical, tablet, interface, overlay cover, visual, feedback, touch-based controller

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1. Introduction

As the amount of cars is rising and the competitiveness between the car industries is growing, a new era of autonomous driving systems is introduced, thanks to rapid technological advances. Information technology is highly integrated in almost every vehicle nowadays and industries compete in providing the best possible driving experience, promoting safety, comfort and enjoyment (Harvey et al. 2011). Extensive research in the domain of vehicle automation is conducted in order to deliver a commercial release that will utilize the strengths of this technology and offer a novel user experience. A gradual transition from manual to autonomous driving is already in the process with the integration of Advanced Driving Systems (ADAS) in the cars, which aim to support the user in the driving task (Engström et al. 2004). One of the most popular technologies is the Adaptive Cruise Control (ACC), which adjusts speed to maintain a safe distance between the car and other vehicles in the road. Interaction designers are constantly exploring this new design space, aiming to define the challenges that emerge and propose solutions in respect to the user's mental model of autonomous driving. Hence, it is important to study user envisions and expectations of future autonomous cars (Pettersson 2014) in order to achieve user satisfaction and acceptance (Rogers et al., 2005).

Furthermore, the extensive use of nomadic devices, and the dominance of touch displays is promoting solutions that integrate them with the vehicles' infotainment systems (Android 2015; Apple 2015). Especially, the emerging use and the increased ownership of tablets (Müller et al 2012) is extending the design space by encouraging the implementation of solutions in various everyday contexts. Even though tablets are primarily used in the home environment mainly as a stationary entertaining device (Müller et. al 2012), automation can potentially expand the design space for extending their use into the car environment.

Current In-Vehicle Information Systems (IVIS) encourage users to bring their nomadic devices in the car, thanks to connectivity technologies, including bluetooth and wifi. However, the integration of nomadic devices with the IVIS should be established with safety. Thus, the issues emerging from the use of mobile phones and tablets in vehicles and the challenges introduced by automation should be elicited. The ambition is to generate solutions that will enhance the experience of autonomous driving, by utilizing the intuitive interfaces of personal touch-based devices, which follow users in their everyday lives.

1.1 Research Problem

The main issue of automation is related to the amount of control that the user has over the system. High complexity and misunderstanding of the system functions can lead to mental overload (Endsley & Kiris 1995). Otherwise, automation may trigger over-reliance on the system (Sheridan & Parasuraman 2005), which results in mental underload (Stanton et al. 2007). Both effects decrease driver performance (Stanton et al. 2007) and situational awareness (Endsley & Kiris 1995) potentially leading to accidents or incidents due to loss of control. Endsley & Kiris (1995) describe this problem as the 'out-of-the-loop performance', when the user is either overwhelmed or over relied on automation and consequently is removed from the control loop. Billings (1997) underlines that pilots should always be involved in the operation of the automated aviation system by remaining in the control loop. Endsley & Kiris (1995) state that loss of control leads to 'loss of situational awareness', 'decrease of system acceptance', 'loss of mode awareness', 'deskilling' and 'increase of mental overload'. Thus, it is important to establish the user as the supervisory operator and highlight the supportive role of the autonomous system (Sheridan & Parasaruman 2005).

Specifically, the 'out-of-the-loop performance' during autonomous driving can lead to severe accidents in case of system failure when the user is asked to take manual control (Niemann et al. 2011). Thus, situational awareness can be increased by keeping the driver in the loop and guaranteeing safety. Niemann et al. 2011 underlined that the reaction time in case of critical situations, is minimized, as the driver is involved more in the driving task.

Walker et al. (2001) marked safety, efficiency and enjoyment as the three fundamental driver needs connected with the secondary features of the IVIS. ADAS in synergy with IVIS aim to cover these needs and various design frameworks have been built to generate design solutions for enhancing the driver experience (Engström et al. 2004; Jansson et al. 2014; Harvey et. al 2011). IVIS interfaces aim to provide enjoyment through tertiary features, such as music and communication, but can also increase the performance of the driving task, by keeping the driver in the loop with navigation and alert functions for instance. On the other hand, they could lead to visual distraction if solutions are poorly designed, an issue discussed in section 3.3.2.

The transition between autonomous and manual control is considered a task switching which can also increase the mental workload dramatically (Niemann et al. 2011), causing the problems discussed previously. A smooth transition is established by giving the primary control to the driver with an intuitive and not obtrusive manner (Petersson et. al 2005). When automated operations are conducted, they should be obvious, not overwhelm the user by invading his workflow unexpectedly and aim to support the driver and not replace him (Petersson et. al 2005).

One more issue arises, when the user is interacting with the tertiary functions of the IVIS, such as navigation, communication and music features. Even if the control rests primarily on the autonomous system in this case, the user should still be able to easily switch to manual control. The main problem is that IVIS functions may cause high visual distraction (section 3.3.3), which can lead to 'out of the loop' performance. Thus, the design challenge is to keep the driver in the loop even when controlling these features, enabling him to easily get the control of the car and respond fast in critical situations.

Based on this discussion, the research problem of this master thesis is summarized in the following problem statement:

"Keep the driver in the loop of the autonomous driving task, allowing to switch easily, thus providing smooth transitions between assigning driving commands and controlling tertiary features."

1.2 Research Question

The research problem is approached by proposing a solution for a tablet based controller for autonomous driving. As noted in the introduction and described in the background section, the rising use of tablets is encouraging the exploration of a touch-based solution. The main hypothesis of this thesis is that a tablet interface can enhance the driving experience in future autonomous driving by providing tactical and tertiary functions to perform the corresponding tasks. This master thesis adapts Richter's et al. (2010) discrimination of the primary, secondary and tertiary tasks of in-car systems. The primary tasks are the actions performed for maneuvering the vehicle and the secondary tasks include the functions that are related with roadworthiness such as the windshield wiper, direction indicator and advanced driving assistance functions. The tertiary tasks are all non-safety-related functions such as entertainment, communication, temperature control and navigation features. Michon (1985) defined three levels of driving control: operational, tactical and strategic. The operational level concerns the lateral and longitudinal control of the vehicle. Tactical control concerns the performing of driving maneuvers, like changing lanes or turning to intersections. The strategic level of control is related with general planning of the trip, including route, goals, modal choices and evaluation of costs and risks. In the context of autonomous driving, the operational level of control is on the automated system, performing the tactical tasks, issued by the tablet controller. Some strategic functions are also offered by the interface, but the focus of the thesis is on evaluating the delivery of the tactical commands and the handover between these and the infotainment features. Thus, the tablet provides two main modes: Tactical controller for enabling the user to assign specific driving maneuvers and get feedback about his decisions and the car status and tertiary controller for controlling infotainment system features such as navigation, music and indoor temperature functions.

The research question is based on a task assigned by Semcon (1.4), run by the Research and Innovation Department within the UX group and it is part of the AIMMIT (Automotive Integration of Multi-modal Interaction Technologies) research project (AIMMIT 2015). The project was also inspired by a concept idea of an autonomous car controller by Claes Edgren, Research Project manager in Vehicle HMI at Volvo Car Corporation (VCC). The tablet is used as a stationary device which placed on the armrest of the driver seat. The seat is set at the rearwards position while the car is in autonomous mode and the user will mainly interact with the tablet controller, without been within the reach of the steering wheel and the pedals. When the tablet is set in the tactical mode, a smart overlay cover is used to cover the display, consisting of grooves and ridges that indicate the interactions for assigning the specific tactical commands. The goal is to explore the cover's potential of providing a more efficient interface by underlining the input and output features of the tactical controller.

Given the above hypothesis, the research question is formulated as follows:

How can a tablet interface be designed to keep the driver in the loop of the autonomous driving task by functioning as a tactical and tertiary controller, providing an easy switch between these modes?

Will a tablet-based tactical controller, augmented with a smart overlay cover increase the efficiency of the interface, providing a clear distinction between the input and output functions?

1.3 Scope

Given the research questions, the focus is on the interactions with the tactical controller and specifically the design of a suitable layout that highlights and promotes the driver-in-the-loop concept (Niemann et al. 2011). As far as the tertiary controller is concerned, the main purpose is to provide an easy-to-use interface, focusing on the layout and gesture patterns rather than the deep navigation workflows for achieving specific tertiary tasks, such as assigning a specific destination through the GPS. The aim is to deliver an efficient handover between those two modes and explore the tasks and operations of the tactical controller. The tablet display is used for both input and output and in the scope of this master thesis, the interface will provide only visual feedback. It will not include haptics and auditory feedback as the highlight of this thesis will be on increasing efficiency of an interface design through smart overlay cover. Also, the design will not include additional controls and devices inside the car apart from the fundamental ones.

Despite the various levels of automation, this master thesis focuses only on intermediate levels of automation where human and automation's workload are balanced. In these targeted levels, automation is capable of performing a task without human's instructions. The human could take over if there is problem in the system and automation could always continue working, even if the human in charge is not giving out commands. Hence, the design solution to be delivered is meant to be used when the car is driven semi-autonomously in intermediate level of automation. The operational level of control (Michon 1985) lies entirely on automation, executing the commands given by the user. It is taken for granted that automation performs only safe and legal tasks, informing the user accordingly about the availability of each action. Therefore, the level of automation as discussed in 3.1.2 is on the intermediate level, where the user is the supervisory operator.

To sum up, the design space is limited on tablet interface solutions in the context of autonomous driving for supporting tactical tasks and tertiary functions. The primary goal is to provide a proof of the driver-in-the-loop concept that would encourage the integration of touch displays in future autonomous cars by enabling the driver to retain tactical and strategic level of control.

1.4 Stakeholders

This master thesis was conducted by the Research and Innovation department of Semcon within the UX group and Chalmers University of Technology and is a part of the AIMMIT project which is run in collaboration with Viktoria ICT institute and Volvo Car Corporation (VCC). AIMMIT stands for "Automotive Integration of Multi-modal Interaction Technologies" and aims to explore multimodal HMI concepts for establishing safety, competitiveness and client-user satisfaction in the automotive sector (AIMMIT 2015).

Semcon is an international consulting company which delivers wide range of solutions to its customer. The company is divided into several sectors including energy, life science, industrial and automotive and is known for providing innovating design solutions to numerous client companies. Semcon is one of the main collaborators of the AIMMIT project along with Viktoria ICT and Volvo Car Corporation (VCC), providing us all the suitable hardware and software tools for implementation, along with working space and constant support for fulfilling our goals.

Volvo Car Corporation (VCC) is a leading car company originated here in Gothenburg, Sweden. The company is proud to present its core values, namely safety, quality and care for the environment. Thus, VCC pays close attention in delivering the safest car to its customer with the most innovative technology. With the aim of being the leader in motor vehicle technology, VCC has shifted its focus toward autonomous cars, collaborating with Semcon to explore innovative solutions striving for customer satisfaction.

Viktoria Swedish ICT (Information and Communication Technology) and Chalmers University of Technology are research institutes providing us access to valuable knowledge resources and access to Lindholmen Safer vehicle simulator to validate our solution. We, Juntima Nawilaijaroen and Vasileios Golematis were working along with our supervisors, Dimitrios Gkouskos, Phd student of the Interaction Design and Technologies department of Chalmers University of Technology and Jan Nilsson, Project Manager and UX Research & Innovation Leader of Semcon, who were our guides during the whole working process. We both are interaction design master students with experience in conducting research studies, applying suitable design methods. During the master program, we developed a special interest in the fields of mobile technologies and human to vehicle interfaces. Therefore, we decided to conduct our master thesis research in the field of HMI for future autonomous cars.

1.5 Terminology

This section provides a list of the terms with their meanings, which are used continuously in this master thesis:

Adaptive Cruise Control (ACC)

This term refers to an optional autonomous cruise control system in car. ACC was invented, aiming to provide a more relaxing driving experience. In this thesis, we put our focus mostly on Volvo's ACC system. ACC system implemented by Volvo Car Company employ a mechanism of maintaining speed and safety related functions such as auto detection for pedestrian. These functions were used as a foundation for semi-autonomous cars that are expected to be implemented in the near future.

Autonomous Driving (AD)

AD refers to autonomous driving. The main objective of AD is to provide a better driving experience by handling tedious tasks such as maintaining speed and keeping the car in the lane.

Advanced Driving Assistance Systems (ADAS)

Similar to the two terms mentioned above, ADAS refer to an automated system, which aims to enhance the driving experience by supporting the driver in the driving task. (Engström et al. 2004; Harvey et al. 2011). ACC is one example of ADAS.

Automotive Integration of Multimodal Interaction Technologies (AIMMIT)

AIMMIT refers to a project run by Volvo Car Corporation (VCC) in cooperation with Semcon, Viktoria Swedish ICT and Chalmers University of Technology. The project aims to integrate the theories of HMI as well as multi-modalities to the automotive industry with the objective of providing a better driving experience to driver. (AIMMIT 2015)

Human-Machine Interaction (HMI)

Human-Machine Interaction (HMI) belongs in the field of interaction design with a particular focus on the interaction between human and machine. In this master thesis, machine refers to the system of an autonomous car.

In-Vehicle Information System (IVIS)

In-Vehicle Information System (IVIS) refer to the infotainment systems which are integrated into cars. They are discussed in depth in section 3.3.

Participatory Design (PD)

The term of participatory design (PD) refers to a method of interaction design which is conducted mostly within a group, involving designers and users. Sections 4.1 and 5.3 cover this method in depth.

2. Background

Related research, work and existing products were sources of inspiration and guidance for the thesis project. Car companies have been trying to integrate nomadic devices with the IVIS in order to enhance and personalize the driving experience by enabling users to connect their personal mobile phones with the car infotainment system. Touch-displays in IVIS are dominant in the car industry and tablet mounting products encourage users to bring their personal tablet devices in order to boost driving performance and convenience.

The Volvo on Call mobile application and Volvo Sensus touch-based infotainment system utilize connectivity technology to boost in-car conveniences (Volvocars 2015). Android Auto and iPhone CarPlay applications bring the familiar interface of the personal device along with the user's preferences to the in-car touch-display (Android 2015; Apple 2015). Chevrolet's Onstar Remotelink smartphone application establishes connectivity with the car's in-dash touch display similarly with the previous products (Chevrolet 2015). On the contrary, BMW's iDrive system (GmbH 2015) consists of a rotary tactile controller for input and a separate display for output to interact with the IVIS. Following a different approach, Audi has built a tablet designed to fit the car's context, providing infotainment features, but targeting only passengers (Audi UK 2015). Hence, most products favor touch-based displays and several are aiming to achieve a seamless integration of personal devices with the IVIS.

A lot of research has been conducted to ameliorate visual distraction caused by these systems reducing driver performance (Bach et al. 2008; Van Erp & Van Veen 2004; Ecker et al. 2008; Richter et al. 2010). One main issue that is observed with touch displays is their high demand of visual attention (Harvey et al. 2011; Ecker et al. 2008). The pieTouch project (Ecker et al. 2008) presented a specific layout pattern that provides a more intuitive interface. In addition, gestural patterns are explored, as they require less visual attention over simple touch interactions (Bach et al. 2008, Rümelin et al. 2013). The precision of tactile devices in contrast with touch-based controllers (Harvey et al. 2011) has triggered research on haptic feedback on touch displays further minimizing visual distraction on IVIS (Richter et al. 2010; Van Erp & Van Veen 2004). In case of autonomous driving, this problem may not be so critical, but it may lead to 'out of the loop' performance (Endsley & Kiris 1995), thus, it should be definitely taken into account for our design.

Research has also been conducted in the context of autonomous vehicles, most of it focusing on providing strong guidelines and design frameworks that introduce designers to this design space. AIDE (Adaptive Integrated Driver-vehicle InterfacE) provided a wide set of methodologies for integrating nomadic devices with ADAS and IVIS (Engström et al. 2004). MODAS (Methods for Designing Autonomous Systems) is a model for generating design solutions for autonomous cars (Jansson et. al 2014). Based on this model, Scania illustrated an autonomous vehicle in which all information is displayed on the heads-up display and controlled by a tablet device (Scania 2015). Niemann et al (2011) presented a manoeuvre based approach for improving the driving performance by assigning complex driving patterns in a simple way through a touch-based display, keeping the driver in the loop.

Finally, Mercedes Benz's F015 is a concept of a futuristic automated car without a driver's seat (Mercedes-Benz 2015). The car model is moving toward to lounge-like interior design, fulfilling users' envisions of rotating seats facing each other in Pettersson's workshop (Pettersson 2014). Apart from the socializing factor, automation implies convenience. Thus, setting the driver seat in the rearwards position during autonomous driving aims to fulfill this need.

3. Theory

This chapter presents theories in relation to the research problem and questions and consists of four fundamental sections as follows: the relationship between human and automation, autonomous driving, in-vehicle information systems and touch - based devices and interfaces.

The first section describes the relation between human and automation in general. It also discusses the interaction between human and the automated machine, advantages and disadvantages as well as effects to human overall. The second section introduces background information on autonomous driving, providing a set of theories regarding how drivers interact with a semi-autonomous car. The third section presents In-Vehicle Information Systems (IVIS) linking them also with Advanced Driving Systems (ADAS) aiming to highlight their roles and relations in the driving context. User needs and design challenges regarding these systems are also elicited in this section. The final section focuses on touch - based devices, aiming to highlight their unique characteristics. Analysis of touch interfaces and interactivity patterns follows and emphasis is given on tablet devices. Finally the design challenges that emerge from touch interfaces in relation to the autonomous driving context are underlined.

3.1 Human - Automation

This section presents fundamental concepts of automation focusing on the relationship between automation itself and human, followed by a brief description about levels of automation and concluding with design challenges and limitations that designers may face when designing for automated systems.

3.1.1 Relationship between Human and Automation

People have long been trying to find a way to improve the quality of work with minimum effort. Hence, automation was introduced. Automation refers to the use of automatic equipment in manufacturing and other process or facility. (Oxford English Dictionary) Nonetheless, with today's technology, the usage of automation has been extended from being used exclusively in the industry to private sectors as well. Individuals get more access to automation. Automation helps humans go through various type of works ranging from being a performer of repetitive tedious tasks that humans do not want to handle by themselves to a more complex task such as being decision-making aids. The term 'automation' therefore has been slightly changed from the past. To be more contemporary, automation may refer to automatic equipment used to reduce human's physical and mental workload. (Sheridan & Parasuraman, 2005)

For many years, humans have been working along with automation to achieve their goal in a more efficient way and to get better results. Working side by side with automated machines, humans are becoming more passive as they are benefactors from automation. (Sheridan & Parasuraman, 2005) However, integrating vast amount of automation doesn't mean humans get to be replaced. It is rather a form of a stronger relationship between human and automation. Humans are now

unable to avoid an interaction with automation. Human interactions with automation mostly are giving instructions and commands. Thus, the relationship between human and automation is comparatively to an authority with his subordinate. (Sheridan & Parasuraman, 2005)

Even so, the interaction between the two agents in our concern is not always a one-way interaction. Automation in these recent years is coupled with artificial intelligence which is capable to provide richer feedback to human authority. Machine's feedback methods are ranging from basic modalities such as small pieces of information, auditory alert sounds to advance forms such as recommendations of courses of interactions.



Figure 1. Interaction between human and automation

Regarding the interaction model shown in figure 1, we can see that the human is relying primarily on information feedback from automation in order to give out an instruction. Hence, an issue emerges when automation does not provide sufficient feedback of the system states. Following that, it is hazardous when human authority has problem understanding automation. Incidents may be caused when the human in charge of the system is not well-informed of its state or when there is a great mismatch between the human's mental model and system's behavior.

3.1.2 Levels of Automation (LoA)

Every automated system differs from each other. Its characteristics can be defined by the degree of automation. Sheridan and Parasuraman (2005) proposed an idea of classifying automation into levels based on its performance and how demanding it is to the human operator.



Figure 2. Levels of Automation

Levels of automation are ranging from the simplest level of automation, when the system relies solely on a set of instructions given by human operator to the most complex level when the system is completely automated and requires no instruction from the human operator. The focus of this master thesis will be on the intermediate levels of automation highlighted in Figure 2, as the driver is the supervisory operator of the automated system similar to a passenger of a taxi who is giving specific tactical commands to the taxi driver (e.g. turn to an intersection).

