FutureNav

The Design and Evaluation of a Strategic Navigation Interface for Semi-Autonomous Driving in Urban Environments

Master of Science Thesis in Interaction Design & Technologies

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Department of Applied Information Technology
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2016

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Abstract

Turn-by-turn GPS systems are designed for todays manual drive cars, focusing primarily on providing short-term instructions on steering the vehicle. In the future, semi-autonomous vehicles will take over much of the steering duty, and in the process, change the type of navigation information which is valuable to the driver. We identify 2 scenarios where information provided by the navigation interface could be valuable. The first is a challenge: to enhance the driver awareness of their surroundings in the case they have to take over operation. The seconds is an opportunity: to provide strategic long-term control of the vehicle's heading. In accordance with these 2 scenarios, we conducted a 50 person survey to study the information needs of drivers of semi-autonomous vehicles. The results indicate that these information needs center primarily around Time, Location, Route Conditions, and Self-Driving Parts. We also find that these vary between different trip purposes: social trips, home trips, and shopping trips. To test the validity of these findings, we design and construct a working prototype of a navigation interface, FutureNav, which provides this information and gives drivers high-level control over it. Testing the hypothesis that such an interface may increase driver awareness, we conduct an experiment in the real-world comparing FutureNav to Google Maps as a baseline, using standard measures for testing situation awareness on all 3 levels. We identify certain features of FutureNav, such as the ghost car,map landmarks, and the 3D viewpoint as potential sources of increased situation awareness. Finally, we reflect on our design decisions, and the learning from conducting in-the-wild experiments that focus on situation awareness, noting that such information may be useful for the design and testing of future navigation interfaces designed for semi-autonomous vehicles.

Keywords: navigation, autonomous, vehicle, strategic, situation awareness, previewing, tactical, future.

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Contents

1

Introduction

New forms of mobility and technological advancements are changing the way people move throughout their environment and particularly, in the city (Arthur D Little Future Lab, 2013). The self-driving car is forecast to be at the center of this transition, reaching wide availability by 2025 (Berger, 2015). The space around vehicle automation is undergoing rapid advancement, with vehicle manufacturers such as Volvo, Mercedes, and Audi developing and testing initiatives. These companies are developing what are known as semi-autonomous vehicles, able to drive on their own in some situations, while still needing the driver to take over in others. Examples of these include Volvo's drive.me project which aims to continually test over 100 cars around highway roads (Victor et al., 2017), and the recent Mercedes test drive which covers it's founders historic test route from Mannheim to Pforzheim covering complex urban situations, this time in fully automated fashion (Ziegler et al., 2014). On the other hand, technology companies are also pushing the state-of-the-art, with Google's self-driving car program logging over 1 million miles on public roadways. These companies are preparing to leapfrog traditional manufacturers by moving directly to fully autonomous vehicles without traditional control systems like a steering wheel.

As Norman (2009) points out, successful automation brings about its own set challenges. Even the most advanced autonomous vehicles in testing today require a supervisor to be available to take over, raising the issue of driver awareness. This awareness can be influenced by a number of factors: the environment (Leshed et al., 2008), the state and behaviour of the driver (Merat et al., 2012), and the interfaces between the driver and the vehicle. In current vehicles, Advanced driver assistance systems (ADAS) automate and enhance parts of existing interfaces, while in the future, semi and fully autonomous vehicles will take this a step further by self-navigating along given GPS paths. In this case, the navigation interface starts to carry on more importance as the main nexus of control between the car and the driver. Navigational interfaces in vehicles encompass both the challenges and opportunities of automation. The main challenge we identify is providing information and control to the driver in such a way that supports their 'situation awareness'. By removing the need for constant operation of the vehicle, drivers will have the opportunity to navigate in accordance with their high level trip goals. Studying the needs of the driver of semi-autonomous cars, and how the navigation interface can be designed to address these needs will be the focus of the work in this thesis.

1.1 Research Problem

Two main research problems exist which are linked to the challenges and opportunities of designing navigation interfaces for semi-autonomous vehicles.

Driving a semi-autonomous vehicle will not require the same level of attention as driving a fully manual vehicle, therefore, when transitioning from autonomous to manual driving modes, the driver may lack the information necessary to take command of the vehicle. This causes ‘out-of-the-loop’ problems where the driver’s lack of situation awareness results in degraded performance (Endsley and Kiris, 1995). The concept of situation awareness will be covered more comprehensively in the theory section, but briefly, it refers to a drivers ability to understand, comprehend, and predict their situation. Navigation interfaces, as one of the central information hubs of the vehicle, will play a key role in keeping the driver aware of the situation, both in terms of short term and long term readiness.

While addressing the problem of driver awareness is the foundation of the thesis, there are additional problems that are related to this space. Drivers have general navigation information needs, for example, spatial knowledge, environmental complexity, and knowledge of traffic conditions. These are the navigation needs where drivers need the most support (Münter et al., 2012). The context of semi-autonomous driving will likely change these information needs, necessitating further study in this area. In future driving scenarios, supporting drivers through technology will still be a highly desired function (Gkouskos et al., 2015). Therefore, another issue to address is how to map these needs to an interactive interface that can best support drivers.

1.2 Research Questions

The research questions are formulated directly on the basis of the research gap identified concerning using navigation interfaces as a way to raise situation awareness. We propose one primary research question with sub-questions to investigate its different aspects.

How can we design a navigation interface to support strategic level situation awareness during semi-autonomous driving?

- What are the associated navigational information needs of drivers in this mode?
- In which scenarios of the future are drivers likely to use this type of navigation interface?
- Can we design and build a navigation interface that raises situation awareness when tested under common usage scenarios?

- If so, can we identify aspects of this interface which raise situation awareness?

1.3 Project Goal

Needs for the future are difficult to elicit by simply asking users (Van Elslande and Fouquet, 2008). Therefore, one goal is to produce an interactive prototype that might serve as a platform to evaluate the needs of navigation for semi-autonomous vehicles. For example, various iterations of the prototype can test the mapping of information to the different parts of a screen. Furthermore, as an artifact that embodies the design research performed throughout the thesis, it can be used as a reference design that can inspire further work in the field (Zimmerman et al., 2007).

A second project goal entails that the developed prototype be tested in the real-world, as opposed to a simulator environment. This is in line with our vision to create a real, working prototype, which we argue could only be tested to its full capabilities in real-world scenarios (Broy et al., 2015).

1.4 Scope

First, the thesis focuses on problems related to drivers being out of the loop, which inevitably is triggered during handovers to manual driving. There are already existing systems which handle the details of the handovers themselves, and thus, we explicitly avoid this area. Instead, we restrict the area of study to the parts of the semi-autonomous drive which are fully autonomous.

Second, the research will be focused on a particular subset of driving scenarios which contain 3 of the most common type of destinations that drivers visit, are short in length, and are set in an urban environment. Scenarios involving daily A to B type trips will not be considered, and long trips on rural or high speed roads will also not be considered. These scenarios are based on research showing the most common usage vehicles in the most common type of setting (Krumm, 2012; Mackett, 2003). The framework section contains a more thorough explanation behind the reasoning on the developed scenarios.

1.5 AIMMIT

This thesis is part of the work packages contained within the Automotive Integration of MultiModal Interaction Technologies Project (AIMMIT). As such, the research and findings in this thesis are closely related to previous projects, particularly thesis work that has contributed towards an overall vision.

1.6 Stakeholders

This master thesis is in collaboration with Semcon, Chalmers University of Technology, Volvo Cars and Viktoria Swedish ICT as a part of the AIMMIT research project. As the primary stakeholders, Semcon has established the focus of the project and has provided the office space, resources, and logistics needed to carry out the research. Semcon bring considerable expertise and knowledge about the automotive industry. Volvo Cars is a vehicle manufacturer and leading automotive technology provider. The Volvo Group's vision is to become the world leader in sustainable transport solutions. As an industry partner in this project, Volvo provides feedback on technological approaches, and informing on high level industry direction. Chalmers and Viktoria Swedish ICT provide additional academic support.

1.7 Ethical issues

When a car enters semi-autonomous control, the implementation by the car manufacturer will affect the safety of the driver and the bystanders. Issues arise when an accident occurs on how responsibility is distributed between the supervising driver and the autonomous car. Our research aims to increase the situational awareness of the driver so that the result may be used to increase the safety of driving a semi-autonomous car, since the driver will be able to instruct the car to avoid critical situations and be in-the-loop in case a critical situation occurs.

One goal of the project is to evaluate a high fidelity interactive prototype in a moving vehicle on road. Therefore, the safety of participants in the study will have to be ensured. This could depend on the distraction factors related to the prototype itself, and the type of simulation for autonomy that will be performed.

Certain parts of our research methodology involve the dissemination of user questionnaires. In this case, privacy plays an in important role in protecting confidentiality of participants as well as considerations related to discrimination.

2

Theory and Related Work

This thesis aims to undertake work which is at the cross-roads of a number of established and developing fields. The related works presented below serve to give a brief overview in these fields, identify areas in which a research gap may exist, and propose a focus that will be used to guide the thesis work in later processes.

2.1 Automation in Vehicles and Driver Role

Autonomous systems in vehicles vary in terms of their capabilities. Models for classifying automation in vehicles have been proposed with the aim of making clear the precise degree to which a particular vehicle automates its functions. The US National Highway Transportation Safety Agency (NHTSA) is a government regulatory body which has issued a set of recommendations for classifying autonomous vehicle capabilities. There are 5 levels of automation, from 0 through 4 2.1. This thesis will focus on level 3 vehicles with limited self-driving automation:

> "Vehicles at this level of automation enable the driver to cede full control of all safety-critical functions under certain traffic or environmental conditions and in those conditions to rely heavily on the vehicle to monitor for changes in those conditions requiring transition back to driver control. The driver is expected to be available for occasional control, but with sufficiently comfortable transition time. The Google car is an example of limited self-driving automation."