3.1.3 Design Challenges and Limitations

Interestingly, studies found that humans, without notice, often respond to automation in similar ways to how they respond to other humans. (Nash et al. 1995; Reeves and Nass 1996) In addition, humans are more likely to interact and give more trust to automation which is capable of interacting naturally with the human. The fact mentioned makes trust become a key concern when designing for automation. Trust is related to human's emotions and attitude. (Lee & See 2004) Trust in automation is built in the human operator's conceptual mind when automation works flawlessly. However, the ability to perform smoothly without any error is not only one factor considered in designing for trust. Parasuraman et al. (1993) conducted a study where he tested how much a good or a bad interface could affect human's trust in automation. The results showed that a good interface can not only enhance the user experience but also increase user's perception in robustness. In addition, the effect of good interface design is powerful enough to overcome automation's bad performance. Likewise, bad interface design would neglect user experience as well as user's trust to the system. Nonetheless, Riley (1996) pointed out that trust could be perceived as a benefactor to the design as well as a risk. Trust is certainly a good thing since the perception of trust is a perception of robustness. Perception of robustness as defined by Sheridan and Parasuraman (2005) is a perception of ability to perform a task under a variety of circumstances. When humans perceive robustness, they are likely to use automation more often than before. They will also become more comfortable in using automation. Even so, trust could

be considered risky when the human is over-reliant on automation and becomes completely passive. Regarding the level of automation we are considering in this master thesis, it is dangerous that the human may become unaware of the situation and leave all the control to automation.

As mentioned in section 3.1.1 the primary interaction between human and automation is providing feedback. Humans rely greatly on feedback when they are proceeding to give the next command to automation. Insufficient amount of feedback may result in failure to both the human operator and the automation itself. Thus, a design challenge is to provide users adequate amount of feedback (Billings 1997). Sheridan and Parasuraman (2005) suggested that machine states and essential information should be presented to the user clearly. Users should be provided with an interface that requires the least possible effort from them. They need to be able to grasp all the information at once when they glance at the interface in order to prevent the loss of focus of the task they are doing. (Sheridan & Parasuraman 2005)

In the same way with automation, humans also have limitations. Not everyone is capable of controlling automation. Automation usually understands a specific language of commands (e.g. binary code in computer). While designing, one could easily make a mistake assuming that everyone is an advanced user. As a result, a designated interface is very hard to use and greatly increase human operator's mental workload. The potential operator of a certain automated system must undergo training. (Billings 1997; Casey 1993; Degani 2004; Parasuraman & Riley 1997; Reason 1997; Sarter et al. 1997; Vicente 2003) However, a good training requires time and effort. Bad training though can be hazardous in controlling a machine. In order to solve the problem, C.A. Miller (2004) pointed out user interface design guidelines for automation, underlining that we should not assume that every user is the same.

By combining the factors mentioned together, we could sum up that automation should be designed strictly according to human centered design disciplines in order to avoid issues that may arise while the human operator is performing tasks and to enhance user's experience whose work is bounded with the machines for an extended period of time.

3.2 Autonomous Driving

This chapter is specifically focused on autonomous cars. Referring to the previous section, which describes automation and its characteristics in general, this section is going to explore the car context which is our main research domain. The topics in discussion are issues and theories in relation to autonomous driving as well as challenges that might occur during design. The Human operator who is entitled to give commands to the autonomous car will be referred as driver in this section.

3.2.1 Driver in the loop

Regarding the previous section where the disadvantages of passiveness of the human operator were discussed, it is considered to be the designer's job to keep the human in the loop and focus on the performing task. The purpose of keeping the driver in the loop is mainly to fulfill the needs

of the driver. Walker (2001) pointed out safety, efficiency and enjoyment as the primal needs, which are expanded and discussed more in depth in section 3.3.4. Keeping the driver in the loop is important for fulfilling these needs.

On the other hand, Niemann (2011) pointed out that there is no solid negative effect of out-of-theloop performance unless there is a system failure. However, in the long run, Parasuraman commented that out-of-the-loop performance can easily cause deskilling in which might result in the inability of the human to stabilize the car when the system malfunctions.

Niemann (2011) also remarked that the downside of highly automated systems discussed in section 3.1 could be reduced by a maneuver-based approach. A study was conducted for the purpose of finding a way to reduce the out-of-the-loop performance problem. Subjects were divided into 3 groups. Three groups performed the same task of driving on the highway for 15 minutes in driving simulator. The groups' tasks differed by the level of automation. The test results showed that subjects who are mostly involved in driving (so called in-the-loop), excel in controllability. Interestingly, their measured rate of acceptance and trust to automation are much higher than the subjects who drove in a higher level of automation. Drivers with a lower degree of automation gave more trust to the system as they knew that they could still assign commands and be in charge of the system. On the contrary, in the higher degree of automation where the automated system has greater authority and therefore the driver did not feel secure.

3.2.2 Transitions between LoA

It is common for a highly automated machine to move from one level of automation to another. A well-designed transition between each level of automation is needed. Transition in levels of automation normally composes of two factors namely direction and initiator. Direction indicates which level of automation the machine (in this case, the car) is heading to. Since there are several levels of automation (3.1.2), for each transition, both the car and the driver need to know in which direction that it is going to turn to. Lower level or higher level of automation, for example. The initiator indicates who begins an action. In an autonomous car, the one who takes control can either be the car itself or the driver.

In this master thesis, the focus is on the operator and supervisor levels of automation (Figure 2). For the operator level of automation, the human plays the role of the operator where he can give out commands to automation. Automation is able to perform a task according to the command given. Automation is also liable to give feedback to the human operator to tell what is happening inside the system, establishing him as the supervisor. (Sheridan and Parasuraman, 2004) In this intermediate level, driver is allowed to move between both directions; higher and lower levels of automation. Hence, it is harder for the designers to account for the system's transitions. As mentioned earlier in section 3.1.3 about the hazards of inadequately reporting the system state, it is crucial for the user to know what state the automation is in. The driver should be able to know the level of automation in order to give a suitable set of commands. Not only for the sake of safety but also for user's comfort. Niemann et al. (2011) remarked that drivers would feel more comfortable if they have the ability to transition between levels of automation. Thus, in this master thesis, we are trying to find a smooth way of transitioning between the levels of automation.

3.2.3 The Playbook Metaphor

The Playbook metaphor is a strategy which designers have been using for designing automotive controllers. The purpose of this strategy is to simplify an action of transition between levels of automation. The Playbook metaphor was adapted from the American football's playbook strategy. During the match, communication between each player is problematic since they are unable to have a proper conversation with each other. Moreover, the communication should be fast, short and accurate. Thus, American football players are communicating using short keywords. These short keywords refer to a characteristic of each strategy that is going to be used during the game. Invented keywords had been kept in a notebook known as the playbook. Similarly with highly automated vehicles, establishing communication in order to transition from one level to another is viable. It should be short, fast and accurate just like how footballers communicate during the match. Sheridan and Parasuraman (2004) therefore employed the playbook strategy to solve a problem in transitioning between levels of automation. User studies have been conducted. While using the playbook metaphor, subjects were able to transition between levels of automation easier and faster. However, there is an issue with the playbook metaphor. To understand the transitions between levels, driver must learn a set of keywords. Hence, the driver might not be able to navigate between levels during the first use of the system.

3.2.4 Design Challenges

Based on the theoretical studies described above, two main challenges are addressed for designing autonomous driving systems. Keeping the driver in the loop requires involvement of the user in the driving task. The first design challenge is to establish a proper understanding of the autonomous tasks and deliver solutions that elicit the current level of automation to the driver serving the needs controllability and trust. The maneuver-based approach of Niemann (2011) utilized the playbook metaphor (3.2.3) to involve the driver in the autonomous driving task. Using this strategy, the driver can transition between higher and lower levels of automation with a well-defined set of commands as described in the previous section. The second challenge that is introduced is to properly define this set of instructions so that the driver can easily learn and use without leading to confusions that can lead to 'out-of-the-loop' performance. Therefore, it is not sufficient to just involve the driver in the driving task, but also to ensure that she can easily understand the functions and flexibly transition between levels of automation.

3.3 In Vehicle Information Systems (IVIS)

This chapter covers theories of In-Vehicle Information Systems (IVIS), elicits drivers' needs and describes ways of interactivity between the user and the IVIS. Advanced Driving Assistance Systems (ADAS) are also presented in parallel with IVIS, since they introduce automated features.

The design challenges, resulted from the synergy of ADAS with IVIS, are underlined and provide a solid basis for our design.

3.3.1 Introduction to IVIS

Nowadays, information technology is seamlessly integrated into numerous everyday objects including vehicles. Modern cars are an excellent paradigm of ubiquitous computing (Walker et al., 2001), as computers are an inherent part of vehicles and the amount of information increases. In-Vehicle Information Systems (IVIS) are connected with all the secondary functions that complement the primary driving task (Harvey et al. 2011). They utilize information technology and electronics in order to enhance the driving experience (Walker et al. 2001).

IVIS features aim to increase the efficiency of driving, offer comfort and provide entertainment (Harvey et al. 2011). Navigation systems, indoor-temperature control and music features are functions that serve these goals. It is important to note again that these features will be marked as tertiary in the scope of this master thesis, following the discrimination of driving tasks by Richter (2010) .Thus, the tactical mode of the tablet controller is connected with primary and secondary tasks related to driving maneuvers for performing tactical tasks such as changing lanes and the tertiary controller with the infotainment functions.

3.3.2 Interactivity in IVIS

Visual distraction is the main concern of IVIS and a lot of research is being conducted to minimize it by exploring various interaction patterns (Harvey et al. 2011). The visual mode is the most common mode of information input and output in IVIS (Harvey et al. 2011). Hence, multimodal feedback is explored in order to distribute the load between the different senses and increase visual attention on the driving task. Bach et al. 2008 evaluated tactile, touch and gestural interactions in terms of visual demands by measuring eye glances on the interfaces. Although the touch-based interface was the most dominant in terms of efficiency, it demanded the most visual attention compared to the other two. Gestural interactions ameliorate this problem especially with the addition of haptic feedback (Richter et al. 2010; Van Erp & Van Veen 2004). Fang et al. 2006 underlined that auditory tasks can occur simultaneously with visual tasks minimizing interference between the human's visual and audio channels. Y. Liu and T.A. Dingus (1999) pointed out that multimodal interfaces reduce mental workload. In general, synergizing multiple feedback methods can result to less visual overload and thus more efficiency and safety.

As touch displays are currently dominant in the IVIS, designers have focused on exploring layout and gestural patterns for building touch-based intuitive interfaces which require minimal visual attention. Section 3.4 discusses design principles and examples of intuitive touch-based interfaces, which are used as inspiration for our design.

3.3.3 ADAS and IVIS

Automation currently exists in modern vehicles in the form of advanced driving assistance systems (ADAS) such as Adaptive Cruise Control (ACC). Their main role is to support the user in the driving task (Petersson et al. 2005; Engström et al. 2004; Niemann 2011). Petersson et al. (2005) define ADAS as an automated system used to 'relieve the driver of tedious activities, warn about upcoming or missed events and possibly take control of the car if an accident is imminent'. Thus, autonomous driving has started taking form in the features offered by ADAS. HMI frameworks are built in order to provide fundamental principles for building interfaces for IVIS and ADAS (Engström et al. 2004; Harvey et al. 2011).

AIDE (Adaptive Integrated Driver-vehicle InterfacE) distinguishes the ADAS and IVIS according to their purpose. ADAS aims to support the driver in performing the primary driving task, enhancing safety and comfort, whereas IVIS goal is to provide information to the driver non-related to the primary driving task (Engström et al. 2004). It is also underlined that IVIS functions provide secondary tasks that may interfere with the primary task. Hence, it is important to understand, differentiate the roles of each system and achieve a synergy between them that enhances the driving experience. Therefore, in this master thesis we distinguish the primary (maneuvering) and secondary tasks that are related to the driving task with the tertiary tasks that are non-related (music, temperature control) or aim to support it indirectly by providing additional information (navigation) (Section 3.3.1; Richter et al. 2010).

3.3.4 User Needs

The main issue that IVIS addresses, is distraction which reduces the driver's attention and leads to decrease of driving performance and potentially accidents (Harvey et al. 2011; Engström et. al 2004). The goal of the IVIS should be to provide information in a safe and efficient manner (Tufano 1997). Hence, it is important to grasp users' needs and mental models in order to design IVIS that respect them. The challenge for the designers is to maximize the benefits of the IVIS without sacrificing usability and the needs of the driver (Broström et al. 2006; Lee et al. 2009; Walker et al. 2001). Taking a driver-centered approach is important in order to optimize the interaction between the users and the IVIS, thus identifying and understanding their needs in the context of driving is essential (Heide & Henning 2006; Stanton & Salmon 2009).

Walker et al. 2001 mark three fundamental driver needs as follows: **safety**, **efficiency** and **enjoyment**. Gkouskos, Normark and Lundgren (2014) found various need dimensions in respect to five specific futuristic vehicle concepts. Harvey et. al. (2011) used the three primary needs defined by Walker (2001) as a basis to build a framework for modeling system performance for the task - driver - IVIS interactions. It is important to relate the needs with the functions of the IVIS and automation. In figure 3, we illustrate some of the key needs that we took into account for our design, presenting also the relations between them in a schematic way.



Figure 3. Driver Needs, primary and emerging needs

In the context of autonomous driving, badly designed solutions can lead to 'out of the loop' performance (Endsley & Kiris 1995), violating safety. Control is one of the need dimensions that are connected with automation (Gkouskos et al. 2014), related to human authority on the automated machine (Billings 1997; Miller & Parasuraman 2007). Trust is also a need deriving from automation (Sheridan & Parasuraman 2005) as described in section 3.1.3. Simplicity is also connected to safety, since a complex system can lead to mental overload and potentially to accidents. Thus, minimalism in design should always be considered. The need for driver support (Gkouskos et al. 2014) is related with driving performance and is the primary role of ADAS aiming to provide comfort and convenience. Interaction Fluency (Gkouskos et al. 2014) is a need dimension related with the quality of interactivity of the IVIS. Enjoyment is related to the needs of attractiveness, pleasure and comfort. Enabling users to integrate their own devices into the vehicle is also serving the need for personalization. Enjoyment also includes satisfaction (Walker et al. 2001) and is considered by companies a factor of the usability of products (Harvey et al. 2011).

3.3.5 Design Challenges with ADAS and IVIS

ADAS introduce issues that are connected with automation as described in section 3.1.3. Petersson et al. (2005) point that ADAS should be intuitive, unobtrusive and controllable. Thus, they need to be understood easily by the driver, not replace him but support him in the driving task and rest the primary control on him. High complexity can lead to loss of mode awareness (Niemann 2011), which implies lack of understanding of the functions. AIDE describes the

behavioral changes of the driver caused by automation, which may lead to over-reliance, highlighting Sheridan's and Parasuraman's points about trust (Section 3.1.3).

So, combining ADAS problems with visual distraction and interference of IVIS with the primary driving task, a bigger design challenge is introduced. Designers should be aware of the potential issues of both systems and always take into account the user needs in their design. The main challenge is to integrate ADAS and IVIS into a functioning holistic system in respect to the driver's mental model given the issues that are introduced. The goal is to establish synergy between ADAS and IVIS features and avoid conflicts that lead to user dissatisfaction or accidents. The other challenge is to seamlessly integrate personal nomadic devices into the IVIS achieving the above (Engström et al. 2004). Hence, we take a closer look to touch-based devices and interfaces in the following section.

3.4 Touch-based Interfaces

This chapter starts by eliciting the strengths and weaknesses of touch-based devices in comparison with traditional tactile devices in the context of a car. Then, the interactivity of touch-based interfaces is studied focusing on gestural, layout patterns and tactile feedback. Following that, our decision of using a tablet-based controller, is backed up by researches that encourage the use of tablets. Finally, the design challenges for tablet interfaces in the context of autonomous cars are underlined.

3.4.1 Touch-based and tactile devices

Touch-based interfaces are currently favored by the majority of car companies as noted in the background section. Nevertheless, it is important to understand and highlight the advantages and disadvantages of their use in order to follow a design path that promotes the choice of using a tablet as a controller for autonomous driving.

In the context of IVIS, touch devices are often described as direct controllers, highlighting their main characteristic of offering direct user input to the display screen (Taveira & Choi 2009). Thus, one key advantage is that they do not require translation between input and output in contrast with rotary tactile controllers that demand a separate display for displaying the effects of input (Harvey et al. 2011). Rogers et al. (2005) noted that touch-based devices offer increased level of satisfaction and acceptance especially to novices by providing easy-to-use interfaces. On the contrary, they also marked that tactile devices are better in long-term use by experienced users, but in general they have lower acceptance because of their longer learning curve. Furthermore, touch devices are better in a higher mental workload situation (Harvey et al. 2011). In a critical situation, drivers are more likely to respond slower or incorrectly if what they perceive does not match what they expect (Stevens et al. 2002). Touch controllers are also space efficient, as they do not require separate hand controls, but they require a larger display to support input and output conveniently (Harvey et al. 2011).

On the other hand, the lack of the tactile sensation raises the demand of visual attention in touchbased interfaces (Harvey et al. 2011; Ecker et al. 2009). This problem can be reduced partially by exploring specific gestural and layout patterns (Ecker et al. 2009; Rümelin 2013) or augmenting them with haptic feedback (Richter et al. 2010; Van Erp & Van Veen 2004). Furthermore, fingers can occlude information during touch interactions (Ecker et al. 2009; Taveira & Choi, 2009) and touch devices must be positioned in the zone of comfortable arm reach (Ecker et al. 2009; Dul & Weerdmeester, 2001). In the case of indirect controllers, the position of the display and the input controls can be easier adjusted to provide better visual performance. Touch controllers may result in muscle fatigue, by requiring arm stretching if their position is in the zone of reducing visual attention (Harvey et al. 2011). Lack of precision in contrast to tactile devices is another issue connected with touch-based interfaces. Hence, there is a need to explore the interactivity of these interfaces to reduce the addressed problems.

3.4.2 Interaction patterns

Continuing the discussion from section 3.3.3, it is important to account for visual distraction, by exploring interaction patterns for touch displays that minimize it and provide an intuitive interface in respect to the driver's mental model and needs.

Android and iOS operating systems aim to standardize touch gestures by defining specific patterns and building specific metaphors. For example, a swipe gesture builds the scrolling metaphor and is an intuitive interaction for touch interfaces. However, as gestural patterns become more complicated or are coupled with unexpected patterns, usability is violated. Norman and Nielsen (2010) highlight the need for defining strict usability criteria for gestural interactions, as they fail to be discoverable or result in unexpected effects in numerous mobile applications. 'Gesture hinting' is a way of notifying available gestures to users in an interface (Lundgren & Hjulström 2011). Lundgren and Hjulström (2011) proposed an idiomatic representation of gestures, aiming to make users aware of all possible gestural interactions of the interface in a way that will be instantly recognized in any interface without the need of mental resources. Bach et al. (2008) and Ecker et al. (2009) underline that touch gestures should be a set of simple and welldistinguishable interactions and note that by providing a restricted gesture set the visual attention is limited in contrast with direct touch buttons. Bach et. al. (2008) built up to this point by showing that a gesture-based music recorder requires the least eye glances compared to touch-only and tactile corresponding devices. In general, touch gestures promote eyes-free interactions but need to be carefully designed, as they could dramatically increase cognitive workload (Rümelin et al. 2013), tend to be hidden or inconsistent (Norman & Nielsen 2010) or result in unexpected results by the user.

The design of the layout plays an important role in the usability of an interface. Apart from design guidelines provided by operating systems (Android Principles 2015; Apple 2015), they should not be followed blindly without accounting for main interaction design principles (Norman & Nielsen 2010). The pieTouch project (Ecker et al. 2009) shows a specific pie-layout pattern which may not follow specific operating system standards but manages to deliver an intuitive interface for IVIS, that couples visual elements with specific gestural interactions minimizing visual demand. Rümelin et al. (2013) compared different layouts with specific interactions, providing gesture hinting in an

explanatory way. Results showed that a portrait layout supporting swipe gestures was the best overall in terms of usability, while a horizontal layout with simple touch buttons was the easiest to use, but both of them were minimizing subjective workload. The main idea is that touch gestures can be inferred and easily learned and remembered by an efficient layout design of the interface.

In section 3.3.2., the advantages of using multimodal feedback in IVIS were presented. Especially, for touch-based devices, haptic feedback is explored by augmenting touch displays with vibrating elements (Richter et al. 2010; Van Erp & Van Veen 2004; Senseg 2015). Richter et al. 2010 noted that "touch pressure" adds one more dimension to the input design space of touch displays, but requires touch sensors and actuators. Their haptouch project utilized this dimension by providing haptic feedback when the user pressed a button with force, providing a tactile sensation. Both haptouch and vibrotactile projects (Richter et al. 2010; Van Erp & Van Veen 2004) showed that integrating touch interfaces with haptic feedback, limits visual distraction, thus reducing mental effort and increasing performance resulting to a lower rate of errors than a visual-only touch display during the driving task. Haptic feedback promotes direct manipulation of information, thus enabling users to touch and feel the interface elements providing an even more intuitive tangible interaction (Ishii & Ullmer 1997).

3.4.3 Why tablets?

There is inarguably a rapidly increasing use of tablets in various everyday contexts (Müller et al. 2012). Tablets contain mobile phone features, like cameras gyroscopes and location-tracking chips while being much lighter and smaller than laptops. Their main advantage is their screen fitting the size of books and notebooks, encouraging reading, writing and in general interacting with data in an efficient and intuitive manner (Banga & Weinhold 2014). Furthermore, they are ideal as personal entertainment devices for displaying media in locations other than the living room, as they function both as portable and stationary devices (Banga & Weinhold 2014; Müller et al. 2012). Muller et al. (2012) also discovered that tablets are easier to use for multitasking and transitioning between them and other devices. They found that, although tablets are opted for entertainment, people also tend to utilize productivity apps including email, pdf and word processors. They also observed that one of the most common uses of the tablets was while on the go. IVIS's touch displays' size can be easily compared to a tablet's screen size. Audi has built a tablet specifically for use in the car for the passengers' entertainment and convenience (Audi UK 2015). Tablet mounting products are specifically built for using tablets for accessing the invehicle infotainment system. Ipad's smart cover (Apple 2015) shows ways of changing the position of the tablet according to user preference and is definitely inspiring for the design of the overlay cover for the strategic controller.

Hence, using a tablet is considered an attractive choice for an autonomous car, either by encouraging users to bring their own personal device with their familiar operating system and mount it on the car's armrest or by feeling familiar with an integrated tablet-like interface provided

by the car system, functioning similarly with their personal tablet. The design challenges of using a tablet controller for autonomous driving are summarized below.

3.4.4 Design Challenges

Considering the advantages and disadvantages of touch-based interfaces and the emerging use of tablets, it is important to address the design challenges that complement the discussion in section 3.1.3 and 3.3.5.

Tablets are predominantly used as a means of entertainment as discussed previously, so the main challenge is to produce a design solution in the context of semi-autonomous driving being aware of the issues presented in the previous chapters. Müller et al (2012) underlined that it is important to investigate the tablets unique affordances in order to tailor its usage to people's everyday activities. Norman (1988) defined the term affordance as the fundamental use of an object perceived by the user, for instance a glass is for drinking. According to Gibson (1977), affordance describes all the possible actions enabled by the use of an object independent of user's perception, for example hanging a jacket on a chair. Hence it is essential to explore all the possible features offered by the tablets, utilize and combine those that fit the context and driver needs. Rümelin et al. (2013) pointed out that a device should be held ergonomically, allow quick input and give users time to watch what they are about to review, in order to achieve seamless integration with the IVIS (Engström 2004).

Designing an intuitive and efficient interface is the ambition of this project. The main issue of touch gestures is their lack of affordances (Ecker et al. 2009). Cooper (1995) defined the GUI version of affordance, as the amount of pliancy offered by a graphical element or screen area. The pliancy of the GUI objects should be indicated in a way that would make users aware of the possible interactions. Hence, it is a big design challenge to provide the driver a gesture set that will be easy to learn and grasp especially by novices. The aim of the overlay cover is to provide a layout pattern that hints the gestures which are designed in respect to the driver's mental model, providing also the tactile sensation that encourages eyes-free interaction. The other challenge is to design the interface for simultaneous input and output without occluding information, but also not devoting the attention of the driver on the tablet's screen. Finally, it is important to provide an easy switch between the tactical and tertiary controllers' interfaces, by focusing on defining the affordances of the overlay through our design.

4. Methodology and Planning

In this section, we present the methodological approach and planning that will be the guide for this master thesis. First, the research approach is presented, specifying interaction design strategies and methods in order to provide an overview of the design process. A time plan is illustrated and described in the next subsection aiming to define the milestones from the beginning till the end of the 20-week master thesis project.

4.1 Research Approach

Our research approach is based on an iterative design process consisting of the three main phases of divergence, transformation and convergence of the Jones Model (1970). Suitable methods were picked from design toolboxes (Hanington 2012; LUMA Institute 2012), relevant literature and previous researches aiming to fulfil our goals at each stage of the process. Specifying the methods for each phase of the design process is important in order to define the short-term and long-term goals at each stage. The design aiming to utilize the key strengths of each approach relative to our goals rather than blindly following a specific strategy avoiding methodolatry, which is detrimental according to Norman (2006). Figure 4 illustrates the design process, spanning over the 20-week thesis period, in a diagrammatic way. In the following subsections follows a detailed description of each phase of the design process, including the methodological approach and goals within each stage.

The Design Process



Figure 4. The Iterative Design Process with the three stages of Jones model
4.1.1 Divergence

Divergence is the stage of exploring the design space and framing the problem, indicating 'limits', 'consequences' and paradoxes (Jones 1970). In this master thesis it is guided by literature research, consisting of theories and related work relative to the research problem and hypothesis. **Literature review** is the method of highlighting and defining patterns, categorizing and distributing sources according to their subjects and the perspective they approach the research problem (Hanington 2012). **Triangulation** was essential for establishing credibility (Norman 2006) by justifying our design choices and gathering the key requirements, defined as theoretical triangulation by Denzin (1970) as the method of using multiple theoretical approaches to justify a position. Discussing our personal interpretations of qualitative data within the group, noted as investigator triangulation by Denzin (1970), was also essential to retain a consistent design approach within the group.

In the context of building a tablet interface for controlling autonomous cars, literature research, review and triangulation were conducted to define the design challenges for the context of autonomous driving and touch-based interfaces integrated in vehicles. One more purpose was to extract principles, guidelines and methods created for this domain, which were considered through the entire design process. Throughout the literature study, it was also important to define user needs in relation to autonomous driving and in-vehicle information systems, aiming to follow a driver-centered approach as noted in section 3.3.4. Thus, the main goal of the divergence phase was to complement the existing concept idea and technical constraints with user characteristics and operational requirements extracted by theories and previous researches. We followed the procedure of **requirement elicitation** (Gunda 2008), by creating and constantly updating a list of the contextual, technical and user requirements gathered from methods within the design process. These requirements were translated to system requirements (Endsley 2011), which are input and output functions that need to be provided by the interface.

User requirements were elicited, following a more human-centered approach through a participatory design workshop (Hanington 2012) aiming to explore the users' mental, needs and desires in the context of future autonomous driving. Brown (2008) notes that innovative design solutions emerge from design thinking that takes both user needs and desires into account. Participatory Design (PD) is characterized by user active involvement and collaboration in the designing task (Kensing & Blomberg 1998; Spinuzzi 2005). The PD Session followed a generative research approach in order to explore user's mental model of the interface of the tactical controller through flexible modelling, 'thinking aloud' methods (Hanington 2012; LUMA Institute 2012), video recordings (Hanington 2012) and direct observation (Brown 2008). The purpose was also to capture users' envisions of future of autonomous driving by asking them to utilize the interfaces through bodystorming based in a real life scenario, being inspired by Pettersson's PD workshop (2014). The bodystorming method helped testing specific use cases, encouraging also users to reorganize the elements by applying them in faked real conditions, using the critical incident technique (Hanington 2012) and reflecting upon them. Thus, activity centered principles defined

by Norman (2006) were followed as well, in order to examine various use cases, defining problems emerging early in the design process.

The data collected during the PD workshop, including questionnaires, paper prototypes, observation notes and video recordings, were analyzed qualitatively (Miles et. al 2013) following a variable-oriented approach. Thus, the data were saved into matrices ordered by the important factors of our design task, concerning input and output functions of the interface as long as essential automation variables, including trust, control and authority as discussed in the theory section. After thorough analysis the data were condensed and visualized by building a customer journey (figure 8), as a method for evaluating the user experience with regards to the important automation variables mentioned.

4.1.2 Transformation

Transformation is the stage of 'pattern-making' upon the results from divergent search. 'Patternmaking is the creative art of turning a complicated problem into a simple one, deciding what to emphasize and what to overlook' (Jones 1970). During the transformation phase, ideation methods were utilized in order to translate the elicited requirements into design solutions. This stage of the design process blends iteratively with divergence and convergence as shown in figure 4. The PD workshop aimed to expand the design space of the research problem by involving the user in the transformation stage. The following two iterations belong in both transformation and convergence phases and consist of ideation, prototyping and evaluation by following a parallel prototyping approach (Hanington 2012). The goal was to generate various lower fidelity interactive prototypes which could be evaluated before converging to the final design. Brown (2008) stated that prototyping should not aim to provide a final result but help detect the flaws early in the process, which are highly irreversible in the final implemented solution. Thus, it was important to produce and evaluate a set of initial interface solutions before implementing the final prototype.

Initial ideation was stimulated during the PD workshop by allowing the users to generate and reflect on their own ideas aiming to diverge to additional requirements in respect to the users mental models. By introducing the subjects to the design space through a list of specific requirements and communicating the context of our work with a storyboard (Hanington 2012), we applied the "Clear Panels" method (Brown et al 2010) to extract users' ideas. Various paper prototypes were generated during this workshop, which not only diverged the problem but also provided initial solutions as a source for inspiration for our design. "Thinking aloud" and direct observation (4.1.1) during the prototyping phase contributed greatly in the 'Pattern-making' process (Jones 1970). Nevertheless, the goal at this stage was not to converge to a specific design solution but extracting and eliciting user requirements as underlined in 4.1.1. This iteration of the requirement elicitation is reflected on figure 4.

The first iteration commenced after the divergence phase, having finished requirement elicitation, taking into account both technical and user requirements. A brainstorming session with affinity diagramming (Hanington 2012) was conducted for ideation with post-it notes and sketching, following a bottom-up approach (Jones 1970). Ideas for each specific function of the interface were generated, evaluated and combined, converging gradually to various digital interactive

prototypes. Symbolic methods used for evaluation of In-Vehicle interfaces were considered at this stage (Harvey et. al 2011) in order to highlight the strengths and weaknesses of the prototypes. Due to time limitations, we rejected the method of hierarchical task analysis with users and decided to run an expert evaluation session applying a heuristic analysis (Harvey et. al 2011) examining specific usability criteria. The results of this sessions stimulated a second iteration of ideation, prototyping and evaluation (figure 4).

The second iteration was based on the results of the expert evaluation. Brainstorming during this stage aimed to explore various solutions for improving the previous prototypes and examine various ideas emerging during the expert evaluation session. An activity-centered approach was followed during this procedure (Norman 2006), by examining each function in depth, considering exhaustively all possible interactions in the context of use and gradually converging to a couple of interactive prototypes with very few differences at this stage. Thus, this iteration is leaning closer towards convergence, since the goal was to produce a final prototype by fixing flaws, combining and improving the previous prototypes. The evaluation at this stage was conducted internally within the group but also externally with potential users focusing on feedback regarding the interactivity and the layout of the interface, aiming to evaluate our design in terms of intuitiveness and usefulness and define weaknesses to be fixed during the implementation phase.

4.1.3 Convergence

Convergence is the stage, when the "objectives are set and the secondary uncertainties are reduced progressively until only one of many possible alternative designs is left" (Jones 1970). As discussed in the previous sections the two iterations of the transformation stage aimed to converge gradually to a final design before starting implementation in a higher fidelity level. Constant evaluation within the group, stakeholder walkthroughs (Hanington 2012), and demonstration to users were conducted in order to indicate flaws and lean to a specific solution in the end of the second iteration. The bottom up approach mentioned in 4.1.2 helped not only exploring various potential solutions for each interface function (transformation) but also evaluate them and underline the ones which fit best to our research problem with regards to the requirements elicited during the divergence phase. The results of the parallel prototyping (4.1.2) enabled stakeholders, users and experts to test the interface and highlight advantages and disadvantages, contributing to the convergence of the idea using symbolic methods such as layout, task and heuristic analysis (Harvey et. al 2011) focusing on usability criteria for In Vehicle information systems (IVIS).

Having converged to a specific design after the second iteration and before implementing the final prototype, suitable materials needed to be defined including hardware and software tools for building the interface and the overlay cover. Technology analysis is the "activity of defining the technological assets that will be employed for building the final product" (Endsley 2011). The final prototype was implemented using graphical and programming tools for implementing a high-fidelity solution in the form of an android application. The materials specified for the overlay cover were chosen suitably aiming to provide a clear distinction of input and output features of the interface. Evaluation and critical design choices had to be taken also at this stage of the design

process, triggered by stakeholder walkthroughs (Hanington 2012) aiming to fulfill the needs of the client without diverging from the framed research problem and elicited requirements.

At the end of the implementation phase, a validation session was planned and conducted with ten subjects after a couple of pilot session at Lindholmen Science Park Safer (SAFER | Lindholmen Science Park 2015) vehicle simulator, using an existing scenario, which was built based on real traffic (Chen et. al 2014) and changed suitably to fit our validation plan. At this stage, both qualitative and quantitative data were gathered by utilizing usability testing methods for In-Vehicle information systems (Harvey et al. 2011). The primary goal was to evaluate the product in terms of usability and user experience, and provide answers to our hypothesis, and highlight points for future insight. Thus, the experiment's goal was to introduce the user with the autonomous driving context by utilizing SAFER's vehicle simulator using the "Wizard of Oz" method to simulate the experience. The A/B testing method (Hanington 2012) was used to compare the final prototype with and without the overlay in order to compare the two systems (tablet with and without overlay cover) and highlight their unique affordances as perceived by the users (Norman 1988). Data were collected through questionnaires, system usability scales, screen recording, observations and a final interview. The semantic differential technique was considered as an evaluative method for the users to rank and compare the prototypes, but system usability scales (Hanington 2012) were preferred instead in order to capture the spontaneous emotions of using each system separately (Brooke 1996) translated to quantitative results measuring usability. The thinking aloud method (Hanington 2012) and the final interview aimed to describe the user experience while and after using the systems.

4.2 Planning

Figure 5 represents the initial time-plan of the 20-week master thesis project, which was built before starting to conduct our research, aiming to distribute the 20 weeks into the key stages of the design process. During the process, changes had to be made in the choice of methods, in order to ensure the completion of the research project in the time given, satisfying our goals and being able to provide answers to our research questions. Hence, a weekly planning analytical schedule was retained and updated constantly by setting objectives in a daily and weekly basis. The schedule helped in organizing our time thoroughly, including stakeholder meetings, daily working tasks and expected results in the end of each week. In the next paragraph, our initial planning is presented, while the changes are reflected in the following chapter.

First three weeks of the design process would be focused on literature and ethnography study in order to explore the design concept given by Semcon and elicit the requirements emerging from thorough literature review. Interviews and observations would be conducted in the following two weeks in order to retrieve qualitative data for eliciting user requirements through a human-centered approach. Having gathered and elicited technical and user requirements, next four weeks would be dedicated to iterative ideation, rapid low fidelity prototyping and evaluation until converging to a specific design solution. The number of iterations were undefined at this stage but our goal was to produce various low fidelity prototype solutions that would be user tested and evaluated in order to avoid flaws early in the design process. At first, we were planning on

producing a number of paper prototypes and translate them to higher fidelity interactive screen prototypes in the next iteration taking into account user testing results. After having converged to a specific solution, we reserved one week for technology analysis (figure 5) and four weeks for implementation of the final prototype, building the android interface along with the overlay cover. Next 2 weeks were planned for testing and evaluating the final product, conducting the validation session and analyzing the results. At this stage, there was no specific validation plan, but we were thinking about a Wizard of Oz setting, by displaying a recorded video to the subject, which contains a real driving scenario and the participant uses our interface to perform tasks through this scenario. Section 5.7 describes our final validation plan. The remaining weeks were reserved for final documentation of the thesis and preparation for presenting it at Chalmers and at the company.

Description	Schedule																		
	Jan	in Feb			Mar			Apr			May			Jun					
Literature Research- Review Requirement Elicitation																			
Iterative Design Process Divergence Transformation Convergence																			
Technology Analysis (*)																			
High - Fidelity Prototype Implementation																			
Testing and Evaluation																			
Documentation																			
Presentation to both academic institute and company																			

(*) Technology analysis is defining the software and hardware that will be used in the implementation phase as suitable prototyping material to convey our solutions. (Endsley 2011)

Figure 5. Initial timeplan of the 20-week master thesis project

5. The Process

Following the time-plan presented in the previous section and adopting the Jones Model (1970), this chapter describes in depth the working process of this master thesis. It focuses on how the methodology was applied systematically during each phase and explains our design decisions though the whole design process, from framing the problem and eliciting the requirements (divergence), envisioning and externalizing solutions (transformation) to implementing, validating and deploying the final result (convergence).

5.1 Literature Review

During the divergence phase (Jones 1970), the main goal was to define the research problem properly and formulate the hypothesis of this thesis. Based on the constraints given at the beginning, thorough literature study was conducted to explore the design space of autonomous cars. Hence, this phase was devoted on extensive online research, maintaining a literature list, categorizing the papers, triangulating information and discussing about our task and methodological approach based on a solid theoretical basis.

The choice of papers focused firstly on defining the key principles of automated systems and the challenges brought by introducing the human to automation. Initially, a thorough understanding of levels of automation (3.1.2) was important to define the level of our system and be aware of the design challenges and limitations (3.1.3), before conducting extensive research specifically on autonomous cars (3.2). Furthermore, research on In-Vehicle Information Systems (IVIS) (3.3), design principles, challenges and previous works, aimed to elicit system requirements for building information system solutions in a car context considering driver's needs. Designing a tablet interface triggered also research dedicated to tablet devices and touch interfaces, in order to make us aware of the tablets' unique affordances and highlight the advantages and disadvantages of building a tablet-based controller focusing on visual input and feedback. Building a solid methodological approach demanded a thorough choice of papers and design tool-boxes for selecting appropriate interaction and validation methods to design, implement and validate our solution.

Paper categorization and maintaining a constantly updating list of literature, was essential to keep track of the progress and be able to easily trace back and forward to papers during the whole design process. Literature review was conducted by creating separate documents for each category, which were consisted of key notes taken from the various papers. Thus, triangulating the information from papers of the same category was simplified by analyzing these documents and constantly discussing our individual interpretations within the group (theoretical and investigator triangulation). The most important points were highlighted and stimulated ideation in order to elicit the system requirements, discussed in the next section.

It is important to note that some early concerns arose at this stage, considering the use of a overlay cover on the tablet, the tablet positioning in the car and the concept of the system, considering the tablet as a personal device or an integrated touch surface in the car. These

concerns were brought up during user studies (5.3) to justify our design decisions. Hence, during the literature review early questions were raised that required user input in order to make design choices through a human-centered approach, which was considered essential especially in the unexplored domain of future autonomous cars.

5.2 Requirement Elicitation

Aiming to frame the research problem, a concrete design space had to be defined. Since this work is based on the future domain of autonomous cars, specific design standards have not yet been defined. Our key objective at this stage was to ensure that all requirements are clear and visible. The visibility of all requirements is essential as it provides a better view of our research problems. We started eliciting the hidden requirements methodically, in order to transform them to suitable design solutions at the next stages of the design process.