In this definition, The vehicle itself is functioning in what is known as semi-autonomous (SA) mode, which implies the vehicle is fully autonomous only some of the time. The driver of the car acts only as a high level supervisor, although their assistance may be required with sufficient time to transition to lower levels of control. Sheridan and Parasuraman (2005) propose a framework for supervisory control which has four classes of automation centering around information acquisition, information analysis, decision and action selection, and action implementation. This thesis will focus on the first two classes aiming to provide timely, necessary and useful information to the supervisor of the vehicle.

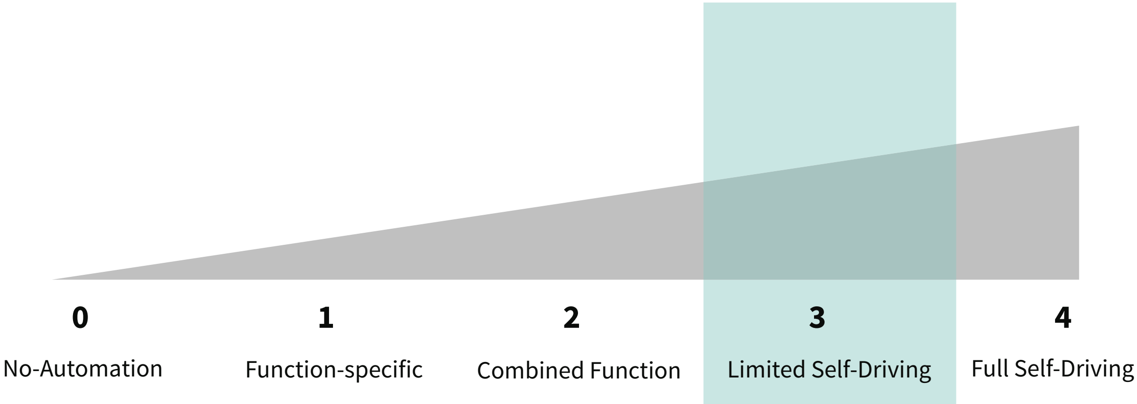


Figure 2.1: NHTSA Levels of Automation

2.2 Situation Awareness

Situation awareness (SA) is a way to model and measure a driver's level of awareness about their environment. Endsley and Kiris (1995) have put forth the most universally accepted definition of situation awareness as: "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future". The model as described in 2.2 has 3 levels: Perception (SA level 1), Comprehension (SA level 2), and Projection (SA level 3). In her seminal work, Endsley identifies short term working memory, and attention resources as important constraints on SA. In addition to this, design guidelines are proposed that could improve SA, for example: "grouping of information in terms of spatial proximity" and "key in on the top level picture and easily access greater specificity". These guidelines can help drive design decisions when creating a navigation interface that support high situation awareness.

Although the concept of situation awareness was originally developed for military purposes (Endsley, 1988), it has been adapted by others to many other domains, including driving (Matthews et al., 2001; Bolstad et al., 2008; Sarter and Woods, 1991). As applied to the driving context, Sarter and Woods (1991) suggest breaking down awareness into the following components: spatial awareness, identity awareness, temporal awareness, and goal awareness such as a navigation plan. Matthews et al. (2001) builds on this definition, and combines it with Endsley's model, suggesting that SA during driving is related to the driving goal 2.3. Finally, Matthews et al. (2001), proposes a research gap which could be addressed by navigation systems: "Navigation and route-guidance systems illustrate this approach. These systems have the potential to enhance SA at all three levels".

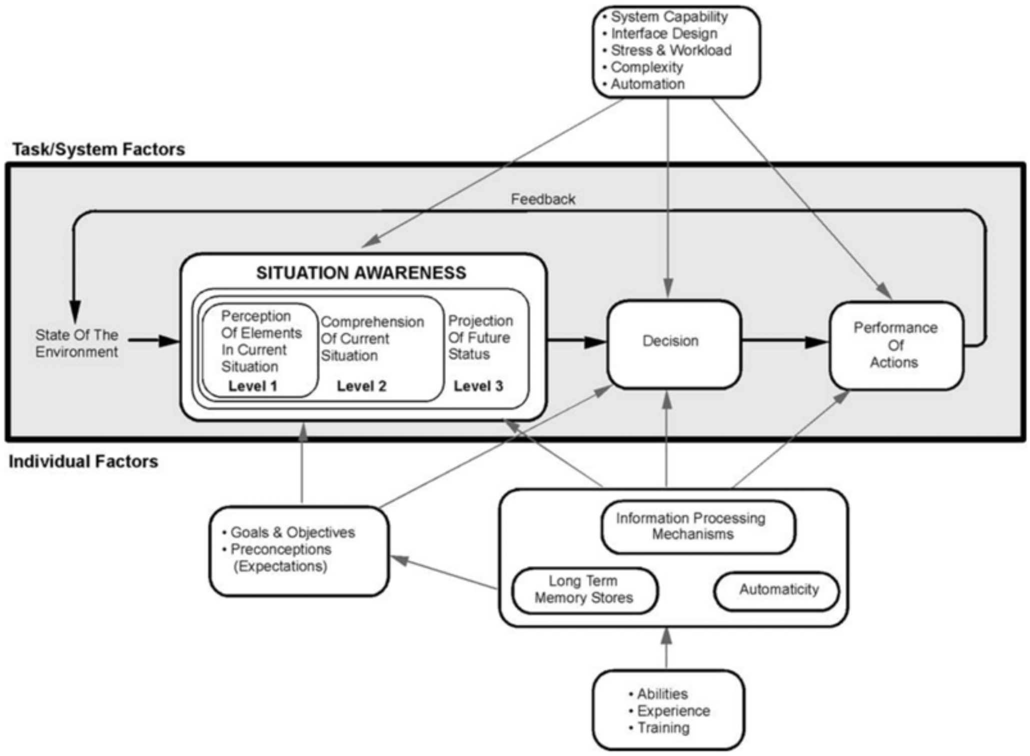


Figure 2.2: A model for situation awareness by Endsley.

2.2.1 Measuring Situation Awareness

2.3 Human Factors in Automation

Previous work in the field of automation has shown the importance of considering human factors when it comes to system design. (Billings, 1991) proposes general guidelines for automation in aircraft including a set of principles for human-centered automation that could be equally applicable in vehicle automation. Endsley and Kiris (1995) characterize out-of-the-loop performance problems as a major consequence of automation where operators have difficulty in taking back manual control. In their study, higher automation conditions produced lower situation awareness (SA) and an increase in decision time. This was attributed to the difference in level of information processing, where more automation resulted in a more passive understanding. Similar studies have been carried out in the automotive domain Julia Niemann (2011), showing that an active processing paradigm involving the driver can decrease reaction times during control decisions. Thus, when designing for higher situation awareness in vehicle interactions, active information processing can be employed to keep the driver in-the-loop.

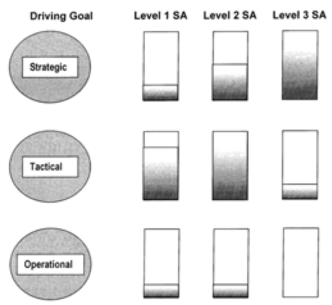


Figure 2.3: How different driving goals affect SA.

In any system where multiple levels of automation are available, transitions can introduce significant problems related to mode confusion (Sarter and Woods, 1995) and context switching penalties (Monsell, 2003). Schieben et al. (2011) propose a layered scheme regarding transitions in automated systems. As applied to autonomous vehicle operation, the four layers consist of (1) explicit switch by the driver, (2) vehicle proposes, (3) car takes over (minimum-risk maneuver), and (4) fluid transitions based on implicit parameters such as grip strength of the wheel. In their study, during take-over requests by the vehicle (layer 2) drivers had difficulty understanding that they needed to perform an extra step to confirm they're in control. This suggests there may be an opportunity to design for layer 4 type transitions, by providing smooth transitions between their level of readiness before asking to take over control.

2.4 Driving Levels

When designing for interactions in the car, it is important to understand decision making process of the driver and the kind of information they need to make those decisions. Michon (1985) breaks down the driving task into three levels: operational, tactical, and strategic. The strategic level involves high level goals of route planning, modal choice, and risk evaluation. Tactical level is about obstacle avoidance, overtaking, and negotiating the immediate surroundings on the time span of seconds whereas operational level maneuvers spans milliseconds and provide basic controls of the vehicles such as steering and braking. Keskinen et al. (2004) suggest that strategic driving can be motivated by even higher goals such as learning to drive or lifestyle, which are referred to as 'Goals for life and skills for living'. Current driver support technology such as Advanced Driver Assistance Systems (ADAS) are more focused on the operational level, and thus there is an opportunity to design systems that offer support on the strategic level (Davidsson, 2009). One example of strategic level support is Tesla's route planning for long distances, which takes into account EV charging station locations (See Fig 2.4).

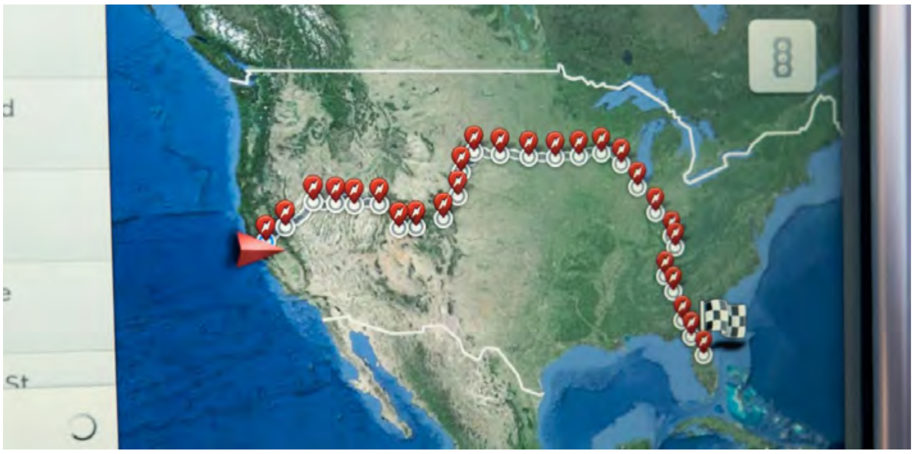


Figure 2.4: Tesla Trip Planner for EV trips.