We started off by brainstorming based on real-life scenarios and taking into account the constraints defined in section 1.3, in order to identify trivial requirements. We reflected upon our driving experience and found out what are common driving tasks that we usually perform. By matching our experience with findings from literature review and omitting operational tasks such as shifting gears and turning the steering wheel, we were able to form a list of driving tasks as listed below:

Driving Phase	Operational Task						
	Change Lane						
Highway Driving	Accelerate - Decelerate						
	Take next exit						
	Stop						
City Driving	Turn left/right						
	Parking						
	Stop						
	U turn						
	Roundabout						

Table 1. List of Main Operation Tasks

Taking the discussion further forward, we exemplified real-life scenarios using the tasks presented in Table 1 combined with situations where a touch-based interface could be used. This method helped us investigate more possibilities and confirm the use-cases that have been previously defined. The scenarios concerned a simple driving route from a house located in Gothenburg city to Lindholmen Science Park. The route was divided between three phases namely starting, city driving, and highway driving and parking as seen in Table 2.

Phase	Task						
	Unlock car						
Starting	Adjust seat in rearwards position						
	Start up an engine through tablet						
	Set destination						
	Autonomous system takes control						
City Driving	User stops (e.g. to buy something)						
	Takes another route (turn left/right)						
	Accelerates/Decelerates						
Highway Driving	Change lane						
	Accelerate/Decelerate						
	Take other exit						
	Decelerate						
	Park the car (predefined maneuver)						
Parking	Closes tablet						
	Locks the car						

Table 2. Real - life scenarios where touch-based interface can be used.

In order to perform each task illustrated in Table 2, we observed that the driver always provides two distinct inputs to the system; direction and speed. Direction concerns tactical control of the car, issuing commands regarding changing lanes and turning to intersections. Speed is connected to longitudinal control; accelerating and decelerating.

As discussed earlier in section 3.1.3, feedback is vital to every driving session. (Sheridan & Parasuraman 2004) Given the design constraint that the driver seat should be adjusted in rearward position, out of reach from the steering wheel, the driver is able to perform driving tasks only through the tablet controller. The tablet provides a display area of 10 inches and therefore

can be equipped with both input and output functions. Using the same real-life scenarios as listed in Table 2, we elicited the required input and output functions for each task as seen in Table 3.



Table 3. Elicited requirements regarding on system input and output

Extracting requirements solely from our past experiences based on the literature review was considerably fast and efficient. Using the above requirements provided us a way to approach the research problem at the beginning of this project. Nonetheless, we believed that the obtained requirements, quantity and quality wise, were not sufficient. There were still special requirements that had not been discovered. We were first considering to use a traditional requirement elicitation method such as observation from the real situation, known as the 'fly-on-the-wall' method (LUMA Institute 2012). However, based on the fact that we were designing for a futuristic context, since autonomous cars are not commercially used, observation or user studies in the everyday context of driving would not provide us with relevant data.

Nonetheless, aiming to follow a human centered approach in order to explore the mental model of the potential end user, we came up with an idea of conducting a Participatory Design workshop for extracting user requirements, described in depth in the following section.

5.3 User Studies - Participatory Design Workshop

In the previous section, we have listed the preliminary system requirements. At this phase, our aim was to update the list with additional user requirements. We therefore planned to conduct a Participatory Design (PD) workshop. This workshop followed a human - centered design approach as discussed in section 4.1. We wanted to explore the user's mental models by introducing them with the concept and define the emerging requirements through a procedure described in the latter part of this section. The work at this stage belongs both to the divergence and transformation

phase of the design process (figure 4) since it resulted in additional requirements (divergence) and initial design ideas from users (transformation).

This section presents a detailed plan of the PD workshop, designed to support the process of requirement elicitation and establish a strong basis for ideation. Firstly, the goal of the workshop is underlined, inspiration and design techniques are noted. A detailed description of the procedure follows including technical information and the adaptation from the inspired design methods, closing with the obtained results after the qualitative analysis.

5.3.1 Planning

Taking into account the design methods described in 4.1.1 and 4.1.2, the workshop was then planned, aiming to build a link between the participants' driving experience and autonomous car technology. Only one subject would take part in each session, so that participants would be able to produce distinct designs without influence from the others. We believed that this approach would give birth to more divergent results, from which we could extract patterns at this stage of the design process. Following a generative research approach added with participatory design and bodystorming (4.1.1), subjects would be able to generate their own designs using provided tools (Build), test their creations (Try) and reflect on their choices through a bodystorming session (Express). The workshop then would end with a final interview aiming to get more general opinions regarding autonomous cars and the concept of integrating them with touch-based controllers. Hence, the workshop was named after 'Build - Try - Express'.

5.3.1.1 Participants

While conducting the workshop, we encouraged each subject to take the role of the designer. During the 'Build' phase, each subject was given a set of design tools with the task of designing a user interface for a touch-based controller. Even though, design and programming knowledge was not required, we valued the thought behind each subject's choice. Hence, there were no strict criteria on how we selected the workshop subjects since we wanted to diverge the design space. The bigger the diversity of the workshop subjects' background, the more design patterns expected to be discovered. Thus, we selected 10 subjects with distinct occupations and expertise. The participants were master students as they were easier to be scheduled, mostly interaction designers, a couple of biomedical engineers and mechanical and control engineers. The generated results vary in terms of past experiences, nationality, educational background, age and sex.

5.3.1.2 Mediating tools

As mentioned earlier, during the 'Build' phase the workshop subjects were instructed to design a user interface for a touch-based controller to be used in an autonomous car. Since we considered it difficult and time consuming for a subject without design knowledge to generate an interface solution, we decided to provide mediating tools to accelerate and support the process. We created the tools with the objective of guiding the subject through the world of design for automotive but still offer room for exploring a wide variety of possibilities. In the end, we came up with a set of

geometric shapes, e.g. circle, square, rectangle and various type of arrows (appendix I – Design Toolkit). The aim of these paper elements was to accelerate the interface design process instead of letting the participants to think everything from scratch which would be too time demanding. The subjects were expected to use them to form these shapes into a user interface. Some blank papers and colored pens were also provided if the subject desired to add her own design element to the prototype.

Apart from the design toolkit, we followed the "clear panels" design technique (Brown et al 2010) by giving the subjects a tablet device with a writable transparent sheet on top. Subjects could draw, cut and stick paper shapes on the tablet using nomadic tape, building their own interface. The "Design Toolkit" along with the "Clear Panels" technique effectively supported the subjects during the workshop giving birth to inspiring interface prototypes in a considerably small amount of time.

5.3.1.3 Context and setup

Due to the technology limitations, time and resource constraints, we could not conduct the workshop in a real or simulated autonomous driving situation by getting the user in a car. We decided to conduct the workshop in an ordinary office environment for space convenience. Nonetheless, we were concerned about the fact that subjects would feel stressed during our workshop. Therefore, we provided a bunch of cinnamon buns to ease out the atmosphere. On the working desk, we provided each subject a design toolkit, an instruction paper describing the workshop tasks and a storyboard for introducing the participant with autonomous car technology, the use and situation where it will be used (appendix I – storyboard, instruction card). Video cameras were placed on the same table with different angles to record subject's choice of design and the reflection upon each choice. A voice recorder was also placed in front of each subject to record the ending interview.



Figure 6. Working desk with design toolkit, instruction papers and cinnamon buns.

5.3.1.4 Data collection methods

Qualitative data were collected during the workshop by applying the methods listed below:

• Questionnaire

Before the subjects were given a design task, they were first asked to fill out a simple questionnaire with contact details, driving experience and experience in using touch-based devices and touch-gestures. The questionnaire can be found at appendix I. The questionnaires aimed to provide ethnographic information about the user group involved in the PD workshop and define patterns of designs from participants with similar backgrounds. Asking for the familiarity and flexibility with touch-based devices and gestures was essential to take into account while analyzing the data, avoiding following paths of complex design solutions. Hence, the questionnaires' purpose was to reflect the character behind each interface solution.

• Design toolkit - Clear Panels

Given the task of designing user interface for a touch-based controller, subjects were asked to build it by drawing and using the elements of the toolkit provided. As discussed in 5.3.1.2, this method aimed to provide an easy and fast way for the participants to create their own designs, but also enabled them to use them with bodystorming, encouraging them to reflect upon their creations. The interface solutions, were kept as a resource for requirement elicitation later on. See figure 7 for reference.

• Observation – Recordings

Throughout the workshop, the participants were recorded, both audio and video, for further interaction analysis. They were also encouraged to "think aloud" to reflect upon their actions during the workshop, reasoning and explaining their thinking behind their design choices. Important reflections, along with silent actions during designing and bodystorming were documented in real time by one of the moderators and the recordings helped tracing back for additional findings. This information was very valuable for the results of this workshop.

• Interview

Towards the end of the workshop, the subjects were interviewed about their general ideas and reflections upon autonomous car. The feasibility of the concept of a touch-based controller, their opinions and feelings about this modality were also touched on during the interview. The goal of the interview was to explore the subjects' mental model of autonomous cars and how they perceive that a tablet solution would be suitable for controlling them. The results are discussed in section 5.3.4.

5.3.1.5 Pilot session

Before conducting the workshop, we piloted the procedure in order to see how it is working out time and efficiency wise regarding our goals. We tested the procedure with an industrial engineer student who had no knowledge neither in the area of interaction design nor in autonomous car technologies. In this pilot session, we followed strictly the planned procedures (5.3.3). When the session was finished, the pilot subject was asked to provide feedback about the procedure. He gave a short comment regarding mediating tools. The design toolkit included pre-designed interface elements such as various type of speedometers, buttons etc. He mentioned that these elements restricted his thinking and biased his choices. Apart from that, he said everything went smooth and the workshop was well planned.

Hence, we changed the design toolkit by providing only simple geometric shapes in order to give more freedom to the subjects to explore the design task.

5.3.2 Procedure

The workshop lasted about an hour. As described earlier, we recruited 10 subjects with different backgrounds, sex and age and held 10 sessions in total. Thus, each session was conducted by one subject at a time and we took the roles of the moderators. One was responsible for setting up the session, observing and note taking. The other guided the subject through the tasks, prompting the participant for "thinking aloud" and asking questions during the interview. Each workshop session was divided into three main phases namely "Build", "Try" and "Express". Below are the steps of the procedure:

• Pre-session questionnaire and instructions

The workshop moderators welcomed the subject, described briefly the concept and scope of our work and introduced her to the autonomous driving context. Each subject was asked to complete a questionnaire as described in section 5.3.2.4.

• Build

The subject was given a storyboard and instructions and was asked to read them in order to understand the design task. The moderator provided further clarifications if needed. When the subject was ready, the moderator guided presented and provided further explanations about the design toolkit. Then she was asked to design a user interface for a touch-based controller using the clear panel design technique and the toolkit provided. This phase took roughly 20 minutes. The subject was also prompted to "think aloud" for better understanding of the reason behind the choice of the specific design elements.

• Try

During this phase the subject was asked to try out her own interface through real-life scenarios. These real-life scenarios are the same scenarios as we had listed while we did preliminary requirement elicitation (5.2). This was the bodystorming phase since the subjects used their interface solutions trying to interact with them. While going through each scenario, there were a few subjects who made changes to their design as they felt uncomfortable with the design elements they chose.

• Express

This is the final phase of the workshop. During this phase, subjects were interviewed about the reason behind their design decisions, their general ideas of autonomous driving and opinions regarding the integration of a touch-base controller in an autonomous car.

5.3.3 Result

After having collected data from 10 subjects, we commenced qualitative data analysis. During analysis, we indicated a relationship between each data set and its implications. We started off by classifying the data into four categories: tablet, user interface, additional outputs and automation related variables (authority - trust - control). These categories and their data were later transferred to a separate partially ordered meta-matrix for each category (Miles et. al 2013), storing the participants' ids as the rows and the variables regarding the categories described above as columns. The matrixes were described by using specific data analysis methods namely cross case analysis, counting, noting pattern themes, clustering and triangulating (Miles et. al 2013). We were then able to form a list of results which is discussed in the following sections.

5.3.3.1 Tablet

The interview answers showed that subjects' opinions regarding the orientation of the tablet were divided into half. 5 subjects preferred to have it in landscape mode whereas the rest favored the portrait mode.

Most subjects would use tablet in the context of autonomous driving instead of the steering wheel, as it is easier to learn and use for beginners, it is convenient and it has more affordances. The interface can be easily changed to tailor the driver's preferences (Normark 2015). Customization was also referred by a subject. On the other hand, 3 participants were skeptical in terms of trust and safety while using the tablet and one mentioned that he preferred the traditional method of driving with steering wheel and pedals over the tablet.

When the subjects were asked for the placement of the tablet, they commented that it would be ideal that the tablet has some level of flexibility even if it is integrated in the car and not be in a

fixed position and orientation. As with iPad Smart Cover, a need for convenience was expressed by the subjects but the importance of the tactical control functions did not encourage total portability of the tablet for half of the subjects in order to ensure safety. Thus, a trade-off between convenience and safety has to be made in the tablet placement on the car.

Concerning the tertiary features such as music and movies, 6 subjects agreed upon an idea that both features should be on the same device as it is easier to control. Also, tablet device should be on the same position with the primary features (controlling the car). The device should not be moved or passenger cannot take it out from the docking station for controlling tertiary feature on his own. Subjects also commented that this controller should not be shared among the driver and passengers. Everyone should have their own devices.



5.3.3.2 User Interface

Figure 7. Interface design solutions extracted during the PD workshop

According to the questionnaire data, most subjects were familiar with gestural patterns to some extent. Thus, there are several gesture patterns presented in this PD session. However, only few participants chose to have more sophisticated gesture (i.e. multi-finger swipe) than the simpler gestures such as tap, swipe and drag and drop. Few subjects chose to have multi-finger gesture for some functions such as changing lane or speed up and down. Interestingly, there were people who chose to invent a new gesture that fits their mental model on the car's moving pattern (e.g crescent moon gesture for overtake).

For the maneuvering commands, there were two common design patterns indicated; a set of arrow buttons and a blank space using to draw gestures. Those who chose to use a set of arrow buttons reasoned that these arrows indicated direction and gave them a visual cue. They could easily tap on each arrow in order to move the car. One subject even employed the steering wheel and pedal mechanisms while using these arrow buttons. For example, tapping and holding left/right arrow button respectively until the car was heading toward the desired direction and long tapping on up/down arrow buttons to accelerate/decelerate. Those who chose to have a blank space marked

that this gave them more freedom for controlling the car. It was also faster than finding and tapping on the specific button. Nonetheless, subjects who chose to have a blank area struggled in remembering all gesture patterns. Some of them lost track easily and made some changes from time to time during the bodystorming phase. One participant followed a different approach by defining a drawer menu with every function. When he was asked to try his own creation, he could easily drag the drawer menu and select the corresponding function.

Remarkably, subjects who are not in the field of interaction design are more accustomed to the use of buttons for every function. They are more intuitive to them for issuing a command. On the other hand, there was one subject who employed two mechanisms in his design, gestures and a menu. He designed an interface with a blank space for gestures. His designated gestures covered every task required and he had a drawer menu for more advanced functions; route related and strategic control functions. His reason was to have menu for beginner as it is easier to learn than gesture.

One subject interestingly defined a drawer menu with every function. When asked to try his own creation, he simply dragged out a drawer menu and tapped on the specific function. He made no mistake when asking to perform different task. This showed that his solution was simple and effective. However, it was not so efficient since it required much more time to respond to the task than every other solution.

Regarding the transition between tactical control and infotainment features, swiping gestures proved most intuitive for the switching between the functions. Nevertheless, other methods were also proposed (menu, settings or home buttons). One subject wanted to always keep the tactical functions on the foreground and would rather overlay the advanced maneuvering functions (parking, overtake) to access infotainment features.

5.3.3.3 Output - Feedback

When the participants were introduced with the design task, they were required to include only two main outputs to their design; speed and fuel.

Regarding the speed output, there were various types of speedometers shown in the subjects' creations. A few subjects chose to display either a digital or an analog speedometer. Those who chose to have an analog speedometer reasoned that it is easier for them to check the speed just with a quick glance at the speedometer needle, as they did not need to know the exact speed. On the other hand, subjects who preferred to have a digital speedometer said that it would be easier and more efficient for them to quickly read a number and drive knowing the exact speed. Interestingly enough, most subjects combined the two models together forming an analog speedometer with a big digital number showing the exact speed.

For the fuel output, most subjects drew a gas icon with a discrete levels' gauge to show the remaining amount of fuel. They also added that if the fuel level goes low, the icon would blink in order to signify that the driver should consider refueling.

A requirement of displaying the **estimated arrival time (ETA)** was emerged during the PD workshop. 3 subjects put ETA output on the same position, top right. The reason was that knowing the ETA is important for both the driver and the passengers and is a value that could be dynamically changed by traffic or environmental conditions. Thus, it would allow them to plan the journey ahead and make decisions upon route related actions, for instance to avoid heavy traffic roads.

Interestingly, 6 subjects mentioned that they also wanted to know about environmental hazards that are related to driving performance and route such as an accident on the road ahead for instance. In addition to that, most subjects mentioned during bodystorming that they would want to know the command that is currently executed by the car. They related this requirement to safety and trust. Knowing the current and the next move made them feel prepared and aware of the automation actions. From these result, we can see that feedback about the car status proved vital in order to build trust for the automated system (3.1.1).

5.3.3.4 Automation variables (authority - trust - control)

Given that an autonomous car is built to be safe and follow strictly the traffic rules, in the scope of our thesis, subjects were mostly trustful and would rather be engaged with other activities than controlling the autonomous car. Half of them wanted to have the authority to take control over the car in any situation, 3 of them would let the car take the control to ensure safety in critical situations and 2 of them would leave the primal authority to the car.

The main difference was observed between beginner and advanced drivers. The former would trust an autonomous car and would expect it to be safe and drive them around. The advanced drivers would need time to trust them and they required that the road environment is built to support only autonomous vehicles, since they would not trust other manual vehicles. Thus, they expressed the need to have the primal authority on the car, being able to take control of it. One of them would prefer the car to bypass the manual control in critical situations to ensure safety, but feedback is always expected. Most intermediate users would prefer to have the primary control, but they were divided in half in terms of trust.

All of them though, expect sufficient system feedback to be aware of the situation.

5.3.4 Discussion

After being finished with analyzing the data and extracting the results, we were able to form a complete list of system requirements. It was obvious that that output features specified previously, were not enough for controlling an autonomous car. Referring to Table 3 of section 5.2, regarding output, ETA, car status, confirmation of command issued by the user, environmental hazard alert and next command to be executed by the car should be explicitly added to the list.

There were no additional requirements regarding the input functions, except from defining how the system is going to respond to user input which should be discussed. Thus, the same set of input functions was used during the transformation stage.

Remarkably, when subjects were asked about their opinion upon automation, some of them would not want to use the car because of trust and controllability issues. Our aim then was to maximize trust by keeping the control in a neutral level. **The driver is the supervisory operator in our semi-autonomous context.** He should be able to take control of the car, except from critical situations when the car should take control to establish safety but providing suitable feedback to keep the driver in the loop. In situations that the driver desires to take the manual control of the car even if his actions would violate the traffic laws, a dilemma emerges:

- 1. Car handles the situation to establish safety and follow the traffic rules, not allowing the driver to take manual control, but providing sufficient feedback to keep him aware of the situation.
- 2. Allow the driver to take over control but still warn him about his actions.

According to our user study the users were divided among these two cases. We decided to follow the 1st rule at least for our tablet interface. The driver could take manual direct control of the car with the steering wheel and pedals, but he shouldn't be able to give indirect commands that breaks the traffic rules. Since, these tasks are directly performed by the automation, the system should never break the rules. A safe autonomous car was demanded by all subjects. The tablet functioning as a tactical controller should translate user's goals to operating commands that abide with the traffic laws. Taken an example of driver wanted to reach the destination as soon as possible. He therefore would assigned a command of acceleration and overtaking to the car. This certain action could possibly be translated as driver wish an automation's performance to maximize. However, do not wish to violate safety and traffic laws.

A customer journey was built for condensing the results by visualizing the automation variables of trust and controllability in relation with each use case examined during the bodystorming session (figure 8).

CUSTOMER JOURNEY





9 to

Parking Place

Driver is looking for parking place.

Car knows the best place to

Go to parking lot and command a car to park.