Source: http://www.theverge.com/transportation/2015/4/16/8430037/tesla-range-assurance-hands-on

2.5 Navigation Theory

On a more fundamental level, navigation in a car can be related to human wayfinding behaviour. Cognitive mapping, as defined by (Golledge and Garling, 2002), consists of establishing locations, understanding distances and relative directions, and the ability to convert a mental map into knowledge of the surrounding physical environment. Essentially, the purpose of a cognitive map is to allow a person to get from one place to another. The next step in the process involves some decision making in the form of route choice which can be selected *a priori* (planned) or *en-route* (dynamic) (Golledge and Garling, 2002). Dynamic route selection presents an interesting case, as it is often assumed that the selection criteria should stay constant throughout a trip, however, a study by (Golledge, 1995) showed the opposite. For example, whereas 'least time' was the 2nd most important criteria at the start of the journey, the itinerary undertaken by the participants showed that in reality, it was 6th in importance. (Bovy and Stern, 2012) refer to this selection process as 'adaptive route choice', which are decisions taken by the traveller based on changing circumstances. The process that encapsulates all of the above steps, and guides the traveller through the environment is called navigation (Golledge and Garling, 2002). Based on the above definitions, the work in this thesis will focus on providing information that will specifically assist in making en-route decisions during navigation.

Golledge and Garling (2002) suggest two methods of acquiring route knowledge, survey and experiential. This 2 methods roughly correspond to the two types of decision making. The survey method is used when a viewing the landscape from above, in a 'birds-eye-view', while the experiential method refers to physically walking or moving through a particular environment. Anchor point theory states that we build up cognitive maps based on specific locations we identify as salient Golledge and Garling (2002). These locations are highly personal, although they can also be common, for example, a church, or a mall, or a person's home. Through the survey method, such as looking at a GPS map, or physically viewing all anchor points from above, we can link their relative locations. Similarly, by experiencing a route, either by moving through it, or by previewing it, a person's route knowledge can be increased. Very few, if any navigation interfaces stress both of these methods of route knowledge, for example, providing detailed 3D landmarks which are custom to a person's journey, while allowing for a quick way to zoom out and see all locations together.

2.6 Multi-Purpose Trips

Motivations behind vehicle trips was analyzed by (Krumm, 2012) which looked at data from over 150 thousand U.S. households. The most common destination is going home, which accounts for 34 percent of all trips, followed by 'buying goods' (i.e. errands) and going to work at 12 and 11 percent respectively. However, in 3 destination sequences in combination with home trips, 'buying goods' is followed closely by 'pick up someone' and 'visit friends/relatives'. This suggests that although work trips may be very common, in more dynamic, non A-to-B type trips, social needs play a more significant role. A study in the U.K focusing on short trips (Mackett, 2003) found similar results, placing shopping and social activities as the two highest usage scenarios for vehicle use. Multi-purpose trips become interesting in the context of route selection, as many studies have shown that trip purpose is the primary affecting factor in route criteria (Mackett, 2003; Wachs, 1967; Mahmassani and Shen-Te Chen, 1993). It therefore becomes the imperative of the navigation interface, to be able to adapt and provide information that is contextual to the trip purpose.

3

Methodology

The following chapter will explain the research process of this master thesis.

The research were conducted using a design based research approach. We do so to be able to iteratively produce something that can easily be conceived and interpreted by all stakeholders and it can be efficiently evaluated in a way for human needs to be met. Research through design also gives the possibility to produce artifacts that produces a level of detail that is impossible to attain in a written account (Gaver, 2012).

The process will be performed in a Human-Centred Design ethos. The interdependence of human-centred design activities is explained in ISO 9241-210 (ISO, 2010). This is an iterative design process which is not linear but each stage depends on the output from the other.

The process will be executed iteratively through three major steps:

1. **Eliciting information needs in semi-autonomous navigation.** Eliciting the important information required for car drivers to efficiently navigate around an urban commuting scenario.
2. **Ideation and implementation of a multimodal prototype that addresses the information needs.** From the findings of 1. there will be ideation sessions with the desired outcome of a concept that in an intuitive way addresses the information needs.
3. **Evaluation of the design concept.** Evaluating the concept created in the previous stage to see whether it fulfills the goals and to see what aspects affect the outcome.

3.1 Research Through Design

Research through design is a way of performing Human-Computer Interaction research through a continuous iteration of ideating and critiquing the solution and problem formulation in an attempt to make the "right thing" (Zimmerman et al., 2007). The outcome of research through design is a concrete problem formulation and a formulation of a "preferred state" together with a set of artifacts that communicate the result of the research.

The term was first coined by Frayling (1993) in his paper "Research in Art and Design", where he proposes a way to differentiate different types of research. It is often explained as the link between research and industry (Zimmerman et al., 2007; Koskinen et al., 2011; Gaver, 2012), where the design artifact is used as the communication tool between these two parties. Research through design allows for a more holistic research contribution (Zimmerman et al., 2007).

The thesis aims to contribute to research in the field so that the knowledge and insights gathered from the project can be used and extended into further research. As part of the research process there is a opportunity to use a design artifact as a tool to conduct design research by iteratively conceptualizing and evaluating and critiquing the design concepts.

Gaver (2012) discusses about the opinions and expectations of research through design. He argues that we should not expect to get traditional results from research through design bur rather see the artifact as the fundamental achievement. He suggests that research through design should not only strive for a convergence in the research but that a divergence of many alternatives and ideas and critiquing is beneficial for the community.

Zimmerman et al. (2007) lists criteria on good research through design which he formulated in 4 categories; Process, Invention, Relevance, Extensibility. These criteria was used as a guideline to produce a higher quality thesis.

3.1.1 Process

The first proposed criterion is about the process and documentation where the author states; "Interaction design researchers must provide enough detail that the process they employed can be reproduced. In addition, they must provide a rationale for their selection of the specific methods they employed." (Zimmerman et al., 2007)

The thesis aims at explaining the process of each step of the project in the three chapters to follow. For each chapter it will be an explanation of the process in enough detail so it could be somewhat reproduced with a similar outcome. The methods are ought to be motivated and shown with a clear connection to the outcome.

3.1.2 Invention

The second proposed criterion regards the novelty and invention of the outcome. "The interaction design research contribution must constitute a significant invention. Interaction design researchers must demonstrate that they have produced a novel integration of various subject matters to address a specific situation." (Zimmerman et al., 2007)

To communicate the argument for invension we present an extensive literature review in the first theory section of this thesis to situate the work and demonstrate the research's novelty in the field.

3.1.3 Relevance

The third criterion, Relevance, considers the importance of the result and how this is communicated. "In addition to framing the work within the real world, interaction design researchers must also articulate the preferred state their design attempts to achieve and provide support for why the community should consider this state to be preferred." (Zimmerman et al., 2007)

The thesis aims to research what aspects increase situation awareness. By making the driver more aware of the situation and in-the-loop we hope that it can lead to safer vehicles in the future. The prototype will be used as a manifestation of the preferred state.

3.1.4 Extensibility

The fourth criterion ensures that the work is extensible for other researchers by encouraging valuable documentation. "Extensibility means that the design research has been described and documented in a way that the community can leverage the knowledge derived from the work." (Zimmerman et al., 2007)

Each stage of the thesis aims at producing an extensible artifact. A framework is created in chapter 4 on which a researcher could use as a basis to develop his own version, explained in section 4.4. The concept and prototype explained in chapter 5 is developed such that it could be easily modified to evaluate different parts of the design aspect. The comparative study explained in chapter 6 provides with a baseline for future product evaluations and research contributions, where a researcher could perform a corresponding study and refer to this baseline as reference.

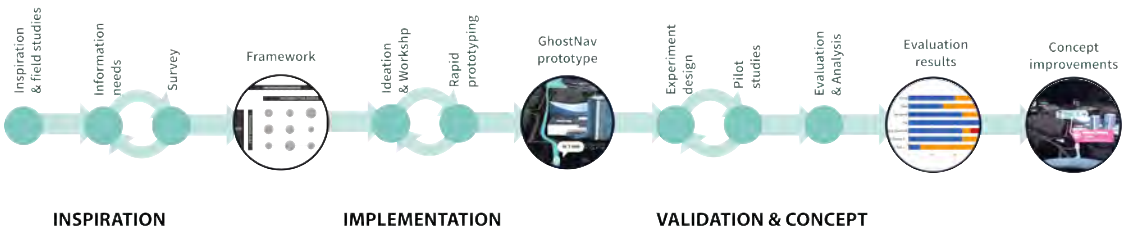


Figure 3.1: Overall design process diagram

3.2 Design process

The overall process of the thesis work is illustrated in figure 3.1. For each chapter in the thesis the process is illustrated in more details.

The process and it's methodology is inspired by Human-Centred Design(HCD) with the goal of capturing a broad viewpoint of the information needs for future drivers. HCD aims to include an explicit understanding of users and their environment (ISO, 2010). HCD as an approach follow an iterative process where users are involved during the whole design development. By choosing a Human-Centred approach we prevent 'designing the users', as Redström (2006) puts it, meaning a design will reflect users mental model and support their behaviour.

The three stages inspiration, implementation and validation & concept was performed consequently, each with it's own product and presented in it's chronological order in the thesis but a product of the first stage could be refined after the second stage has started. Each product was iterated and critiqued both with the help of users and internally.

A challenge of the process was that it required the researchers to elicit needs for future users. True semi-autonomous cars does not exist yet as of the writing of this report and the task was to find the needs of the time when semi-autonomous cars are in use on public roads.

Querying users directly about their needs is generally not a preferred method (Patnaik and Becker, 1999; Laurel, 2003). Eliciting needs of a non-existing product will add an extra challenge since a need can be relevant to a feature that already exists but a need can exist for features that has not been discovered yet (Van Elslande and Fouquet, 2008). By utilizing ethnographic-inspired methodology and scenario based co-design sessions we uncover an opportunity to extract needs that are not obvious and that the users are not able to express explicitly.

Each stage of the process includes user involvement and critiquing in an attempt to evaluate our research and design outcome in an iterative way.

The process follows a form of design process where divergence and inspiration is prominent in the early phases of the process and convergence of ideas gets more focused towards the end of the process until there is a refined design suggestion. The result from the individual studies themselves will also serve as strong research value.

3.3 Human Centred Design

Human-Centred Design is a design process that has emerged from the fields of ergonomics, computer science and artificial intelligence (Giacomin, 2014). The International Standards Organization defines Human Centered Design as an approach to interactive systems development that aims to make systems usable and useful by focusing on the users, their needs and requirements, and by applying human factors/ergonomics, and usability knowledge and techniques (ISO, 2010). It's a process that encourages to examining users in their natural environments, and it requires the researchers to involve the users in the research process.

The methodology and process of the thesis is inspired by the Human Centered Design guidelines in a way to try to capture a holistic picture of the future users' needs.

3.4 Expert interviews

Expert interviews can serve as a tool to collect industry and academic insights and a broader perspective of the current state (IDEO, 2003). Experts of the field is interviewed with a set of questions for a period of time while notes are written down.

Expert interviews served as a basis for knowledge in the area of research and provided insights and direction of the research in terms of how to frame the research space and what has been done in previous research. The expert researches was done primarily in the early stages of the thesis work.

3.5 Literature Study

In research through design, a literature study is used to understand how the work integrates within existing research, and how it might advance the current state of the art (Zimmerman et al., 2007). Our literature study involved searching across a number of different sources, including web searches, related master thesises, specifically within the AIMMIT project, and articles within related journal publications, specifically DUXU 2015, CHI 2013 to 2015, and AutomotiveUI 2010 to 2015. Google Scholar served as the main literarature search engine, in part because of it's broad coverage (De Winter et al., 2014), and intuitive citing mechanism. Searches targeted articles with keywords: "vehicle navigation", "semi-autonomous", "situation awareness", "automation factors", "driver needs", "car usage", "research through design", and many more articles targeted specifically by their title or authors. Articles were then sorted within the main categories of "navigation", "multimodality", "methodology", "visual modality", "haptic modality", "automation". Each article is summarized and relevant quotations are extracted and added to the overall description of each article in Trello. This method allowed us to easily find and filter information by high level topics and identify areas that need further research.

3.6 Field Studies

Performing field studies is an ethnographically inspired method where user studies take place in the environment in which a product will be used (Dix, 2009). With little or no instructions, users are observed and/or interviewed while using a product in a chosen environment. Field studies was performed to study how users naturally behave today when assigned to navigate a car.

3.7 Participatory Design

Participatory design is a way to utilize the experience and knowledge of people that have experience and insights that extends the experience of the designers. In participatory design, users are treated as experts. The goal is for designers, researchers and users to collaborate and generate a shared learning (Spinuzzi, 2005). A participatory design session could be done in the form of a focus group or workshop, where designers and users collaborate in designing a solution.

Participatory design was used as a means of involving users in the process of developing a preferred design and also as an opportunity to evaluate an existing design concept and as a way to analyze users' mental models.

3.8 Prototyping

The creation of a design artifact involves a number of intermediary products, which can be supported through the creation of various prototypes. Lim et al. (2008) describe prototypes as a tool for traversing the design space which leads to meaningful knowledge used towards the construction of the envisioned design. The design space can be explored by creating prototypes with different purposes. A simple system is offered by Houde and Hill (1997) which plots prototype dimensions on a triangular space with 3 features: role, look & feel, implementation. In a similar manner, Snyder (2003) suggests a system consisting of 4 dimensions: Breadth, Depth, Look, and Interaction. Prototypes can also be classified as hi-fidelity and lo-fidelity. Hi-fidelity prototypes integrate the high level design elements (Houde and Hill, 1997) and can be used for evaluation (Macaulay et al., 2000). Lo-fidelity prototypes capture early design ideas (Macaulay et al., 2000) and are typically built with paper Snyder (2003). The selection of which prototype to build is determined by using an iterative approach to identify the most important open design questions (Houde and Hill, 1997).

This thesis took use of the models above to decide what types of prototypes that was needed to do in order to capture the relevant aspects before creating a high fidelity field-testable prototype.

3.9 Strong Prototyping

Strong prototyping is a bodystorming methodology in which the designers will build and test their prototypes in an environment that closely resembles the context of use (Schleicher et al., 2010). The method allows the designers to get a first-hand look at how the artifact would fit into the context of use. This method was used to rapidly prototype various interface concepts for the semi-autonomous car by creating, modifying and evaluating prototypes of different materials while inside a car.

3.10 Oblique Strategies

Oblique strategies is a method that can be used to induce lateral thinking in a creative process (Taylor, 2003). The method was originally created to help musicians in their music making process, but has been adapted in various fields where there is a need to think in new ways.

Oblique strategies uses a set of sentences on a deck of cards or similar. One card is randomly drawn and read out loud. A sentence on the card could be "Towards the insignificant" or "Lowest common denominator". The sentence is meant to be cryptic and to be interpreted by the team and the discussion will hopefully lead to a new direction of thinking or new ideas.

Oblique strategies was used in the early phases of the concept generation to rethink and improve on established ideas and to produce additional ideas that could lead to other focus areas.

3.11 Bodystorming

Bodystorming is a simple method for the designers to physically and mentally experience a situation (IDEO, 2003). The designer will, with or without props, act out roles to be able to generate and test concepts that depend on the context and behaviour.

Bodystorming was used in the early phases of ideation to generate ideas for the semi-autonomous vehicle, which was hard to mimic by other means since it did not exist as the writing of the thesis.

3.12 Immersion

Immersion is a method about putting the designers in the context of use (IDEO, 2015). It let's the designers experience the context of where the product will be used. An immersion session could be initiated by letting the designers spending time in the environment in which the target use scenario will take place.

Immersion as a method was interpreted in combination with Bodystorming (3.11) as a way for the designers to get insights on the experience of navigating a car and a future of semi-autonomous cars.

3.13 Insight Combination

The insight combination method is a method to generate ideas from insights gathered from ethnographic research (Kolko, 2010). Insights are written on one type of paper note and design patterns are written on another type of paper note. These are then combined and the designers have a short period to come up with an idea that incorporates the both.

The insight combination method was used to convert insights from ethnographic research and constraints of the semi-autonomous setting and technology limitations of the project into a multitude of different ideas.

3.14 Affinity clustering

Affinity clustering is a way to sort information gathered from research according to similarity (Institute, 2012). Quotes, insights, thoughts or any gathered information is put on individual notes and then sorted into clusters by the design team by moving them around on a board, the outcome is then discussed and rearranged and lastly the clusters are named after the containing notes. The result is called an affinity diagram.

An affinity diagram was created and used to find patterns in insights from field studies and literature studies.

4

Information Needs & Scenario

The goal of the first research sub-question is to elicit information needs for navigating in a semi-autonomous vehicle. General information needs of drivers have been studied extensively in the past (Mackett, 2003; Wachs, 1967; Mahmassani and Shen-Te Chen, 1993), however, these needs may change in scenarios which involve driving semi-autonomous vehicles. Not only are the information needs change, the scenarios themselves will also shift as urban travel patterns and car use evolves. This directs us to our second research sub-question, which asks which are the most likely scenarios under which semi-autonomous driving will take place in the future. We employ a multi-pronged, multi-step process described below in more detail. The end result is a set of information needs that are specific to the scenarios under which they will be used. We further suggest a way to standardize this process so future designers can perform similar research in accordance with our research through design methodology (Zimmerman et al., 2007).

4.1 Process

The process of eliciting information needs and creating a framework is summarized in figure 4.1. The first step involved using a number of inquiry methods to yield the main set of factors. These were filtered, organized, and ranked in a survey by 50 participants. Finally the results of the survey were organized in an easy to understand framework.