Stop at a specific slot and instruct a car to park there.

park

Red Traffic Light

Driver is running late. But the traffic light is red.

Car will warn and take the control.

Car will not allow me to take

control

Figure 8. Customer Journey summarizing the findings of the "Build-Try-Express" workshop

This customer journey broke down the one big problem of driving in an autonomous car into several smaller tasks. The illustration highlighted where controllability is required which goes along with the level of trust. As we can see from the illustration, when level of required controllability rises, the level of trust drops. Take the roadworks use case as an example. The level of trust has dropped down to a negative region whereas level of required controllability rise higher up. Subjects were asked what kind of action they are going to perform when face up with this roadworks use case. 6 out of 10 subjects answered that they would take an action to bypass them. As noted by Parasuraman and Sheridan (2005) that feedback is vital and could be used as a tool to build up trust. In addition, the feedback also can be used as a tool providing sufficient knowledge for user to make a decision of what kind of action should be performed next. The results shown emphasized this fact. Hence, the design solution to be delivered must assure the user while performing each action by providing sufficient amount of feedback. (Billings 1997; Parasuraman & Sheridan 2005) Lastly, it is important to note that time and environmental issues are important factors since trust is built as time passes.

5.4 Iteration 1



Figure 9. Affinity Diagram with post-it notes and elicited requirements (top right)

Having analyzed the qualitative data of the PD workshop and condensing them into the customer journey described in the previous section, user requirements were elicited along with the technical requirements during the literature review. The translated system requirements were gathered in a document and printed as the primary source of stimulation for ideation. They were thoroughly examined and discussed by the group and the key points were highlighted. The patterns identified from the users' designs from the PD workshop were set side by side with the required tactical instructions.

5.4.1 Affinity Diagram - Brainstorming

The printed requirements and the customer journey were put on a whiteboard and ideation started with a brainstorming session and applying the affinity diagramming method (Hanington 2012). Over 50 ideas were generated and put into post-it notes, which were placed into corresponding categories marked at the whiteboard as shown in figure 9. Three main categories were defined including input functions, noted with a red marker, output functions noted with blue and ideas concerning the switch between the tactical controller and the tertiary controller marked with green. The two first categories included a set of subcategories marked at the whiteboard arranging it line by line. Hence, a bottom-up approach was followed, by aiming to generate ideas for the specific functions of the interface, evaluating them and combining the most dominant ones to synthesize an initial design solution. The least dominant ideas were gradually put aside after the brainstorming session after evaluating them in terms of relevance and obedience to the requirements through critical discussion within the group. The following table summarizes the ideas underlined after the session which stimulated the parallel prototyping phase (5.4.2).

INPUT	Circular Space with interactive map
Direction commands	Tap or one-finger drag gestures
Speed and Lateral	
movement	2-finger drag
Overtake	Tap or one-finger drag gestures
Stop and Park	2-finger drag down and long hold (menu)
OUTPUT	Above (vertical layout) or Left (horizontal layout) to input space
Speedometer	Digital and analog display
Fuel	Icon with gauge. Tap to find gas stations
Alerts	Glow animations. Blinking fuel icons. Polygonal shapes
Next Move	Current move (in circular space). Queue of moves (rectangular menu)
Confirmation	Gesture trails. Animating command text into the next move box
TERTIARY MENU	Circular menu. Swipe: up/down to access. Left/right through functions

Table 4. Affinity Diagram categories with dominant ideas after evaluation

Taking into account the users' patterns of the PD workshop, in which they tended to distinguish input and output features, we came up with the idea of a circular input space with a generic road map background, with lanes and intersections for issuing tactical commands. The circular shape was preferred over a rectangular input space, which introduces corners that take the attention of the eye and increase the visual cognitive load (Lang 2009). The decision of a map background with the road was made to make the interface more intuitive, by positioning each direction command to the corresponding spots. Furthermore, the idea was to have an interactive map, where the user either taps on icons planted on specific spots or issues one-finger drag gestures that are hinted dynamically when she touches the map or statically with arrows that signify the gestures. The interactive map would be static, which means that it would not be updated according to the real world environment. Nevertheless, having a dynamically updating navigation map was discussed at this stage and later in the process but was rejected mainly because it was considered

more complicated and susceptible to errors especially for new users. The **overtake** command would be issued as the rest of direction commands, by either dragging or tapping on a car icon representing the vehicle to overtake. The command would be available only if there is actually a car to overtake or the overtake action can be taken. For **speed control** and small lateral **movements within the lane**, 2-finger drag up/down and left/right were chosen respectively in order to distinguish them from the direction commands, since they concern operational control. For this reason, changes were constantly made through each iteration in order to establish them as tactical commands since the operational control lies entirely on automation while using the interface. By 2-finger dragging down and long holding, a menu appears to choose either to stop or park the car. The differentiation of these two use cases was made, since the parking feature would contain additional options for choosing specific places. Emergency stop, though emerged from the user study as a unique distinct command, was rejected at this stage since it is an operational command that should be handled manually using the brake pedal for safety reasons. Nevertheless, it was still considered a question to be asked to users after the first iteration of the process.

The output functions would be positioned above or left to the input space for a vertical or portrait layout of the tablet respectively, considering the patterns of the PD workshop. A digital and analog speedometer was chosen for notifying speed and a fuel icon with a gauge building the traditional car's HUD (Heads Up Display) metaphor. Alerts include modeless feedback for establishing environmental awareness, such as displaying obstacles ahead, intersections, etc. and alerts about the car status, for instance blinking fuel icon in case of low gas level, glowing animations and so on. The "next move" category shown in table 4 included the display of the currently performed task by the car on the circular input space and a rectangular box containing the next task, which could be expanded to show a queue of commands to be followed by the automated system. A strategic level of control (Young 2009) through the interface was approached at this stage, expanding the idea of providing a queue of commands, enabling the user to input multiple tactical commands to decide the route. An interactive fuel icon for finding gas stations and a button for finding parking places were also ideas that generated for providing strategic functions through the interface. The final category of output concerns confirmation of the user input in the form of gesture trails and animations in order to notify the driver of the accepted or rejected input command, keeping her in the loop of the driving task.

Based on the elicited requirements, the tertiary features were offered as a secondary menu within the tactical interface instead of totally separating them by dedicating the entire tablet layout for the infotainment functions. Thus, retaining the output features which establish situational awareness while accessing these features, was our design choice. The tertiary menu would be an overlay circular drawer menu to be accessed by swiping down a handle in the top of the input space. Swiping left and right was also considered to cycle through the various tertiary functions. This gesture pattern was considered most intuitive according to the PD workshop results and touch interfaces' design principles.

5.4.2 Parallel Prototyping

Based on the ideas underlined for the various functions, a parallel prototyping approach was followed (4.1.2) to combine them into various interface designs. The goal was to generate high fidelity interactive prototypes in order to explore alternative solutions to be evaluated by experts and tried by users. This and the following iteration aimed to converge to a final interface solution by building upon evaluation, establishing a polished and well-grounded final prototype implementation. Work was divided at this stage between graphical design and interactive prototyping, using sovereign software including Sketch and Photoshop for graphics and Axure for interactions. The prototypes of this iteration are the result of constant discussion, sketching, critical thinking about each and every choice, collaboration but also dedication on our individual roles. Two different input layout patterns are presented along with the design choices concerning the continuous operations defining the commands concerning the operational level of control (speed control, move left/right within lane), the output features and the tertiary menu.



5.4.2.1 Prototype 1.a - Interactive map

Figure 10. Interactive map prototypes with portrait and landscape orientations

The first prototype features an interactive map layout for input. In order to issue a tactical command, the user places the finger down on the car icon and the available choices appear on the map as glowing green marks. In order to perform a task the car icon is dragged on the corresponding mark and when the finger is lifted, the car is animated to signify the task and a text is displayed showing the command and animating to the "next move" box, confirming the issuing of the command and showing that it is processed by the car. The drag and drop operation is conducted with one finger touching and moving the car on the yellow spot marked in figure 10.

The appearance or disappearance of the choices as the user touches or removes the finger from the car icon gives the hint of the drag and drop operation, but the user has to be told that the car icon is the interactive part of the interface. Understanding the drag and drop operation, it is easy to understand how to issue each corresponding command thanks to their location on the map. The concept of this layout is to provide an intuitive interface by building the metaphor of moving the car on the road reflecting the actual action with a simple gesture pattern on a graphical generic map.



5.4.2.2 Prototype 1.b - Pie layout

Figure 11. Pie layout prototypes with portrait and landscape orientations

The second prototype features a pie-layout similar to the pieTouch project (Ecker et al. 2009). In order to issue a command, the user holds down one finger on the car icon as shown in figure 11, and drags the finger to the respective command icon. The selected icon turns green and when the user lifts the finger the command is issued and the same animations are fired similarly to the first prototype.

This prototype does not really builds the metaphor of moving the car, but provides descriptive icons that clearly identify the tactical commands. One problem is that the user needs to be taught resemble about the specific interaction, since the icons tap buttons. The appearance/disappearance of the menu is a way to hint the interaction but it could definitely be designed as a toggle menu. Thus, the user could just toggle on or off the menu and tap on the icons, which would be definitely easier to understand. However, the thought of tapping was considered more susceptible to errors and more difficult to cancel an issued command. The drag and drop operation can be easily canceled by lifting the finger outside the menu and even though it needs training in the beginning, it was considered to be more efficient in the long run. Furthermore, this layout integrates easily the first, second and third turn ahead commands, which are not covered in the first prototype.

5.4.2.3 Continuous Operations



Figure 12. Continuous operations for speed control (left) and lateral movement within lane (right)

One of the main challenges was to find a design solution for the speed control and lateral movement within the lane among with the tactical commands. The problem was that these functions concerned operational control and were marked as continuous operations because opposed to the tactical commands which have a specific result, these functions should change the lateral and longitudinal state of the car continuously. Furthermore, since the autonomous system should establish safety, additional feedback should inform the user that she cannot increase speed above a limit or move outside a lane for instance.

The prototypes of the first iteration enable these operations by hold and dragging the car on the yellow spot shown in figure 12. Due to software limitations, they are conducted by 1-finger dragging but our idea is to perform 2-finger gestures for continuous operations. Four arrows notify acceleration, deceleration, and move left/right turning green depending on the corresponding operation. If the operation cannot be performed the arrows cease to light green and especially for accelerating, the digital speed changes color to orange when approaching the limit and red when it is reached. The main problem about the continuous operations is the lack of hinting as the user needs to be taught about their existence. Furthermore, introducing multi-finger gestures makes it more difficult to grasp for novice users, but it is an easy way to separate these functions with the tactical commands and avoid confusion that leads to more errors.

5.4.2.4 Output



Figure 13. Output features and feedback

The prototypes feature both portrait and landscape layouts without big differences and since the user study results yielded an equal preference, we found it worth evaluating both types. The output features are positioned at the top and left to the input space for the vertical and horizontal layout respectively. The speedometer, fuel and alert warnings were designed to resemble the car's HUD in order to be easily grasped by the user. We also decided to utilize space for displaying the destination point and estimated time of arrival, positioned at the top-most and top left-most spots for the respective layouts. Although not important for the purpose of this prototype, they were considered useful when the user wants to make more strategic decisions and be aware of the trip status. Right to the speedometer, road signs and warnings are displayed in order to increase environmental awareness. The "next move" box varies between both interfaces, displaying only the next command to be performed by the car in the vertical layout and the queue of commands in the horizontal layout. In the portrait mode, the user has to tap on the "next move" box to view the queue of commands as an overlay table on the circular menu, something that was not implemented but thought at this stage. Thus, the landscape layout presents an advantage of constantly displaying the queue, but provides a slightly smaller input space due to space organization. The remaining output consists of confirmation feedback, with animations as described in 5.4.2.1 informing the user about the accepted command and highlighting the "next move" feature making him aware of the automated system's tasks.

5.4.2.5 Tertiary menu



Figure 14. Tertiary Drawer Menu

As described in 5.4.1, an overlay drawer menu idea was generated for delivering the tertiary features, retaining the output features in the interface while the user controls infotainment functions. The menu is accessed by swiping down the handle as shown in figure 14 and then tapping on the corresponding function. In the scope of this thesis, the focus is on validating the tactical features and the handover between them and the tertiary functions, thus we did not go deeper in the implementation of specific infotainment features. More emerging thoughts on the delivery of the tertiary menu are discussed later in the design process.

The menu choices are "controller", "music", "movie" and "settings", while the GPS was considered to be accessed by tapping on the destination and toggle the tactical map to a navigation map. The "movie" setting implies that specific features should enable full screen in case of a long trip for instance. The user would be able to either tap on the specific choice to access the specific function or cycling through the functions by swiping left/right. Switching back to the tactical controller is done by simply swiping up the tertiary menu from the bottom handle.



5.4.3 Expert Evaluation

Figure 15. Expert evaluation session

Heuristic analysis (Harvey et. al 2011) was picked as the symbolic method for evaluating the first iteration prototypes aiming to elicit their advantages and disadvantages and converge into a final design in the end of the next iteration. A user testing session was considered initially for evaluation applying hierarchical task analysis on the interface, but abandoned due to the time limitations of

the project. An expert evaluation was planned instead, with a cognitive specialist, a traditional interaction designer and a novice interaction designer aiming to judge the interface in terms of specific criteria.

Each session lasted about an hour and the four prototypes (interactive map and pie menu horizontal and vertical layouts) were presented to them for analysis. They were encouraged to think aloud, explore the interfaces and judge them upon specific usability criteria, including layout, content, accessibility, navigation, process and interaction, learnability and satisfaction. During the sessions, notes were taken, which were transferred later to a partially ordered meta-matrix (Miles et. al 2013). The columns' meta-data are stacks of the four prototypes (interactive map, pie layout both orientations) for each expert and the lines' meta-data contain the heuristic criteria. Next sections present the results for each criteria and underlines the most important points that stimulated the second iteration of the transformation stage.

5.4.3.1 Layout

Two out of the three experts preferred the horizontal orientation and the interactive map prototype, but in general no specific advantages or disadvantages of either of the orientations was noted as it was just a matter of preference. The interactive map prototype was favored by two experts and the third one stated that he would like a combination of both, by integrating the symbolic icons of the pie layout prototype to the interactive map. An interesting point was raised about the positioning of the parking function on the interactive map, stating that confusion in the mental model of the user may be caused by choosing to place the parking spot on the right side of the road map. In this case, users may think that the parking place is always on the right side on the road. We marked this remark and realized that building a metaphor may be misleading if not designed carefully, thus the parking function was removed in the next iteration from the map.

5.4.3.2 Content

Even if the interactive map was favored, experts highlighted the advantage of the icons of the pie layout prototype, making it more descriptive. An expert suggested an important improvement on the road map, making it easier to understand the commands by having three lanes with the car in the middle lane instead of two lanes with the car in the middle which would cause confusion. The idea of displaying a navigation map, discussed in 5.4.1, emerged by all experts and taking into consideration for future insight, providing a way to toggle between a static and a navigation map. Regarding output, experts were positive about displaying alerts and the animations for confirmation of commands. One stated that it was even redundant to animate the car, since the animation of the command issued was enough to show the confirmation. They liked the speedometer and fuel output and generally appreciated the output and feedback content. Nevertheless, a need for more visual cues or hinting was expressed in order to urge the user to touch the car icon and drag it, as it was disregarded during the sessions and it was difficult to grasp the way the interface works without explanation.

5.4.3.3 Accessibility

The lack of accessibility to the GPS function was mentioned, since it was not present in the tertiary menu. Thus, suggestions including toggling the static map to the GPS by toggling, or including it to tertiary menu or having a GPS icon in the interface. The lack of understanding the distinction

between tactical commands and continuous operations was expressed by all experts. Even if the current prototype did not support multi-finger gestures, they mentioned that there should be hinting, if we chose to use a double-finger gesture, making it easier accessible. The accessibility to the tertiary menu was considered easy and intuitive by swiping on the drawer handle icon.

5.4.3.4 Navigation

The lack of visual affordance on the car icon and hinting was underlined, making it hard to explore the tactical functions of the interface. Furthermore, the display of the arrows for speed was considered misleading since they imply direction and fit more to the lateral movement, but it was easily conceived for controlling acceleration/deceleration.

5.4.3.5 Process and Interaction

As expected, tapping proved to be the most intuitive interaction especially in the pie layout, where the icons urged the experts to tap rather than drag onto them. Nevertheless, they were positive about our decision of choosing drag and drop over tapping, but triggered more critical thinking during the second iteration to justify this choice. Two of them tapped outside the map to switch from the tertiary menu back to the tactical controller. All tried to tap on the "next move" box of the vertical layout prototypes and since it was not interactive at this stage, when we explained our idea of retaining a queue, they were positive about it. They also appreciated the idea of tapping on the fuel icon for getting the car to refuel but one pointed out that he would prefer to pick the gas station from a navigation map. In general, they tried to interact by tapping of almost every element of the interface, something that triggered more thinking about making the whole interface interactive, providing more information and functionality, instead of strictly separating input and output.

5.4.3.6 Learnability

The pie layout was considered better overall in terms of short-term learnability, easier to grasp in the beginning thanks to the descriptiveness of the icons. However, they stated that the interactive map prototype would be easier to use long-term thanks to the move-car metaphor.

5.4.3.7 Satisfaction

The experts were mostly satisfied with the prototypes in terms of output and feedback but underlined that the main flaw was the lack of affordances, which hinders the understanding of the functions and reduces the motivation of exploring the interface functions.

5.4.4 Overview

Summing up the results of the expert evaluation, we elicited the advantages and disadvantages of the prototypes in order to perform the next iteration. The information architecture was good and all input and output features were proved relevant and useful. The design needed to be evolved in terms of visual affordances in order to communicate the functionality of the interface to the user. The switchover between the tactical controller and the tertiary features were taken very positively. Tap gestures were preferred over drag and drop, but we believed that the latter was hindered due to lag of the interface at this stage limited by the prototyping software.

5.5 Iteration 2



Figure 16. Multiple sketch ideas generated during the second iteration

The second iteration was stimulated by the results from the expert evaluation (section 5.4.3). The goal was to improve the design of the user interface, providing better visual feedback and an easier way to interact with the system.

5.5.1 Ideation - Brainstorming (Design Decisions)

At this stage, brainstorming, sketching and critical thinking methods were used to find every possible interaction with tablet. The main problem of the first prototypes was the lack of visual affordances on the car icon. So the user would need time to explore the interface and learn how to interact with it. The other problem was the simultaneous presentation of speed and move left/right, considering them as continuous operations.

The drag-move action of a car icon was not so smooth at this stage of prototyping due to software limitations. However, we believed that it would be more efficient in a long run than tapping. First it requires a closure of action, which means that the user needs to do a longer gesture to complete an action than just tapping. Hence, she could be able to regret her action before completing it and she would avoid errors in contrast to tapping which is not forgiving since it's an instant gesture. Moreover, the drag and drop operation builds up some mnemonic gestures that users can use them intuitively after some training and has more precision than tapping when not looking at the screen. Furthermore, an interactive map with icons planted in the specific spots provide an easier way to understand and relate it with each command (change lane, turn right, etc.). However, hinting of the drag & move interaction is important to get the user learn faster how to use the interface. So, we believe by making the icons on the map affordable users would intuitively try to tap on them on first use and get a hint of the drag & move mechanic. A visual cue will be also added to the car so that the user will be prompted to tap on the car. By just tapping on the car a generic hint for the one-finger (direction) and two-finger (speed) interactions should be displayed. Then the user will know that dragging-moving the car is the primary way of registering input commands. Tapping will be used though for the secondary commands like parking and refuelling,

which will be icons placed not on the roadway, so that users would not be confused if parking for example is on the left side of the road and the icon is positioned on the right side (5.4.3.1).

Controlling speed was decided to be a 2-finger drag gesture with a gradient slider. When the user places the two fingers on the car, the slider will appear and by moving up or down he will be able to accelerate or decelerate respectively. In order for the user to learn about this interaction, he can just tap on the car to get a generic hint for one-finger and two-finger interactions.