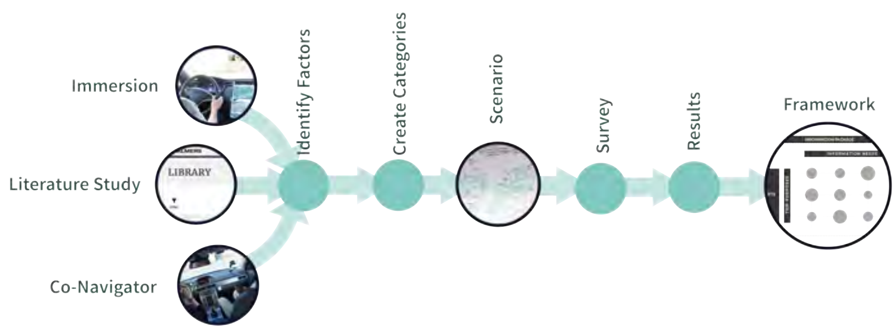


Figure 4.1: Process diagram for framework creation

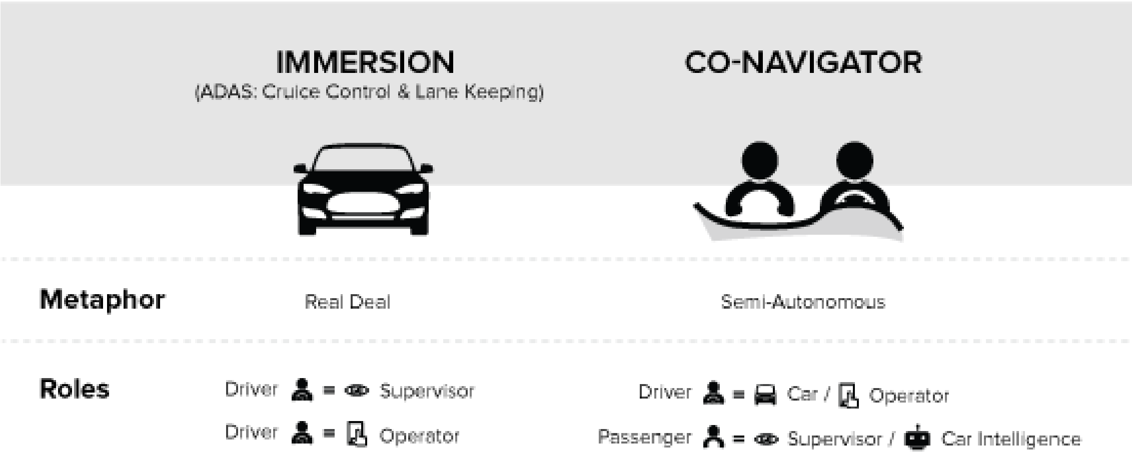


Figure 4.2: Field Study Methods Comparing Observable Roles

4.1.1 Field Studies

Two types of field studies were conducting early on in the process of the thesis with the purpose of understanding and observing driver behaviour in different roles (See Fig 4.2), specifically as operator and supervisor in a semi-autonomous setting.

The co-navigator scenario provided insight on how drivers navigate in a multi-destination scenario. This study was inspired by a similar study performed by Perterer et al. (2015). A handful of drivers were selected in pairs to navigate in the city of Gothenburg, Sweden. Each pair was assigned 3 tasks to complete that varied between studies. Tasks included finding a coffee shop, picking up a friend, and driving to a shopping destination. Data from the field studies included field notes, video recordings, and post-hoc interviews.

The authors also test drove a vehicle equipped with Advanced Driver Assistance Systems (ADAS) including lane keeping and cruise control. Sections of the route included handing over the control entirely to the vehicle, for up to several minutes at a time. This was to get a feeling on how the semi-autonomous setting would impact the navigation of the vehicle.

4.1.2 Literature studies

The bulk of the factors were gathered by conducting a literature study across a number of papers related to navigation, route choice, and driver needs. A similar method was used by (Münter et al., 2012) on gathering driving information and support needs for navigation. They identified 3 relevant dimensions: driver, vehicle, and environment. From this list, a survey showed that drivers need the most support with spatial knowledge, particularly in unfamiliar routes. Gkouskos et al. (2014) looked into future driving scenarios by asking the question "how are vehicles used in this future?" and eliciting driver needs, ranking them based on their originality, evaluative ability, descriptive richness, and dominance dimensions. Zhang and Levinson (2008) conducted a study to understand the value of travel information with 113 participants. Models derived from the results included factors for accuracy of information, trip purpose, traffic density, road safety, and others. Finally, articles related to factors in GPS navigation (Leshed et al., 2008; Brown and Laurier, 2012) rounded out the sources by providing practical needs experienced by drivers today.

4.1.3 Information Needs

Based on the factors identified in the literature review and field studies, a list of 155 factors were extracted onto a spreadsheet. Shaping these factors into something more manageable requires returning to the original research questions, as summarized: What are the information needs for strategic navigation and can this information support a high level of situation awareness? Using this as a baseline, factors were subjectively assigned a situation awareness level (1-3), as well as Michon's driving levels (Michon, 1985). Only factors which affect situation awareness comprehension or projection (level 2 and 3 respectively) and strategic level driving control were selected. This resulted in filtered list of 54 factors that affect situation awareness in strategic car navigation.

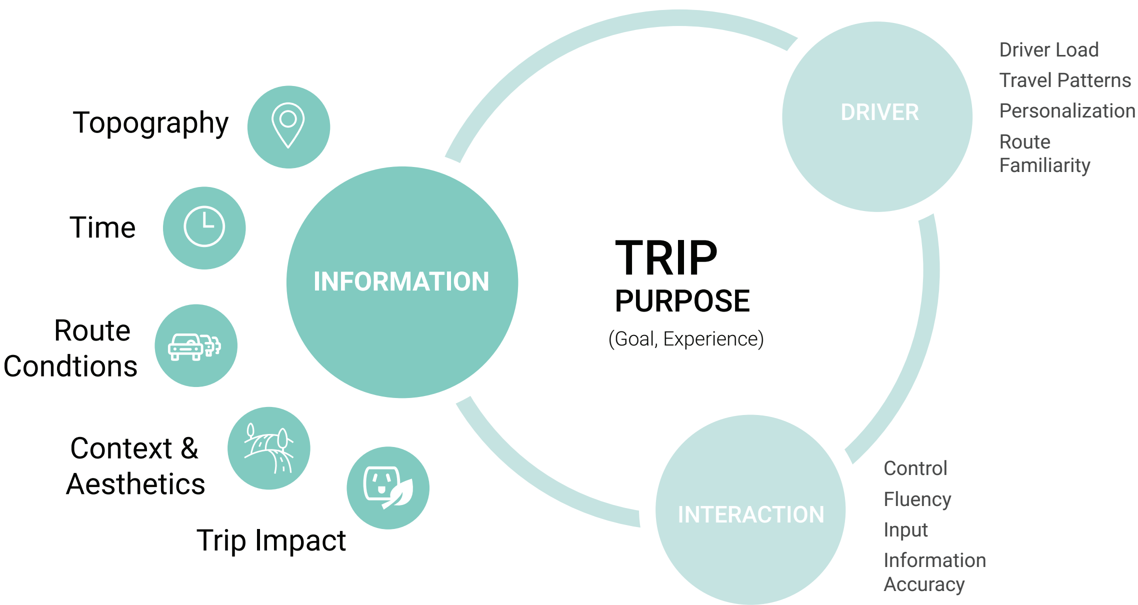


Figure 4.3: Final result of Affinity Mapping. The main categories created under Information Needs are: Topography (later renamed to Location), Time, Route Conditions, Context & Aesthetics, and Trip Impact. Factors under Driver and Interaction are not investigated any further in this thesis.

In the next step, the factors elicited from the filtered list were sorted into categories using the affinity clustering method. The affinity diagram resulted in 10 categories:

time, motivation, topography, experience, route conditions (dynamic/static), trust, driver load, driver profile, interaction, and spatial knowledge. Returning again to the first research question, some of these categories do not fit as an 'information need'. Therefore, the categories and factors were re-sorted into 3 higher level categories: information, interaction, and driver. Furthermore, all high level categories are affected by the trip purpose, which has been shown in the theory section to be the primary affecting factor in driver information needs (Mackett, 2003; Krumm, 2012). The final categorization is represented in Figure 4.3. All further work in the thesis maintains a focus on these core information needs. While the factors in the driver and interaction categories were henceforth dropped from further study, they present an equally valid starting point for future research.

4.2 Driving Scenarios

The information needs gathered thus far represent the contemporary driving environment for the specific purpose of raising situation awareness through strategic control. These same information needs however, may not apply, or may differ when looking at new contexts such as semi-autonomous driving in the future. In order to verify and rank these needs against the proper context, a scenario can be created which reflects the desired frame of reference.

In our scenario, we include the setting, the tasks, and the time frame. Each of these is chosen based on the research in the introduction and theory sections. First, the setting is set in the city, where travelled urban kilometers are expected to triple by 2050 (Arthur D Little Future Lab, 2013). The tasks in the scenario are based on the multi-purpose trip analysis presented earlier, which shows that the 3 most common trip purposes are home, shopping, and social (Mackett, 2003; Krumm, 2012). The time frame is also carefully chosen to coincide with the introduction of semi-autonomous vehicles in the city, which is projected to happen in 2021-2025 (Berger, 2015).

We argue that the linear nature of A to B type trips such as highway driving to and from work would not place stringent demands on navigation interface usage. In addition, the proposed time frame implies that some manual driving will be required, particularly in complex city environments. The resulting scenario is a non A-to-B type trip, situated in the city, with multiple stops, requiring some parts of the route to be driven manually 4.4. On the way to each destination, we strategically place events that stress different information needs. For example, the 'Get Location' and 'Park' events are querying for the **topography** of the destination, while 'Route Selection' emphasizes at the **time** and **route condition** needs. We make use this scenario as the basis of our survey on information needs and empirical evaluation of navigation interfaces for semi-autonomous vehicles.

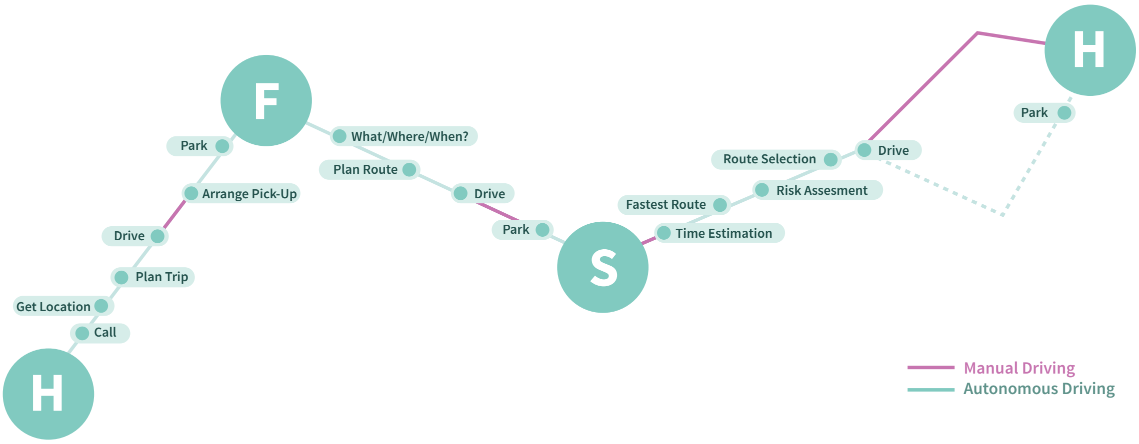


Figure 4.4: A dynamic city type scenario constructed to test navigation interfaces for semi-autonomous vehicles. H = Home, F = Friend (Social Trip Purpose), S = Shop (Shopping Trip Purpose). Manual driving sections are represented in pink.

4.3 Comparing Information Needs

An online survey was created with the purpose of verifying and weighing the importance of the found information needs for navigating a semi-autonomous vehicle in the specified scenario. A similar survey approach was used by (Pfleging et al., 2014), with the difference that they used expert focus groups for factor elicitation.

4.3.1 Survey Design

The hypothesis was that different purposes of a trip would affect the information needs. Therefore, it was decided that each information need would be individually ranked for each purpose. As such, the survey consisted of 3 main sections, each corresponding to a trip purpose: picking up a friend, going shopping, and going home.

The survey was constructed using the scenario as a basis for a story that was textually explained with short paragraphs, together with a related picture. Each textual story included a related task assignment. For each story and task the survey included an importance rating of each information type.

Since the found information types were broad and could be interpreted in different ways it was decided that the survey would also include some examples of different information items that could relate to these. 16 examples were extracted from the same list of factors and traced back to the source to determine a concrete example of information that could be provided in a navigation interface.

These examples were provided, in addition to the category rating, as individually selectable options for if the participant considered the information interesting to complete the task in the story. Each example was slightly modified to make sense in each story but one were related to only one information type. To reduce bias between each story the order of the examples were randomized. To prevent participants to tick all information as interesting and to force them to prioritize the information they were required to tick less than 7 items.

4.3.2 Survey Pilot

The survey was piloted with 3 participants. The main feedback concerned having too many example check-boxes, one for each category, per trip purpose. This resulted in combining the examples from all the categories in one list, which made them more ambiguous, however, allowed participants to compare them against each other. In addition, some of the category names were translated to be more readable for everyday users. Topography was ranamed to Location, and Context and Aesthetics was renamed simply to Setting.

After the survey had been revised and improved the link to the online survey was published via social media channels including reddit/r/SelfDrivingCars, Tesla Club Sweden forum, related facebook groups, as well as individually messaging contacts of the project team. The full survey is available in appendix A.1

4.3.3 Survey Results

The survey was completed by 50 persons with a mean age of 30.5 (SD 11.2), consisting of 66 % male and 34 % female respondents. Participants were distributed globally with 58 % in Europe, 22% in North America, 4 % in Asia. Urban settings included 21 different cities of varying sizes, with large cities (> 400,000 population) comprising 56% of respondents and small cities 22 %. Driving frequency of participants ranged from 52% for frequent drivers (daily or weekly), 28% for infrequent drivers (monthly or yearly), and 20% for non-drivers.

Survey results showed a clear delimitation between primary and secondary needs (see 4.5). The categories of time, location, route conditions, and self-driving parts were ranked significantly higher than the categories of setting and trip impact. From this point, we discuss these primary information needs, and link them to the specific information types in Figure 4.6.

> **Time**: Consistently ranked high irrespective of the trip purpose. Time to destination is ranked slightly higher than the expected time of arrival, and time delays become more sensitive as the trip purpose switches to going home.
>
> **Trip Conditions**: Home trips are more sensitive to condition information needs, which can be linked to time delays in the time category.

Location: Varies widely across trip purposes. Distance is highly desired in cases of shopping, while location information is needed in both picking up a friend and shopping scenarios. A picture of the destination is useful in shopping and social scenarios.

Self-Driving Parts: Based on the results of the individual examples, the self-driving example checkboxes did not correlate with the parent category of Setting. The checkbox example was checked at a much higher rate than the preference for setting information. Therefore, it was factored out as its own category. Overall, it was rated as useful at exactly the same rate across all 3 scenarios, hence some degree of self-driving part information is always needed irrespective of trip purpose.

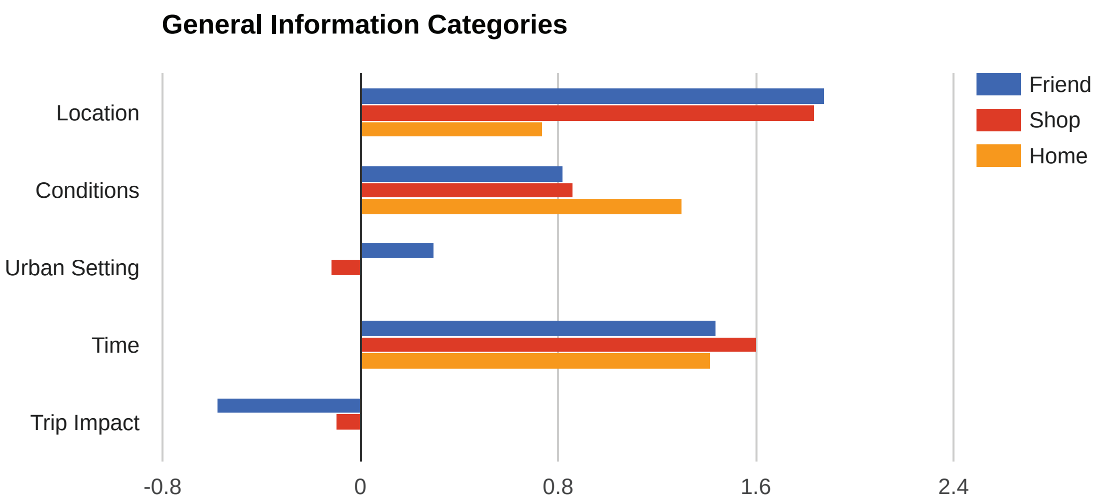


Figure 4.5: General Information Categories. For each scenario (Home, Friend, Shop) it is important that I am given information regarding the particular information category. Rated on a 5 point Likert Scale.

4.3.4 Additional Survey Insights

Although the sample size is limited at 50 participants, some insights can be made across geographic and demographic distributions. The most significant finding is in comparing big cities to small cities, where the need for information regarding self-driving parts is 78% in big cities. On the other hand, small cities need more information on estimated time of arrival which is 69% higher than in big cities. Delving into region differences, drivers in North America had higher needs for delay information (73%), visual location information (40%), and self-driving parts (52%) than their European counterparts.

The driving experience also showed a strong influence in information need preferences. In our data, frequent drivers showed higher interest in traffic, delays, expected time of arrival information. This type of information might be more associated with

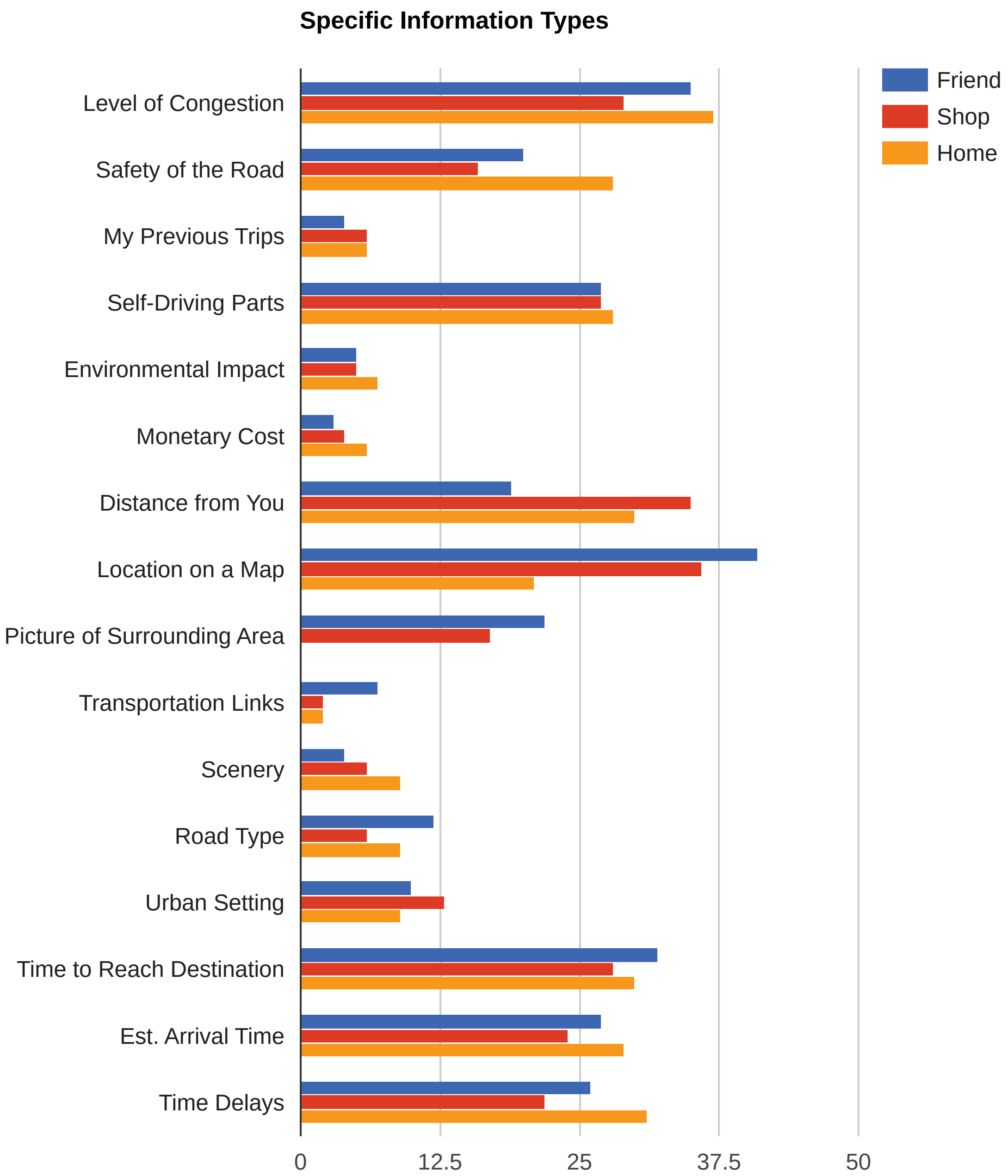


Figure 4.6: Specific Information Types: For each scenario (Home, Friend, Shop) what kind of information would be most interesting? Each Tick of a checkbox is 1 Point.