The output elements were appreciated by the experts and no big changes were made. The only negative aspect was that they tended to interact with them too. We believed that by improving the affordances in the input area by adding more visual cues, will prompt the users to interact with this area. The addition of the overlay would also make it even more obvious as it was designed based on this concept (5.6.6). The next-move panel was also tapped by the experts and we explained our intentions of interacting with it and displaying a list of detailed commands, which was confirmed as a positive feature by them.

When starting the car and inputting a destination, a "powering up" function of the tactical controller was thought to be included. The items on the tactical controller would be greyed out when the car is not set in motion. When the destination is input and the car starts, the interface elements would fade in by glowing, building also the metaphor of the car's hud that is lit when the car engine is powered up.



5.5.2 Prototype 2 - Map with icons

Figure 17. Prototypes of second iteration - Different positioning of advanced functions

The results of this iteration combine elements from the prototypes of the first iteration, based on the design decisions described above. Two new interactive prototypes were implemented without significant difference from the previous iteration, but are improved based on the results from the expert evaluation. Figure 17 presents the prototypes of the second iteration.

The prototypes were developed based upon an idea of the interactive map as shown in section 5.4.2.1. According to the expert evaluation session, the interactive map prototype was lacking in terms of understandability of the tactical commands. Hence, instead of green spots indicating the areas of interaction, the newer prototypes displayed clearly a set of icons representing available actions as can be seen in figure 17. The icons were placed suitably on the specific spots of the road map, according to the corresponding command (e.g. change to left lane icon was placed on left lane.) We kept the same input gesture of dragging and dropping the car icon to any of the command icons. Above the map, a box indicating the queue of commands was presented. This change of placement was done to make it easier to read as suggested by a cognitive specialist during the expert evaluation. Furthermore, the strategic functions concerning parking, route selecting and finding gas stations was distinguished from the tactical commands and grouped together as a set of menu icons. Two ideas were considered for the placement of these icons (figure 17). In the first prototype the icons are above the interactive map, next to the next move command, always visible and available to the user. In the second prototype, the icons were hidden and could be accessed by tapping on a plus icon which was positioned inside the interactive map on the bottom. Since they were considered secondary functions for our concept, this prototype's goal was to prevent the user tapping by mistake as in the first prototype and let her reveal them and use them only if necessary. We were skeptical about which approach we would follow and thus we proceeded to another round of evaluation within the group and by demonstrating to a few fellow interaction design practitioners for further feedback.

5.5.3 Internal Evaluation - Final Design

Another round of design evaluation was conducted. This round was done informally and within a group of known interaction design practitioners for the convenience of both designers and evaluators.

The evaluators stated that the tapping gesture required to reveal the hidden function in the corresponding prototype (figure 17), is hard to access. It costs more interaction than needed and lacks in term of discoverability since the user may never tap on that specific plus-sign icon to reveal a menu unless instructed to do so.

Furthermore, the evaluators were positive about the appearance of the prototypes and stated that they both are intuitive thanks to the different placement of input and output features, successfully providing a clear distinction between them. That also made the action of issuing a command easier. However, they were concerned about the appearance of the command icons. Specifically they stated that they did not appear like a container where they need to drag and drop the car icon in order to issue a command. They would rather tap on them intuitively. Thus, graphical improvements have to be made in their visual affordance as containers and not as tap buttons. Most of evaluators also asked for the reason behind our choice of the drag and drop interaction

instead of tapping. They suggested that the tapping interaction is easier and more intuitive for the user to perform. Nonetheless, we insisted on keeping the drag and drop interaction for the reasons described in 5.5.1 and we believed that after a short amount of training it would be possible to grasp and become familiar with this interaction minimizing errors that can easily invoked by simple tapping interactions.

During a discussion, one evaluator expressed the need of knowing the exact speed value on speedometer. He said that this would make it easier for him to decide which command to issue next and thus influence his tactical decisions during semi-autonomous driving.

More than two evaluators questioned why the car present on an interface does not stay in interactive area in which the command was issued. Also, why the car is not moving when a command is executing. We took these into account and therefore proceeded to the next design iteration.



5.6 Implementation

Figure 18. Tablet without and with overlay cover in the end of the implementation phase

Having converged to a final prototype after the second iteration, the implementation phase commenced. The roles were also divided at this stage between developing the software on the programming level and redesigning the graphical elements and visual cues to a higher fidelity level. As mentioned in 4.1.3, before starting the implementation, we did a thorough technology analysis to define the hardware and software assets to be used during this phase. Since, the main load was put on building the interface and the design of the overlay cover would be dependent to the final state of the interface, the material for this purpose was decided at the latest stages of implementation.

This chapter starts by specifying the technology and materials used for the final implementation and continues by presenting the evolution of the interface during this stage. Constant evaluation took place within the group and stakeholders leading to specific design choices which are discussed. At the end of this phase, two systems were deployed, the tablet interface without an overlay cover and the tablet interface with an overlay cover, presented in figure 18. An additional application was also built during this stage, named after "Wizard app" in order to conduct the validation session with a 'Wizard of Oz' setting, discussed in the following chapter.

5.6.1 Technology Analysis



Figure 19. Hardware and Software used for implementation

Figure 19 displays the hardware and software used for the implementation of the final prototype. The interface was developed for a Samsung Galaxy Tab S, which was provided by the company from the beginning of the master thesis. The tablet cover was acquired at the latest stages of the implementation and is made of easy to cut artificial leather material, allowing us to build the overlay suitably in order to fit the interface layout. The graphic design was done with Sketch 3 and Adobe Photoshop running in a MacBook Pro laptop. The front-end development was done using Android Studio 1.1.0 with a Fujitsu laptop running windows 8.1. The software was retained as a private online repository and was constantly updated with the graphical and programming modules using git as version control software. Thus, it was easy to keep track of the progress, make changes and revert to previous versions if needed by tracing back to previous instances of the software.

5.6.2 Layout

Figure 20 illustrates the interface layout categorizing the elements according to information and functionality. No big changes were made to the placement of the elements compared to the prototype of the second iteration (5.5.2) apart from the positioning of the overtake command icon. If the user issued a command for turning to an intersection in the previous prototype version (figure 17) her finger would touch the overtake icon during the drag and drop operation. Thus, if she decides not to take an intersection while dragging the car, she may eventually lift the finger on the overtake icon, issuing this command unexpectedly. Hence, this use case was prevented by positioning the overtake icon at a higher height from the turning icons (figure 20).

The tactical map consists of the car icon, the command icons in front of a generic road background with three lanes similarly to the previous prototypes. The drawer handle is also included in the uppermost part of the map for switching to the tertiary features. The box on the left-top of the map displays the current task performed by the car. If no maneuvering command is issued by the user, it displays the current driving mode of the car, which is described more in depth in the next section. Similarly to the previous prototype, button icons for inputting destination and picking fuel stations and parking places are included. These concern strategic control since they are connected with route planning (Young 2009) and they were not implemented as they would not be examined in the scope of this thesis. Nevertheless, they were considered important to be included there separately to the tertiary features, since they directly concern the driving task in the strategic level (Young 2009) and were constantly discussed during the whole design process.

At the upper part of the interface, feedback is provided, concerning the car status, including a digital speedometer and fuel level with gradients for visualizing the speed and fuel levels as in the previous prototypes. Right to the speedometer, environmental indicators are displayed including road signs and obstacle alerts. These output features aim to establish situational awareness and support the driver in the tactical control by providing feedback as discussed in 5.4.1. At the uppermost part of the interface the destination and estimated time of arrival are displayed, retaining them from the previous prototypes, since they provide route information which, in the real context, could be changed from the user or environmental conditions. Hence, even if they are static in this interface, they were considered important to include them.



Figure 20. Interface layout elements

5.6.3 Tactical controller

The main functionality of the tactical controller was maintained from the previous prototypes, thus by dragging and dropping the car to a specific icon, the corresponding command is issued. Visual improvements were made to the representation of the icons to define them better as drop containers looking more like holes than buttons. A white glow outline to the car was added to enhance the visual affordance of the icon as discussed in 5.4.4. The drag and drop operation for issuing commands was retained from the previous prototype and implemented without lagging issues in this level of fidelity. Figure 21 illustrates the use case of taking the next right turn using the interface. While dragging the car, its size changes according to the position on the map to enhance the perspective feeling on the map. When the user is issuing a command by moving the car into the corresponding command, the respective icon is tinted green. As soon as the finger is lifted to complete the command, the car is outlined with a green glow and a fade in animation is fired, displaying a message of the command issued updating also the 'Current Task' box. The car icon remains in place and can be cancelled by just dragging the car away of the current position unless it is processed by the car. When the autonomous system processes the task, a yellow glow is applied to the car icon and it is locked in place until the car completes the maneuver. This design decision was made as a way to prevent the driver for cancelling a task while is it performed. for example while the car is taking a turn and it would be unsafe to stop this action at this point. A separate application was implemented to simulate the car automated system, which is described in section 5.6.6.



Figure 21. Taking the next turn to the right

The use case of turning to later intersections was covered by the pie-layout prototype during the first iteration (5.4.2.2), when the user desires to take the second or third turn/exit ahead on the road. In our implementation we considered this use-case of less importance so we avoided overloading the map with more command icons, although the idea of changing the map to contain three intersections and the corresponding turning icons was discussed. We believed that this would make the tactical map more cluttered, susceptible to error and would cause confusion. Another idea was to link the turn icons to additional hidden icons for the second and third turn similar to the pie-layout (5.4.2.2). These would spawn when the user holds the finger inside the turn icons, prompting the user to pick later turns by continue drag and dropping the car icon onto them. This idea was considered better but was dropped, because we would still need to change the map design and the icons structure to make it efficient. Since we wanted to preserve the
simplicity of the tactical map, our final design choice was to cover this use case, by dragging the car icon and long holding for 1-2 seconds on the corresponding turning icon (figure 22). Applying this interaction, an alert menu dialog is popped out and the user is prompted to choose which intersection she prefers to turn, or cancel by tapping on the corresponding button or anywhere on the map. Hence, we maintained the simplicity of the tactical map, but on the other hand we were aware of the lack of discoverability which was the main tradeoff of this choice. Since we believed that this function would not be useful during early use, this tradeoff would not affect the efficiency of the interface considerably, as long as the user is taught about the way of accessing the function. Nevertheless, issues emerging from the lack of understanding of this command are marked in the result section.



Figure 22. Taking the third turn to the right

Another important design choice that was made during the implementation phase concerns the continuous operations discussed in 5.4.2.3. As stated before, the lateral movement of the car within the lane and acceleration/deceleration are tasks on the operational level of control (Young 2009). The goal of the interface is to enable the driver to take tactical control of the car, but the automated system is responsible for the operational control ensuring safety. The function of moving the car within the lane was removed for this reason, as it was also considered redundant since the automated system is responsible for preserving the lateral position within the lane. However, in some use cases which involved for instance driving in a wide parking lot, where the driver may desire to move left and right, the need for this function emerges. For this reason, we considered that the "changing of lane" commands can be used suitably to control lateral movement, but for the scope of this thesis the interface was built only for road driving.

The function for controlling the speed also changed since the second iteration and evolved through the implementation phase after constant evaluation. The double finger gesture was abandoned mainly because of the hardware and software limitations. Specifically, the two finger touch points on the surface were translated as one by the android API, when the two fingers were attached and the fingertips were too close to each other. Thus, in order to avoid confusion and inability to use in this case, we decided to not include multi-finger gestures. Our design choice was to implement a vertical slider for controlling the car speed, which is toggled by interacting with the car icon. Thus, the dragging up and down interaction was preserved for accelerating and decelerating, by interacting with the thumb of the slider. Initially, toggling on the slider was done by long tapping on the car icon, which proved very inefficient and was simplified by just single tapping in the final implementation. The functionality of the slider passed three stages (figure 23). In the first stage, the result of interacting with the slider was the immediate change of the speed value on the speedometer. Thus, an operational level of control was reflected from the interface, since the slider functions similarly to the gas pedal in this case. In order to establish the tactical level of control, the functionality of the slider was changed so that the user sets a specific speed value from the slider and the automated system is performing the operation of acquiring this car speed. A speed label tooltip displays the current value of speed while interacting with the slider and when the finger is lift an alert dialog box asks for confirmation of the speed change. A lot of critical discussion was triggered by this choice, which even though was acceptable for our concept, the idea of setting the value of speed was conflicting with the user mental model of longitudinal control using the gas pedal. Evaluation within the group and with stakeholders led to the third stage of development of the speed slider. Our aim was to simplify the function by approaching it from the user's perspective in an autonomous driving context. Looking back at the PD workshop, no participant expressed the need of precise control of speed but just accelerating and decelerating by tapping buttons or assigning gestures. The final instance of the slider is a slider with four specific modes: Performance, Normal, Economy and Stop. The user selects basically a driving mode depending on her preference and the automated system sets the speed of the car accordingly. The modes on the slider are reference points regarding not necessarily just speed but also fuel consumption and driving maneuvers. Thus, for instance, in performance mode the car would take the initiative to overtake a slow vehicle ahead and in economy mode would try to maximize fuel efficiency. The slider also is not discreet so depending on the slider position the car will drive more performance-wise or economically respectively, except from "stop", when the user is prompted to confirm that the car will stop and park aside the road. Nevertheless, this solution puts more authority on the automated system and less control on the driver since the modes are abstractly defined regarding their specific effect, but we believed that this design choice is a legit path in the context of future autonomous cars. Influence for this idea was gained from the eco-pedal which is included in various modern cars and research conducted for promoting economical driving behavior minimizing fuel consumption (Meschtscherjakov et. al 2009).



Figure 23. Evolution of the speed slider to Eco-slider

Another feature that was changed in this phase concerns the command queue discussed in section 5.4.1. Figure 24 presents a command list (left), which was implemented initially to enable user to queue multiple commands. A list button was placed inside the "current task" box in order to toggle on/off the queue. De-queueing commands was possible by tapping on the X button to the right of each command. This function, as stated in 5.4.1, can be used for route planning, especially if the user is used to the interface and desires to input a set of tactical commands. For example, if she wants to get to the right lane in the highway, decrease the speed, take a specific exit to the right and so on, without having to explicitly set each command separately and wait for the car to perform it. Our aim was to provide a strategic level of control through the interface for more advanced or experienced users, but also for the novice driver by letting her assigning one command at the time. This decision triggered also a lot of critical discussion within the group and evaluation with the stakeholders and after thorough evaluation, we decided to drop it. The main negative side of this approach was the risen complexity and the potential misuse or lack of understanding of this function. A novice user, for instance would accidentally queue commands and would not understand the tasks performed by the automated system leading to mental overload as discussed in the theory section. Furthermore, this feature was considered unimportant for early use and even if the user could just issue one command at a time, she still needs to remove the command through the list if she desires to cancel it. Thus, this feature was removed and only one command can be issued at a time in the final implementation. Our goal was to simplify the use and keep the control on the tactical level. The user can issue a command by placing the car icon on the corresponding icon and wait for the car to perform the task. Cancelling the command is done by simply dragging the car out of the corresponding icon, providing also feedback of this action (figure 24).



Figure 24. Command Queue (Left) - No Queue and displaying driving mode (Right)

5.6.4 Tertiary Menu

The design of the tertiary menu did not change, apart from color changes in order to fit the visual theme of the interface (figure 25). It was implemented as a drawer menu overlay, which the user can access, by either tapping or dragging or swiping the handle. It contains the options: "Strategic Controller", "Music", "Movie", and "Settings". Either by tapping on the first option or by swiping the handle from bottom to up, the user hides the tertiary menu and returns to the tactical map. The name of this option would be changed to better describe the effect of the button, since the controller focuses primarily on tactical control in the final stage of implementation. The other options are not interactive, since our goal was to validate the handover between the tactical and tertiary control and not the functionality of the latter. "Music" and "Movie" concern entertainment features and especially for the second option, the potential of using the full screen was discussed by tapping in the middle of the tertiary menu, on the white area. Thus, using the whole screen for tertiary features was considered but not implemented in the scope of this thesis. Finally, cycling through each tertiary function was also discussed by swiping left and right once the functions are implemented.



Figure 25. Switching to tertiary menu

5.6.5 Overlay Cover

Having converged to the final design of the layout of the interface, we commenced the design and implementation of the overlay cover. Our aim was to provide a clear distinction of the input and output features in order to make the interface more intuitive and efficient. Figure 26 displays the overlay cover, which consists of three layers. The opaque layer covers the non-interactive parts of the interface and it was cut to fit the interface layout. The material of this layer was a tablet cover made of artificial leather. For the output features, a transparent layer was used in order to underline their function, making it more similar to the car's HUD. A transparent sheet was used for this layer similar to the material used during the PD workshop (5.3.1). The remaining parts were left exposed for the user to interact as shown in figure 26. These parts include the tactical map and the strategic functions. We considered adding a transparent conductive cover in the position of the tactical map and leave only the command icons exposed so that the user can feel the holes when dragging the car icon onto the various icons. This would add tactile feedback and promote eye's free interactions, but we didn't proceed with this idea because it would collide with the use of the tertiary menu and the eco slider. For the latter, the exposed part could be expanded for the entire road but the design of the tertiary controller hindered this choice. Hence, we decided to leave the whole tactical map exposed, but considered these choices if the cover would be dedicated to tactical control. We also rejected the idea of attaching and removing the cover for tactical and tertiary control. Our goal was to compare the use of the interface with and without the cover and highlight the differences between these two cases during and after the validation phase.



Figure 26. The overlay cover consisting of three layers: opaque, transparent and exposed

5.6.6 "Wizard" app



Figure 27. "Wizard" and tactical controller and the type of data transferred through Bluetooth

An android "wizard" application was implemented to simulate the automated system by providing feedback on the tactical controller interface. This application was installed in a second tablet and was used during the validation phase for the Wizard of Oz setting discussed in the next section. The two devices are connected with Bluetooth to transfer information as illustrated in figure 27. Specifically, when the user issues a command from the tactical controller, it is displayed on the second tablet. This command can be tapped in the "wizard application", highlighting in green in both tablets and locking the car in place on the respective command icon with a yellow glow. Thus, the user gets visual feedback notifying that the command is currently processed by the car and can't be cancelled, for instance while the car is turning to an intersection. The wizard application also provides a slider for controlling the speed, changing the value of the speedometer. Furthermore, toggle buttons are provided to disable commands on the tactical controller. These commands are marked as inactive with a grey tint, when they are invalid, for example when there is no car to overtake, the car is already on the right lane and so on. The rest of the buttons are intersection signs and an obstacle alert button which are displayed to the tactical controller for additional feedback to boost environmental awareness. The goal of this application is to simulate the experience of autonomous driving without the need of integrating the interface with the simulator which would be too time consuming and demanding. On the other hand, since it is an application for Wizard of Oz testing, the performance of the person using it, is critical for the credibility of the validation results.

5.7 Validation

The goal of this validation session was to evaluate the usability of the implemented prototypes and to discuss user's reflections in a simulated autonomous driving context. We were aiming to define the strengths and weaknesses of the software in order to build a solid basis for future iterations. We also wanted to conduct a comparative study between the tablet with and without overlay cover, in order to find which is more efficient and easy to use for controlling a semiautonomous car. Hence, the validation session employed the method of A/B testing (Hanington 2012) of the two systems: A is the tablet without the overlay cover and B is the tablet with the overlay cover. The setup process of the validation session is described first followed by a list of the procedural steps of each session. The results extracted from qualitative and quantitative analysis from the data collected during the session are discussed in the next chapter.

5.7.1 Objective

The ultimate goal of this validation session is to evaluate the ideas and design solutions of the touch-based controller we proposed. The session covers three main aspect listed below:

1. Efficiency, Effectiveness and Satisfaction Rate

The design solution to be delivered must be efficient, effective and provide user satisfaction. Thus, we were trying to evaluate these usability factors by extracting both objective and subjective measurements, which are going to be discussed in section 5.7.1.5.

2. Perception of Trust

Referring back to the 'Build - Try - Express' participatory design workshop (section 5.3), results shown that users' trust on autonomous cars falls upon the negative side in certain actions. In the same fashion, controllability rises higher in the graph (5.3.4, figure 8). This showed that users would not trust an autonomous car wholeheartedly. Hence, the designated design solution presented in section 5.6 was designed to increase these factors. These factors were discussed subjectively during a closing interview at the end of the session.