manual driving information needs. Infrequent and non-drivers showed interest in location related information such as a picture of their surroundings and a map of the destination. They also showed slightly higher interest in knowing which parts of the route would be autonomous. This type of information could be interpreted as applying a more strategic level of navigation.

4.3.5 Participant Comments

The qualitative results of the survey include participant comments on their choice of factors, the 'other factor' free-form entry field along with the general comments and ideas about navigation in semi-autonomous cars. For the 'other factor' field, the most common request was to show available parking locations. Driving directions (as in turn-by-turn) and road data (one way streets) were also on the list. The pick up a friend scenario yielded some interesting discussion regarding factor choice. One participant noted that information accuracy plays a key role in the time dimension:

“When you're picking up Bobby, you want to know precisely when you'll get there, so you can let him know if you're going to be delayed.”

Another participant prioritized location information in order to make optimal route choices:

“If he is closer to Macrosoftś shop, then it makes sense to drive in his direction, otherwise we could also meet half way.”

In the general comments, the low needs in the 'Urban Setting & Scenery' category can be summarized by one participant's comment:

“I guess I don't care about the scenery, I just want to get to where I'm going”.
Several participants requested that the navigation can incorporate a ride-sharing system “so you can fill up extra seats in your car if you want”. Finally, one participant wanted to have their data displayed in “a bright bold H.U.D. projected on windshield, or flexible clear OLED display”.

4.4 Discussion and Patterns for Future Use

This section of the thesis undertook the task of answering the first 2 research sub-questions: What are the likely scenarios of car usage in the future, and what are the information needs of drivers of semi-autonomous vehicles under these scenarios. The results showed that there are 4 primary information needs: *Time*, *Trip Conditions*, *Self-Driving Parts*, and *Location*. Overall, the results may seem somewhat obvious, these are needs that are even needed in today's driving. However, we have showed that these core needs will remain necessary despite the changes in context, and more importantly, have showed that they vary according to the trip purpose. Furthermore, we quantify the particular information types that are most needed for each purpose in Figure 4.6.

The process we have undertaken to identify the information needs of semi-autonomous vehicles consisted of a identifying a likely future use cases, sourcing base needs from literature, constructing a likely scenario out of this, and querying current drivers on their needs based these scenarios. This process yields an interesting design pattern which may be used when expanding vehicle interfaces to new contexts (e.g. fully autonomous), or to different scenarios (A-to-B type trips). At the heart of this pattern is the idea of 'Trip Purpose', serving as the driving differentiation in information needs. Using this as a basis, it is possible to construct a scenario consisting of likely trip purposes (or destinations), and add motivations for information during the trip.

In our case, we studied the scenario of city driving with en-route planning in a semi-autonomous vehicle. The found information needs are location, time, route conditions, and self driving parts. And the most common trip purposes are social, shopping, and home. An example of using the same pattern could be the scenario of country driving, with pre-trip planning, in a semi-autonomous vehicle. We can suppose that the designer has found context & aesthetics, as well as trip impact to be more significant than in the previous example. The trip purposes would also be quite different depending on the overall goal of the trip, which could be for example, a vacation on the coastline.

In the next section of the thesis, the scenario and found information needs will be used to build up a concept for a navigation interface. Further on in the thesis, we apply the scenario and context of semi-autonomous driving to evaluate this interface.

5

Prototype & Concept Development

We state as one of our thesis goals the production of a real, working prototype which may be tested in the field. The following chapter explains the process and outcome of designing a multimodal interactive prototype for strategic navigation in semi-autonomous cars. The outcome of the previous chapter is used in ideation and prototyping. The result is a fully working high fidelity prototype with live routing and GPS support.

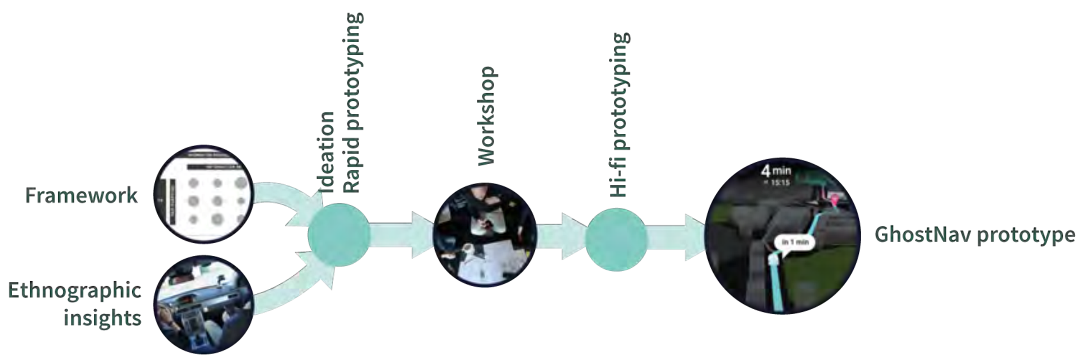


Figure 5.1: Process diagram for development of the concept

5.1 Process

The overarching process for generating a concept and prototype is shown in Fig 5.1. The insights gained from our literature studie, scenario creation, and field studies in the previous stage of the thesis was used as a basis when ideating on the concept. A co-design workshop was also held to capture the mental model of users on how they would prefer to display the information needs identified in the previous chapter. Numerous prototypes was created to evaluate different parts of the concept.

5.1.1 Design restrictions

Some restrictions and goals for the design steered the concept generation. These are listed briefly below. The first two follows by the scope of the project explained in the introduction of the thesis.

1. The concept should primarily support the situation where the car drives autonomously in a semi-autonomous car.

2. The concept should primarily support strategic navigation and improve level 3 of situation awareness (Projection).

3. The design should work well in a three-destination trip in the city. The same reason for using the scenario created for the survey.

4. The design should be extendable for future research. A wish from the authors to contribute to future research by building a concept that can be reused for future research, in the ethos of Research Through Design.

5. The design should be testable in real-life situations. Creating a concept that was feasible to build as a working prototype for the length of the master thesis project, which is of interest since something that has, in the context of the semi-autonomous vehicle, has not yet been extensively reviewed in published works.

5.1.2 How might we?

By going through the field studies and information framework we could write down a number of insight statements in short scentences. These insights were categorized with the use of affinity clustering. The categories would point out common themes and challenges for the design. The themes challenges were synthesized into 8 "How might we?" questions as follows.

1. How might we allow different (detail-)levels of navigation input?

2. How might we tailor the information infrastructure to the trip purpose?

3. How might we assist a multi-stage trip?

4. How might we display relevant information for selecting a route?

5. How might we clearly communicate information about autonomous parts. (differentiate from other types of information)?

6. How might we relate information to the surroundings?

7. How might we reduce the effort required in interacting with the system?

8. How might we enable a smooth overlap between a high level and low level interface?

The how might we questions were used in ideation to brainstorm on concepts for the design.

5.2 Early revisions

The early stages of the process focused on diverge and produce as many ideas as possible. Bodystorming, immersion sessions and strong prototyping were used to get a deeper understanding on what could be the future needs of semi-autonomous driving. Insight combination method, 3-6-5 and Oblique strategies are some of the other methods used to generate ideas. The ideas generated were prioritized according to the project goals and limitations. A favored idea was to visualize a timeline of the current route that the autonomous car is intending to traverse. Many prototypes was generated during the ideation phase. Depending of the progress of the concept generation and what aspects of the idea that is unclear, different levels of prototypes was created.

Figure 5.2: HUD prototypes

Another prominent idea was to utilize a Head Up Display (HUD), a transparent display shown on top of the windshield, for displaying information in the system. The theory was that this screen residing in closer proximity to the field of view of the environment would support a connection between the interface and the environment. This idea was evaluated first by drawing a paper prototype placed in a car and second by building a functional prototype to see benefits and disadvantages of such a display. See 5.2 for a picture of these prototypes. It was concluded that an HUD had disadvantages that outweighed the choice of a regular screen compared to the advantage in situation awareness it gave, thus the idea was dropped. Difficulties with HUD's arise when the brightness of the surrounding varies, which makes it difficult reading the display when the color of the surrounding may interfere with the color of the interface, which in turn limited the range of colors our interface could use.