3. The Usage of an Overlay Cover

According to the second research question, we made the hypothesis that an overlay cover would provide a more intuitive interface by highlighting the input and output features of the interface. We therefore planned to evaluate the effectiveness of the overlay cover in comparison with the exposed user interface mentioned in section 5.6. The overlay cover (section 5.6.5) was evaluated by both objective and subjective measurements.

5.7.2 Context and setup



Figure 28. Simulator arrangement

With the help from SAFER lab (SAFER | Lindholmen Science Park 2015), we were able to use vehicle simulator to test our prototypes. The simulator was set as shown in figure 28. The simulator consists of four main components as listed below:

1. Vehicle simulator

In this area, a subject will experience driving simulation. The simulator consists of traditional steering wheel and pedals, seat that is set to be rearward as stated in the design constraint, projector and screen projecting road and its elements. Gears are unnecessary for the studies, therefore were removed. In additional to the tradition vehicle simulator, we added a tablet device mounted on flexible holder at the place as also stated in design constraint.

2. Simulator Controller

A computer controlled the vehicle simulator equipped with software named STISim Drive (STISIM Drive 2015). In this software, we were able to program scenarios according to our interests and plan. The scenarios were written in marked-up language called SDL and were built upon already implemented scenarios that were based on real driving situations, which were recorded and translated to SDL scenarios (Chen et. al 2014). The details of written scenarios will be briefly described in section 5.7.1.3.

3. Wizards' Area

Here, the wizards were equipped with the wizard application as described in section 5.6.6 and another set of steering wheel and pedals. For when subject interacts with tablet device, one wizard takes the command and interpret to another wizard who will then use steering wheel and pedals to take control of the vehicle simulator. This way, driver will experienced driving an autonomous car using the tablet controller.

4. Recording Devices

Video cameras and audio recorder were set to record subjects' interaction as well as comments. There were two video cameras set behind steering wheel and on tablet device. Voice recorder were set on the table where interviews were conducted.

5.7.3 Mediating Tools

Our designated prototypes were used as main mediating tools in this validation session. The prototypes were presented to the subjects with verbal guide on how to use. Subjects were allowed to explore the interface before the test drive. These mediating tools were used as main measurement tools discussed in section 5.7.1.5.

5.7.4 Participants

There is no restriction in selection for participants. Nonetheless, we still aimed to find the variety of opinions as similar to what we did in participatory design workshop. This time, 11 subjects were selected. One subject was placed in a pilot session testing on how this session procedure would work. Their backgrounds are ranging from mechatronic, automation, signal and processing, interaction design, cognitive science, and chemical engineering. Both male and female subjects were selected with an age span of 21 - 42.

5.7.5 Data collection methods

In this validation sessions, both subjective and objective results were collected as usability metrics aiming to calculate the efficiency, effectiveness and user satisfaction. These results are discussed in the following chapter and were collected using the methods as listed below:

• Questionnaire

Before, subjects were seated in simulator, they were asked to first fill out a simple questionnaire regarding on contact details, driving experience, experience in adaptive cruise control system (ACC) and experience in using touch-based device. A sample questionnaire can be found at appendix II.

• Think Aloud

Referring to section 5.7.2, subjects were asked to perform driving tasks using our prototypes. While they were performing, they were encouraged to think aloud.

• System Usability Scales

Likert scales were used to catch the spontaneous emotions of the subjects for each prototype (Brooke 1996). Some questions of the original SUS (Brooke 1996) were changed in order to make it more relevant to our concept, aiming to catch the feelings of trust and controllability of the subjects by using the prototypes (Appendix II – System Usability Scale). Subjects were asked to fill in the scales when finished using each prototype. A total usability score was calculated for each subject per prototype.

• Error Rate (ER) and Task Completion Time (TCT)

When subject made error(s) during driving simulation, error rate was counted as well as the task completion time. These quantitative result were collected for the A/B testing between the two prototypes. An error was committed when a subject initiated a dragging interaction and completed it without dropping the car in the correct command icon. Arbitrary taps on the interface were also counted as errors, but only when the subject initiated the trial of the corresponding task, she was instructed to perform. The completion time was calculated in seconds, counting from the point that the subject touched the screen

(mouse down event) when instructed to perform the task till the successful completion of the task.

• Observation and Recordings

Throughout the workshop, subjects were recorded both voice and video for a further interaction analysis. Their interactions and remarks were noted and would then be triangulate with other collected information to see patterns and relationships.

• Interview

Toward the end of the workshop, subjects were interviewed regarding on their opinion about presented prototypes. There were four main aspects to be focused namely modalities, functions, user interface design and overlay cover. The results are presented in the next chapter.

5.7.6 Procedure

The same procedure was used throughout the studies. Noted that we were doing A/B testing between prototype with and without cover. Hence, in this studies, we chose to randomly pick prototype either with or without for subject to try first. This is done so that the result will not be bias to one prototype. The procedural steps are listed below:

- 1. Subjects were introduced to the project. They were informed of scope of our work, definition of autonomous car technology, prototype and simulator.
- 2. Trial session (approximately 5 10 minutes)
 - a. Subjects were guided to the simulator. They were asked to sit on the driver seat with a task of manually driving. At this stage, subjects will experienced the feeling of manual driving that is to be compared with autonomous driving in the step 3.
 - b. Subjects were then proceeding to autonomous driving using tablet. Here, they were given a guide on how to use the prototype verbally. The moderator will randomly pick either prototype with or without overlay cover to show first to prevent the end results from being bias to one prototype.
- 3. Test drive in VCC simulator (overall approximately 30 minutes.)
 - a. In the first 5 minutes, test subject were allowed to drive freely. He could explore an interface in the way he wanted to. We wished to investigate how he is interacting with given prototype.
 - i. While subject is driving, subjects were encouraged to think aloud. Subjects who are not talkative were approached by probing.
 - b. Projected screen presented a highway road with obstacles scenarios. At this stage, subjects were asked to perform an action according to instruction given. A set of scenarios and tasks to be performed lasted approximately 5 minutes. Noted that while performing a task, number of errors made were counted.
 - c. Subjects were then invited to fill in Likert Scales.
 - d. Testing one prototype lasted approximately 15 minutes. We repeat a process from (a.) to (c.) again with another prototype until every prototype was tested.
- 4. Closing interview
 - Subjects were interviewed for subjective measurement as stated in section 5.7.1.5. The interviewing questions are noted in Appendix II.

6 Results

The data collected during validation using the methods discussed in 5.7.1.5, were analyzed qualitatively and quantitatively, saving them into case-ordered matrices (Miles et. al 2013) in order to perform comparisons and counting to extract patterns. First, the results regarding the overall usability and user experience about the two systems (tablet with and without overlay cover) are discussed. Then, the findings connected with the user interface are presented, evaluating the input and output features by triangulating the objective and subjective measurements.

6.1 Systems and Automation

Figure 29 illustrates the usability chart showing the total score given by each subject for each of the two systems. The system usability score ranges from 50 to above 85, yielding an average of roughly 70, which is a positive result, according to Sauro (2011), since it bypasses the 68 mark. It is interesting to note, that subjects are divided in half according to their preferred system, with very small deviation among the two systems.





The average score along with the small significance between the two systems is illustrated in the next chart (figure 30). The confidence interval was calculated, in order to provide an estimation of the true population value (Sauro & Lewis 2012), since only 10 subjects participated. For a confidence level of 95%, the intervals mostly overlap for both systems highlighting the insignificant subjective difference between them (Sauro & Lewis 2012). In other words, if the experiment was conducted by more participants, the average usability score would lie within 65-77 for the first system and within 66-75 with probability 95%, marked as "p=0.95" on the chart figures of this section. In general, most participants found the system simple, easy to use and to understand

after little training. Nevertheless, some subjects were skeptical about the visual modality and expressed the need for additional feedback especially sound. Specifically they underlined the problem of divided attention, caused by the systems, since they needed to constantly switch focus between the interface and the road. Building on that, a couple of subjects touched upon the choice of positioning of the tablet, suggesting placing it in the front or releasing it from the holder.



Average Usability Score



The individual preferences on each system were expressed during the interview. 4 subjects did not notice any difference after using both systems. An interesting point was noted by 2 subjects, stating that the overlay cover made the prototype look more complicated, feeling that it was more difficult to perform the task. Unlike wise, the rest of the subjects expressed their preference for the cover, feeling that it made the interface more intuitive by clearly defining the input and output features. In general, both systems were easy to use and did not provide a considerably different experience. The second system felt overall more dedicated in the tactical control performing better overall (figure 31, 32,33) and highlighting the parts of input and output of the interface successfully as reflected by the subjects. On the other hand, the first system showed more potential in providing additional features by making the whole display interactive, engaging the users to tap also on the output parts (speedometer, fuel), which although it resulted in more errors, it suggested more enhancements in the interface.

As far as automation is concerned, the subjects were asked to express their urge of using the steering wheel, given these systems in an autonomous driving context. Only one participant preferred traditional driving over autonomous driving, stating that he would not use the systems

as he desired to have full control over the car. 3 subjects expressed uncertainty, stating that they need time to trust an autonomous car and thus a tablet interface for driving, something that was also underlined during the PD workshop (5.3.3.4). The rest of the subjects preferred using the tablet for controlling the car, expressing the convenience over the steering wheel. The interface managed to communicate a semi-autonomy level leaning towards full automation for all subjects, when they were asked about the level of control they felt that they have by using the systems.

6.2 User interface

Focusing more on the usability of the interface, the goal of asking the user to perform specific tasks was to extract results that highlight the strengths and weaknesses of each function. Hence, this section presents the objective measurements for each task along with user's reflections on the input and output functions in order to underline key issues that could guide a next iteration of the design. As noted in 5.7.1.5, the error rate (figure 31) and average and mean task completion time (figure 32, 33) were calculated from the video recordings, complemented with the subjects' "think aloud" comments and interview reflections.



Figure 31. Error Rate for each task (p=0.95)

For the first task the subjects were asked to avoid an obstacle by checking their interface for an alert notice and asked to reduce their speed and change to the left lane when they get it. Thus, more errors and longer completion time were expected, since it was the first and more complex task compared to the other seven. Furthermore, misunderstandings of the task led to unsuccessful completion of the task in three cases, as the subjects did not manage to issue the instructed

commands (decrease speed and change lane to the left) before passing the obstacle. Specifically, 2 subjects failed to complete the task with the first system and 1 subject with the second. No significant difference is marked between the two systems regarding the error rate, with around 1 average error for this task and mostly overlapping intervals. The second system required a higher mean TCT of almost 2 seconds and a confidence interval which shows a 5 seconds delay from the first system, notifying poorer performance of the tablet with the cover. Nevertheless, considering the one more failed attempt of completing the task using the first system. One subject mentioned that the feedback provided for showing road signs and alert notices caused insecurity. Specifically, he underlined that it was redundant to show an obstacle notice, since automation is responsible for bypassing it. Some subjects were skeptical about displaying alerts during the experiment but during the interview noted that they needed feedback from the road. Thus, these contradictions suggest further improvements in the delivery of this feature to convey its functionality better to the users.



Mean Time of Completion (sec)

Figure 32. Mean Task Completion Time

The "Right Lane" and "Turn Right" tasks yielded almost 0 error rate for both systems and around 1 second mean task completion time (TCT) with very small confidence intervals. "Accelerate" task yielded no error for the second system and almost 0 errors for the first and 2-3 mean TCT with very small intervals for both systems as well. Thus, these three tasks resulted in the best performance and highlight the efficiency of the interface for performing tactical commands and changing speed, without any reasonable difference between the two systems.



Average Completion Time (seconds)

Figure 33. Average Task Completion Time (p=0.95)

The "Overtake" task yielded a slightly larger error rate for the first system with about 1.5 errors and a big confidence interval (more than 2 errors). The second system performed better with 1 error less than the first system and a smaller interval. The mean completion time was about 2 seconds for both interfaces. The phenomenon of dragging the car onto the overtake command was observed, yielding errors and suggesting improvements for the visual feedback when commands are deactivated. The better performance of the second system implies a better understanding of the disabled command when the tablet had the cover attached. Nevertheless, poor visual affordance of the disabled icon was noted also while "thinking aloud" and during the interview by some subjects.

During the "put music" task, the subjects were asked to switch to the tertiary drawer menu and tap on the music button. The second system yielded a considerably smaller error rate than the first of less than 1 average error in comparison to the first system with an average of a bit less than 1.5 average error and a big confidence interval. Nevertheless, the mean TCT was relatively short for both systems counted about 2 seconds for both. These results suggest improvements for the drawer handle and highlight the advantage of the cover that limits arbitrary taps on the interface, adding also the tactile feeling in the spot of the handle which increases precision. The concept of providing infotainment features in the same device was touched during the interview, asking the participants if they would like to separate tactical and tertiary control into separate devices. 6 subjects noted that they desire to separate the functions, while the rest valued our concept for delivering the infotainment menu, since it always provides feedback establishing situational awareness. The concept of having a full screen infotainment menu and the tactical controller in the same device was declined and hence the overlay cover's design can be improved, if the tablet was used as a dedicated tactical controller.

The "Stop the car" task yielded an error rate of 0.5 difference between the two systems, favoring the tablet with the cover. The mean TCT was about 2 seconds less for the second system considering also the confidence interval establishing the better performance of this system. This task also required considerably more time than the "Accelerate" command reaching more than 3 seconds difference, marking the lack of discoverability of this function. The lack of accessibility of the stopping functions was noted

"2nd turn to the left" resulted in the poorest performance with a big variance between the users for the first system. Although the second system gave considerably better results, the big interval of the first system requires testing with more subjects in order to make more reliable conclusions of the efficiency of this task. Most participants stated that the functions delivered by the interface are useful in the context of autonomous driving except from two subjects, who stated that these functions are unnecessary. They felt that they would not use it if they were not asked to do so. This could also be the result of the poor performance of this task in few specific cases. Furthermore, some subjects mentioned that they felt committed to a command, when they issued it, since they needed to wait until it is performed by the car. Especially, during this use case, it may take several minutes until it is completed and if the user desires to do something else, she would need to cancel it first and assign the desired command. This was the main reason of criticizing the usefulness of this command but also gives birth to second thoughts of providing a queue of commands to the driver (5.6.3, figure 24) for resolving this issue.

Additional remarks and observations worth noting regard the cancellation of commands, tapping interactions and the Eco-slider (5.6.3, figure 23). Specifically, a subject noted that it was too easy to cancel the command by just dragging the car away from the icon, feeling that a mistake could easily be made if she performed this action accidentally. This rises implications for providing better feedback about the effect of this action. Tapping interactions were proved more intuitive in general, observed through the recordings and marked by the users during testing. However, subject's agreed that they may yield more errors and the results showed that after a small learning curve they grasp the drag and drop interaction (5.5.1). Finally, the Eco-slider did not manage to convey its functionality to some subjects and even though it made acceleration, deceleration easy, the effects of each mode need to be defined better. It also reduced the feel of control, as one

participant noted that during performance mode, the car was overtaking slower vehicles ahead by its own unexpectedly. It also hindered the accessibility of the "stop" function.

7. Discussion

In this section, we discuss our reflections upon the methodological approach we followed during the process and the important findings extracted from the final validation which will lead to the Conclusion section. The final part of discussion covers general ethical issues that are important to be taken into account when designing for future autonomous cars in general.

7.1 Methodology and Process discussion

Following the Jones design model (Jones 1970) helped planning our design process to fit our 20week schedule effectively by separating it into three main phases (4.1) and setting important deadlines for completing our goals. Multiple design iterations complemented with constant evaluation ensured the implementation of a polished final prototype with positive user results in terms of usability and user experience (Results section) along with stakeholders' satisfaction.

The "Build-Try-Express" workshop (5.3) provided us essential user requirements following a human centered approach and we think that can be used as a method for extracting user patterns for building user interfaces in general. However, it is worth mentioning that this method demands adequate space and we did not manage to get the participants in a car context to try their prototypes. These would require additional time and patience from the participants, but it would definitely yield better results especially in terms of positioning of the tablet and ergonomic factors. Triangulating the results from the PD workshop with the literature findings we managed to elicit specific system requirements, being able to justify them to our stakeholders and conduct a solid research.

The iterative interactive prototyping (5.4, 5.5) complemented with evaluation at the end of each iteration accelerated the implementation phase and apart from few changes, major flaws were effectively avoided. The interactive prototypes were easy to demonstrate to users and experts, encouraging to interact with them and provide useful feedback. Nevertheless, the software limitations at this stage hindered our choice of the "drag and drop" interaction, which was appreciated and performed efficiently during the final validation. The expert evaluation (5.4.3) was a key decision which not only saved valuable time but also included a different perspective which influenced positively our decisions and greatly improved our interface design.

The choice of SAFER's vehicle simulator (SAFER | Lindholmen Science Park 2015) along with the Wizard of Oz setting, also saved us time, thanks to the premade scenarios which were provided (Chen et. al 2014) and did not need major changes to tailor them to our scenario. Alternatively we considered shooting real-life videos with road driving covering the use cases and projecting them in a car. This would have the advantage of getting the user in the car context and making it more realistic but it would hinder the exploration of the interface. We believed that allowing the user to freely use the interface, getting the intended effect of her actions and encouraging her to "think aloud" provided detailed feedback about all the functions and food for thought for future work. Ideally, a Wizard of Oz setting would be planned in a real car, with a wizard driving the car, a wizard controlling the "wizard application" (5.6.6) and the subject sitting

in the passenger's seat and using the tactical controller. A curtain also would be placed between the driver wizard and the subject for better simulation of the autonomous car experience. Nevertheless, this would raise the complexity of planning the session and since we both do not have driving experience in the roads of Gothenburg, we could not be confident in planning this kind of validation.

7.2 Results discussion

The validation results showed that the interface proved efficient in terms of usability and after little guidance and a short amount of training, the users get used to the drag and drop interaction, even though initially the tapping gesture proved most intuitive. Nevertheless, the visual affordances can be definitely be improved in order to accelerate the learning process. Providing gesture hinting would also contribute greatly to this path by improving the exploration of the functions in an explanatory way (3.4.2) without the need of external guidance. The functions delivered are essential for tactical control but the use-case of choosing later turns invoked some doubts as we believed that it was less fitting to the tactical and more to the strategic level of control. Turning to the second or third exit in a highway may require a considerable amount of minutes and route knowledge in order to be performed by the user. During the validation, a couple of participants noted that they lost track of which exit would the car turn after issuing this command and some subjects expressed the need of issuing other commands, while waiting for the car to take a later turn. Hence, the idea of including a command queue could be revisited for enabling the user making strategic decisions for route planning. Furthermore, the design of the Eco-slider could be improved to better convey its functionality and can be a path for promoting eco-friendly driving. The road map metaphor was appreciated and easily understood, but tweaks can be made to link it better with reality, such as retaining the car icon on the correct lane. Providing a navigation map has been strongly expressed during the process and is also interesting to be explored in future iterations.

As far as feedback is concerned, more modalities should be explored for boosting the efficiency and enhancing the driving experience. The need for audio feedback was expressed especially for confirmation of user input and description of the tasks that the car performed in order to limit the issue of divided attention. Haptic feedback can be also used to improve the precision of the drag and drop interactions, informing the user dynamically through vibrations or by adjusting the design of the overlay cover to provide the tactile feeling in the position of the command icons. The visual feedback provided by the interface was appreciated and considered useful in the context of autonomous driving, trying to establish situational awareness. On the other hand, improvements can be made to signify better the disabled commands, for instance when it is illegal or there is no car to overtake, and a better representation of road signs and alerts to not confuse the user. Especially, for the latter, some participants marked that it is hard to calculate if they should take an action in case they get a road alert, since the automated car is supposed to avoid hazards. Some notified that this feedback made them feel that they are responsible for taking action, which worked negatively in terms of trust. Contradictory wise, they expressed the need for information about the road environment. Therefore, it is not just important to provide sufficient system feedback, but also ensure that it elicits the driver's and automation's roles during the autonomous driving task. Supplying comprehensible and unobtrusive feedback classified suitably into different modalities can greatly reduce cognitive load and build a solid foundation of trust towards autonomous cars.

The comparison between the two systems (tablet without and with cover) yielded interesting points of discussion. As noted before, iterating the design of the overlay cover with the intention of supplying tactile feedback on the input space, can promote eyes-free interactions and greatly increase the efficiency of the interface. On the other hand, it restricts user interactions and tablet space dedicated only for tactical control. The tablet without the cover is able to include more functionalities, by making the whole screen interactive, providing also more levels of information and customization. For instance, the speedometer can be customizable, the fuel area can provide information about monthly fuel consumption and so on. The layout can also be dynamic, by changing the size and positioning on the elements, the orientation of the tablet and in general making adjustments depending on the function but also the preferences of the user. Nevertheless, the design challenges are greater at this case in order to keep the driver in the loop of the autonomous driving task, since more errors and confusion can be invoked by visual overload. Therefore, two different paths were indicated after evaluating both systems. A path towards a dedicated tactical controller interface which can be an integrated touch display on the car with a built-in overlay cover that provides tactile feedback and a specific area of interaction. Or a path towards a controller which utilizes the tablet's unique affordances to offer more features aiming to provide a more enhanced autonomous driving experience. The rapid technological advantages and specifically the commercialization of haptic touch displays signify a brighter potential towards the second path.

The delivery of the tertiary menu managed to receive positive comments from the testing subjects and the swiping gesture proved intuitive and fast for switching between tactical and tertiary control. Retaining the output features while accessing infotainment features aimed to keep the driver in the loop of the autonomous driving task, by constantly providing information about the car status and the environment. Nevertheless, utilizing the whole screen space for tertiary features was considered especially during long journeys, but in this case it is important for the system to provide audio feedback in order to keep the driver aware of the autonomous car's actions. The concept of attaching and detaching the overlay cover for switching between tactical and tertiary control was rejected, since it would put unnecessarily more physical effort to the user and it would rise the complexity of the design of the cover and the choice of materials in order to automatically switch the interface between tactical and tertiary control. Following the discussion from the previous paragraph, utilizing suitably the whole tablet display for providing tactical and tertiary features was the path followed in this thesis work.

An interesting contradiction was indicated between the PD workshop, where most subjects desired to keep tactical and tertiary control on the same device in contrast with the validation session where most participants expressed the need of separating the features into different devices. We believed that this resulted because of two reasons. First, by introducing the overlay cover and limiting the interactions on the interface, the subjects felt that this system would rather

be dedicated to tactical control and not include infotainment feature. Second and most important reason, was the problem of divided attention, discussed before, which was obviously not existing during the PD workshop since there was no effect by bodystorming the interfaces. Discussion was raised from the possibility of attaching and detaching the tablet device being able to share it among the passengers. In this case, the device should be dedicated only to infotainment features according to users, marking concerns about safety. The tactical interface should be integrated in the car and within reach of the driver only. Hence, providing a dedicated system for tactical control, which could include the overlay cover and having a separate device for tertiary features, shows that is worth exploring both paths simultaneously. A covered tactical touch-display integrated in the vehicle and a detachable tablet device for accessing infotainment features. In other words, the concept of separating tactical and strategic control along with other tertiary features into two different systems emerged from the validation results.

The issue of divided attention was also caused due to the positioning of the tablet. Some participants noted that they needed to constantly switch focus between the road and the interface and they would rather have the tablet positioned in front of them. Taking into account that the seat is set in rearwards position in our concept, thus the users are not within reach of the steering wheel and pedals, the tablet would definitely be positioned in the front to limit this issue. On the other hand, it would result to more muscle fatigue since the armrest would not be used for and the arm should be constantly raised while interacting with the interface. Another idea was to be able to detach the tablet and letting the driver hold it conveniently as she desires, which introduces issues discussed in the previous paragraph. In general, adjusting the positioning and accounting for ergonomic factors should definitely be explored more to build a good balance between safety, convenience contributing also in the decrease of visual cognitive load.

The interface managed to communicate the same level of automation to all participants conveying a semi-autonomy level leaning towards full automation. However we should underline that the interface was not tested in the real car context, but a vehicle simulator. The subjects took the role of the supervisory operator during the simulation, getting the sense of control especially when performing tactical tasks, as the car responded successfully to their commands. Nevertheless, the lack of understanding of the Eco-slider resulted in slip of control from the subjects' perspective in some cases. For instance, in performance mode, the car took the initiative to overtake other vehicles, trying to maximize performance, causing confusion to the participants. Hence, more feedback was needed to inform the subjects not only of the car's actions when executing user's commands, but also the automation's actions without the user's input. The sense of control is established not only by giving the driver the authority to command the car but also by constantly providing feedback about automation initiated tasks.

Finally, it is essential to underline that this interface does not intend to replace the steering wheel or be compared with traditional driving. The transition from manual to autonomous driving has to be gradual and considering solutions at this stage without giving the choice of the driver to take the manual control of the car through the steering wheel and pedals would not be acceptable by most users. The validation results along with the user studies have shown that trust towards autonomous car systems needs time to be built. The mental model of the driving task is strongly connected with the steering and pedal control, hence gradually transitioning to autonomous driving should not aim to replace them but complement them with information systems that enable the user to retain a higher level of control. We should also take into account that people enjoy manual driving and it would take a lot of years to build a strong mental model of autonomous driving using specific new tools. Therefore, the implemented solution of this thesis intends to enable the driver to easily perform tactical tasks, leaving the operational actions to be handled by automation safely and legally. The driver can deactivate automation at will by taking over full manual control by using the steering wheel and pedals.

7.3 Ethical Issues

This chapter poses a list of ethical issues that might emerge as we are introducing the use of automation in the car industry. Ethical issues noted are most likely to happen in chain since any of the listed issues appearing would trigger the rest.

The Replacement of Human with Automation

One main concern has been that machines would replace humans in the near future. In section 3.1.1, it was underlined that automation would not replace the human completely. Automation would rather become human's mental labor. (Sheridan & Parasuraman 2005) However, social corollaries need to be considered, when an automated system (in this case, the automated vehicle) which is capable of performing tasks better than the driver, were to be introduced to wide public. We cannot ignore the fact that there might be humans who will be threatened to lose an opportunity to perform a task. (Parasuraman & Riley 1997)The role of the taxi driver would be meaningless as soon as driverless cars are delivered commercially.

Deskilling

Replacement of the human with automation is tightly related to the problem of deskilling in the human operator. As we can see from the assembling line in manufacturing factories, the job of the human operators was to press buttons to let an automated system to perform a task. Sooner, human operators would get used to pressing the button and would get afraid to do the job manually. This incident has a high chance of happening in the autonomous driving technology. The human driving skill may degrade deliberately and in the near future of driverless cars, people may not be able to drive the car flawlessly without the help of automation. Moreover, if humans are giving the control to an automated car, they probably experience a sense of losing contribution to driving which may end up in humans which lack confidence in taking over the control of the machine. (Endsley & Kiris 1995, Sheridan & Parasuraman 2005, Niemann 2011)

Misplacement of Trust

As noted in section 3.1.3, the issue of trust is sensitive when it comes to automated cars. Sheridan and Parasuraman (2005) remarked an issue of trust that too little trust could lead to a severe problem as well as too much trust. When automation could perform a task flawlessly, it is natural for humans to put more trust. However, if the automated system fails, there is a concern about who is responsible for the failure; the human driver or the car. There is a tendency that the car owner would blame the manufacturer or the car company. To avoid this phenomenon, the existing driving legislation should be reviewed.

8. Conclusion

In sections 1.1 and 1.2 we addressed the research problem and posed our research questions aiming to provide answers through a methodological 20-week research process. A touch based controller for autonomous driving was deployed through a tablet interface with tactical and tertiary features and validated in a vehicle simulator with a Wizard of Oz setting to simulate the autonomous driving context. The features implemented were useful and easy to use after a short learning time establishing a semi-autonomy level, where the user felt in control of the car as the supervisory operator of the automated system. The switching between tactical and tertiary control was fast and easy without detaching the driver from the supervisory role by keeping the output features in the foreground. These functions proved essential to keep the driver in the loop of the driving task by establishing situational awareness. Nevertheless, the need for even more and better system feedback was expressed. Improving the visual-only modality of the interface with more descriptive cues and visual affordances as long as complementing it with haptic and audio feedback can lead to a more efficient and enhanced autonomous driving experience, by eliminating the issue of divided attention and reducing the visual cognitive load of the driver. The positioning of the tablet can be revisited to fight this problem but ergonomic factors needs to be taken into account. Especially in the context of future autonomous cars, potential changes of the indoor space will introduce new spatial relations between the driver and the information system.

The use of a three-layered overlay cover resulted in a more efficient system by successfully distinguishing the input and output functions, limiting errors and the time for completing a task. Although it did not yield a significant subjective difference, it invoked a feeling of dedicated tactical control. Providing a tactical only interface with a cover which is designed to provide tactile feedback on the input space can promote eyes-free interactions and drastically raise efficiency. In this case, tertiary features can be delivered by a separate device, which can be shared among passengers. Hence, the two paths were defined by the results of the research:

- A tablet-based controller with tactical and tertiary features with a dynamic interface which can be augmented to provide strategic level functions
- A static tactical touch display with an overlay cover with dedicated input and output tactical driving related functions.

Given the tablet's numerous affordances and evolution in electronics and information technology, we believe that the first path has a higher potential to deliver a unique and more complete semiautonomous driving experience by giving the user the tactical and strategic control of the car along with accessing tertiary infotainment features. The second path is also worth exploring towards a standardized tactical control system that can be integrated in future autonomous cars and combine visual and tactile feedback to establish efficiency, whereas tertiary features can be controlled from separate devices. The transition to autonomous cars should be gradual and semi-autonomous information systems should not aim to replace the traditional instruments but enable a higher level of control while the automated system handles the tedious operational tasks. Trust will be built over time and by constantly enhancing and improving these systems. Concluding, we underline the answers to our research questions, emerging from the 20-week research project, aiming to provide insight to fellow designers and developers in the context of touch-based interfaces for future autonomous cars:

How can a tablet interface be designed to keep the **driver in the loop** of the autonomous driving task by functioning as a **tactical and tertiary controller**, providing an **easy switch** between these modes?

• Define a forgiving and intuitive input method for tactical control

The drag and drop gesture is not an instant action, allowing space for regretting issuing a command before finishing the gesture, thus limiting errors and making it more forgiving. The metaphor of moving the car icon to the corresponding part of the map makes it intuitive and accelerates learning of the interface.

• Output features should aim to establish situational awareness

The interface should provide information about the **automation status** (current task performed by the car), **car status** (speed and fuel level) and **environmental status** (alerts, road signs).

• Output features should always be in the foreground to avoid 'out of the loop' performance

The output features are always visible in the same position at the top of the interface even when accessing tertiary functions.

• Define a fast and easy interaction for switching between the tactical and tertiary features

The swiping gesture proved fast and easy. The drawer overlay menu made the interaction more intuitive, by providing the drawer handle.

Provide sufficient feedback about the automated system

The driver should know when her command is accepted or cancelled, when the automated car is carrying it out and which commands are unavailable (illegal or impossible)

• Provide proper feedback

The driver should understand the feedback and its purpose. For example, a road alert sign should have an informative and not alarming role, since the automated system is responsible for establishing safety.

• Provide multimodal feedback

Audio and haptic feedback can be added suitably in order to reduce the visual cognitive load and limit the problem of divided attention.

Will a tablet-based tactical controller, augmented with a **smart overlay cover** increase the **efficiency** of the interface, providing a **clear distinction between the input and output** functions?

The answer is **yes** based on the following two points:

• Provide three layers: exposed (for input), transparent (for output), opaque (inactive interface parts)

Underline input and output features, limiting errors and building a mnemonic image of the interface in the driver's mind.

• Dedicate the cover to tactical control and provide additional tactile feedback

The tactical map (5.6.3) can be designed to provide tactile feedback in the input space by further limiting interactions so that the user feels the position of the circular command icons. This promotes eyes-free interaction and limits the problem of the divided attention. However, tertiary (infotainment) control would be separate at this case and multimodal feedback is vital to avoid 'out of the loop' performance.

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10. Appendices

List of Appendices

Appendix I: "Build-Try-Express" Workshop Appendix II: Validation

Appendix I - Questionnaire

Personal Information

First Name:	
Last Name:	
E-mail:	
Sex:	Male Female
Year of Birth:	
Occupation:	
Area of expertise:	
Driving Information	
Driving Experience:	Beginner Intermediate Advanced
Car Model:	
Which way do you prefer to g	go around?
Drive yourself	
Someone drive you	

Would you trust a taxi driver to get you around? Why?

Yes	
No	
Touch Interfaces information

Experience in using touch-based devices (mobile phones, tablets etc.):						
No experience		Regular Use		Expert Use		
Frequency of using touch-based devices						
Never		Occasionally		Daily		
Familiarity with touch gestures (tap, drag, swipe etc.):						
	12		5	67		
Don't know them			ŀ	Know all of them		
Flexibility with touch gestures:						
1						
Can't u	se them			Use them ea	asily in apps	

Date of Session:

Designer:

Appendix I - Storyboard



An ordinary day in your life You have an ordinary week day. You either be a student or employed. You are one of a new generation people. You are faimiliar with touch-based device like smartphone and tablet.

Scenario



It's time to go to job / university! You own an automated car. You prefer to go around by your car.



Automated Car with Tablet Controller You get inside your car. What you need to do is set your destination via tablet and the car will drive itself.



You give your car a command An automated car will drive as you command. You can give any command via tablet. (e.g. turn left/right, change lane and take over other car)



Arrive fast, safe and easy The car drive you to your destination safely. You feel it easy to drive the car. It's just like someone drive it for you. You can enjoy yourself while the car is driving. (e.g. reading, watching movies, listening to music)

Appendix I - Instruction Card

Create (20min)

In this workshop, you are requested to create a touch interface for the tablet, through which you can control an autonomous car. You are given a transparent sheet to place on the tablet, where you can stick paper elements in order to build the interface. You should be able to give specific commands to the car to control it. The interface will also need to display specific items. Feel free to add any command or additional items that you would like to be displayed. Listed below are the basic commands and items to be displayed and should be supported by the interface:

User commands

- Move left/right inside lane
- Change lane left/right
- Take the next turn
- Take a turn ahead (second/third etc) left/right
- Increase/decrease speed
- Stop
- Park
- Overtake another car

Items displayed

- Speed
- Fuel and Oil levels

You are free to use the paper elements as well as markers and pencils to draw. A set of touch gestures with icons is also provided to show the method of input for each command. You can use specific gesture icons to indicate a command. During this process, we would like to listen to your thoughts about your choices. Feel also free to ask any questions.

Appendix I - Design Toolkit



GESTURE



Тар



Multi-Finger Tap



Tap and Hold (Long Pressed)





Swipe Left



Rotate Clockwise



Multi-Finger Tap and Hold (Long Pressed)



Multi-Finger Swipe Left



Rotate Counter Clockwise



Double Tap



Swipe Up



Swipe Right



Rotate with One Finger



Multi-Finger Double Tap



Multi-Finger Swipe Up



Multi-Finger Swipe Right



Stop



Swipe Down



Multi-Finger Swipe Down



Pinch



Spread

Appendix I - Testing Tasks

Now it is time to put your design on test. Look again at the scenario card. Imagine that you are inside the car, which you have taken from home and you have already set the destination to go to your job/university. The car will follow automatically a route, which passes through the city, then it takes the highway road and gets into the city again till it reaches the destination. If no commands are given, it will safely reach the destination and park automatically.

We will request you to perform some tasks during the trip and use your interface in order to get control of your car. After each task feel free to make any changes to your design. During the journey, you are also free to give any commands as you wish to test your design.

- A pedestrian is crossing the road. Break the car.
- You want to pass by the coffee shop. <u>Turn the car a bit to the right inside the lane.</u>
- Now command it to turn right to the next intersection.
- Nearing the coffee shop. <u>Start decelerating</u>.
- Reached coffee shop. <u>Stop</u>.
- Car is in the highway in the right lane. <u>Check the speed</u>. (Digital or Analog Speedometer?)
- You notice some road works in the background at the right side of the road, but the car hasn't started yet to take actions to avoid them. <u>Turn a bit to the left inside the lane</u>.
- Now you want to speed up. <u>Accelerate</u>.
- Change lane to the left.
- Low fuel. You haven't noticed. How do you expect the car to alert you? Check fuel level
- In two exits there is a gas station. Take the second exit.
- <u>Stop at the gas station</u>. Car is filled and is on the highway again.
- You notice that you are late. Accelerate and overtake the car in front of you.
- You know a shortcut if you <u>take now the next exit</u>.
- Got into the city. Car starts decelerating by itself. It is likely that you will stop at a red traffic light. You want to <u>accelerate</u> and try to bypass it. The car does not obey to your command as it will break the law. How do you respond? What do you expect from the car (notifications alerts etc.)?
- No you want to <u>turn right</u> to the next intersection to find a parking place other than the usual one.
- Now you are near the parking place. <u>Instruct the car to park</u>. You reached the destination.

Appendix I - Closing Interview

Automation

- How do you imagine a car driving alone? What do you expect from it?
- Would you trust it?
- What would you do during autonomous driving?

Tablet Controller

- Do you prefer using a tablet over the steering wheel and pedals in order to control the car? Why?
- Do you prefer to use your own tablet that you can attach and detach from the car, or should the touch interface be built-in the car armrest?
- The tablet will also be able to offer infotainment features (e.g. entertainment). Would you like to keep the tablet at the same position?
- How would you switch the tablet function from controlling the car, to play a music playlist for example?

Appendix II - Questionnaire

Personal Information

First Name:					
Last Name:					
E-mail:					
Sex:	Male Female				
Year of Birth:					
Occupation:					
Area of expertise:					
Driving Information					
Years of Driving: Less t	han a year 1-2 years Many years				
Frequency of Driving: Daily Weekly Monthly Yearly					
Experience with ACC (Adaptive Cr	ruise Control)				
or other driving assistance feature	es Yes No				
If yes, which?					

Touch Interfaces information

Experience in using touch-based devices (mobile phones, tablets etc.):

No experience	Regular Use	Expert Use	

Frequency of usin	ng touch-bas	sed devices				
Never		Occasionally		Daily		
Familiarity with touch gestures (tap, drag, swipe etc.):						
	1	.24.	5	6		
Don't know them			Know all of	them		
Flexibility with to	ouch gesture	es:				
	1	24	5	6		
Car	n't use them			Use then	n easily in apps	

Date of Session:

Appendix II - System Usability Scale

	Strongly disagree				Strongly agree
1. I think that I would like to use					
uns interface in equencity	1	2	3	4	5
2. I found the interface unnecessarily					
complex	1	2	3	4	5
3. I think that the interface was easy to use					
	1	2	3	4	5
4. I think that I would trust this interface					
to be used in autonomous cars	1	2	3	4	5
5. I found that the various functions in					
this interface were well chosen and fit with the use	1	2	3	4	5
6. I thought there was too much					
inconsistency in this interface	1	2	3	4	5
7. I felt in control of the car by using the					
interface	1	2	3	4	5
8. I felt tired using this interface					
	1	2	3	4	5
9. I would imagine that most people					
would learn to use this interface very quickly	1	2	3	4	5
10. I needed to learn a lot of					
things before I could get going with this interface	1	2	3	4	5

Appendix II - Closing Interview

Modalities

- Would you use this system?
- Why?

Functions

- Did you find the functions of the interface useful?
- Are there any more function that you would like to have?
- Are there any function that you feel irrelevant / not needed?
- This given tablet is capable for controlling both the car and infotainment functions, would you like to use these two features in the same tablet or would you want an external source for infotainment?

Yes 🔿

No 🔿

User Interface Design

- Do you find the interface hard to use? Yes \bigcirc No \bigcirc
- If so, in which situations it was hard to use?
- Are there any problems you found while controlling the car using the interface?
- What do you like most and least about this interface?
- Is the amount of feedback enough to maneuvering the car? Yes \bigcirc No \bigcirc
- Did you feel the urge of using the steering wheel, while using Yes O No O this system?
- Can you easily find the information that you're looking for? Yes \bigcirc No \bigcirc
- What is the level of automation you perceive from the interface?

Overlay Cover

• What is the difference that you feel toward a prototype with and without overlay?