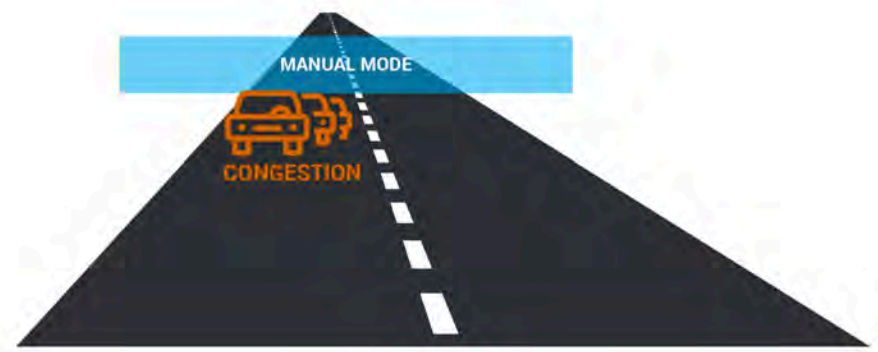


Figure 5.3: Lean gesture functional prototype

On the input side of the equation, we also investigated the idea of using head leaning gestures for additional control of the interface. This idea was evaluated with a functional prototype, a web based application that used a web camera to track the position of the users face (See fig. 5.3). The outcome was promising, the gestures could have the potential of adding a natural interaction. However, there were some issues identified, primarily because the head movement required to do gestures would be too much to be comfortable and at the same time not activate unintentionally. It would also make the interface take up a lot of attention by always moving with the users head, which could have the effect of lowering situation awareness. This feature was taken as far as the pilot studies, but was dropped for the final prototype.

5.2.1 Co-Design Workshop

A simple paper prototype created to serve as a 'role prototype' Houde and Hill (1997) was used in a workshop session to elicit ideas and feedback on the eventual use of the navigation interface during real scenarios. We carried out a co-design workshop as a form of participatory design with paired users on three occasions. The majority of participants were interaction design students as a convenience sample and also for the reason to have other designers opinions of what would be feasible or not to do.

The primary goal of the workshop was to generate a handful of plausible ways that the information needs found in the previous stage could be presented in the semi-autonomous context, and also when this information should be presented to the driver. The workshop material was based on the information types found from the research and prior generated examples for the information representations.

A workshop session was initiated with an introduction of the background of the project and the aim for the workshop. As a warm up, a bodystorming session was held for the participants. This was to help them get a sense on how it would be like in a semi-autonomous vehicle and also to spark a creative mindset. The workshop continued by handing out to each participant three design wireframes on paper. Along with this a special sheet with examples and inspiration for visual, auditory or haptic representations of different information types.

The inspiration sheet was divided into five columns of information types: Time, Destination, Conditions, Self-driving parts and Self-driving point of transition. Each column contained examples of information to show and examples of ways to represent the information. The examples were created after proposed designs that was produced during brainstorm sessions beforehand, both good and bad ideas was presented. The point of the inspiration sheet was to give instructions on what information could be shown in the system but primarily as inspiration for the participants to spark ideas on how the information could be represented.

The participant's task was to create an interface design on the wireframe sheet using the information listed on the inspiration sheet. The design sheets also contained the same scenario as in the survey. The task for the participants was to create a design for each scenario. After the bodystorming the participants were given instructions and 30 minutes to create the three designs. The design session was followed with a presentation session where participants could present their designs and ideas. These were recorded for later analysis.

After presenting the designs, participants were assigned to cut out their designs and put them on a timeline on the trip, to indicate at which time the participants would like to have the information to be displayed in the interface. See an example of a completed timeline in fig. 5.4. The workshop was documented with pictures and some video and audio recordings. The data from the workshop was reviewed and used as a reference in further idea generation and to support other ideas.

5.3 Integrated prototype

The process to follow consisted of settling on a design concept that would fulfill the restrictions specified in 5.1.1 and also support the desired research goal. Insights from the research and iterations of functional prototypes and aesthetic prototypes

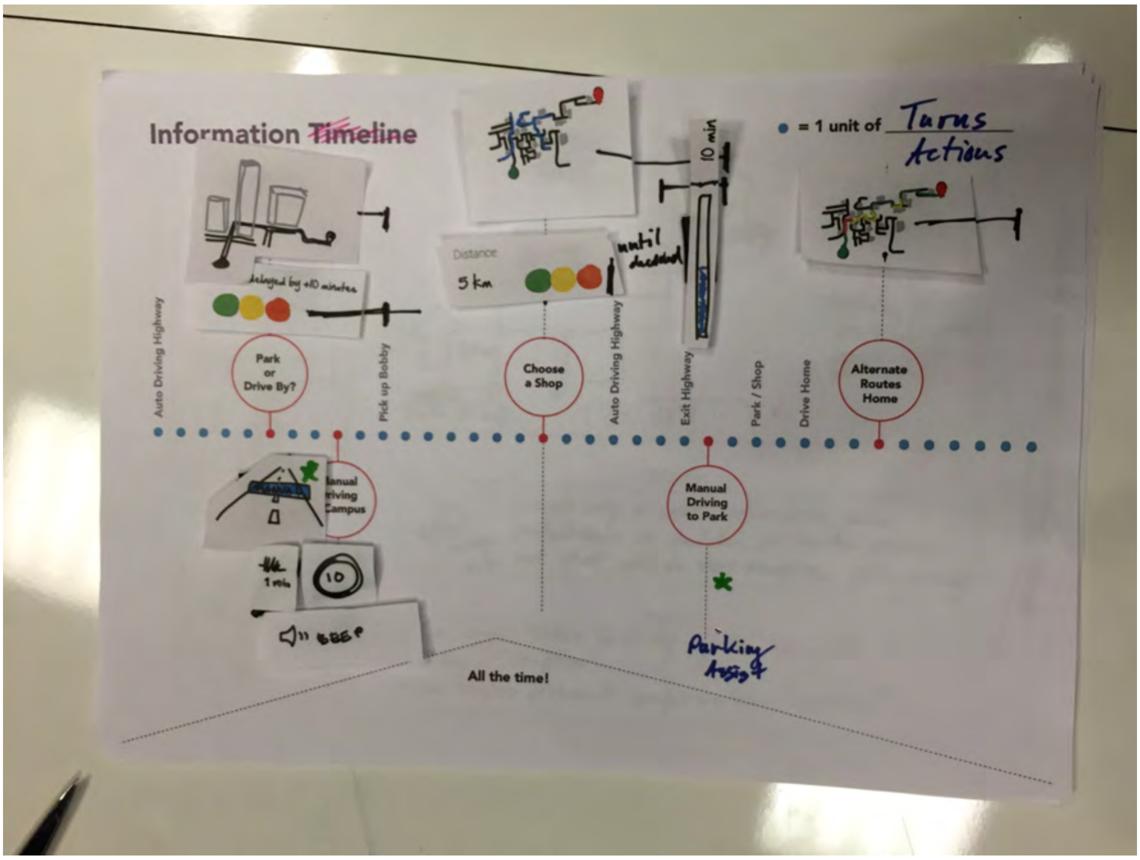


Figure 5.4: Example of a design timeline created by one participant on a workshop

made way to a design that we thought had potential to be a good manifestation of a well functioning navigation system for the context of use with support from the user research that we had done previously.

It was decided to create an integrated prototype that would be testable in a real-world driving scenario. The integrated prototype and its components are explained in the sections below.

The prototype explained below is what was used in the comparative study explained in the next chapter. Data and insights from the comparative study let us iterate on the design concept and refine it further. The changes made to the prototype and concept is explained in section 7.2.

5.3.1 Setup

The prototype consists of two parts, the screen and the remote (See fig. 5.5). The screen is intended to reside behind the steering wheel, straight in front of the driver. The remote is a touch surface meant to be placed at a position so that the driver can comfortably reach it while seated in the car.

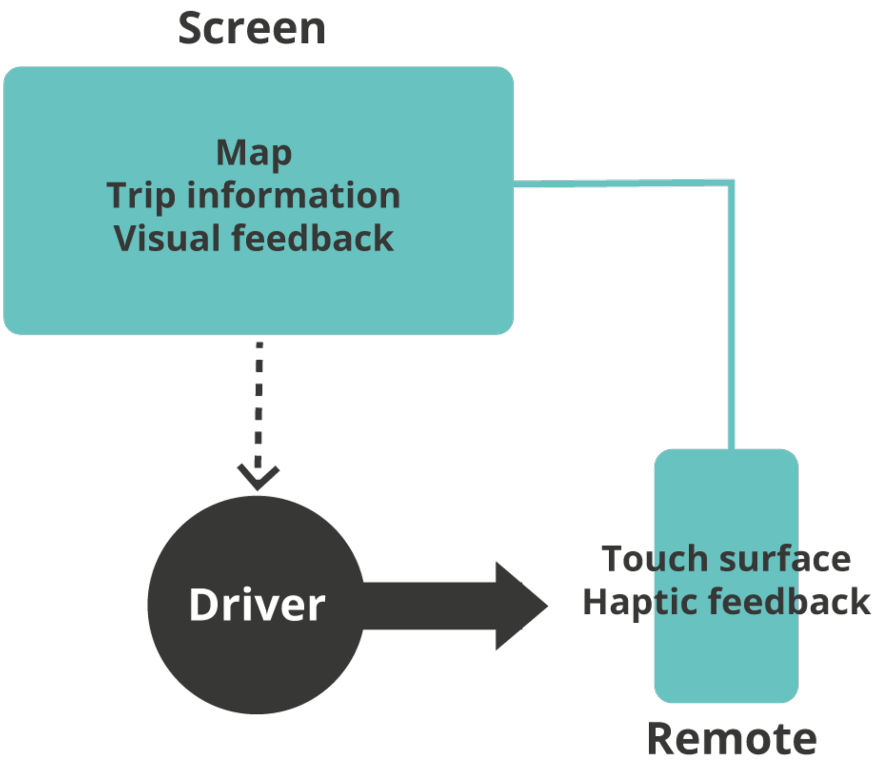


Figure 5.5: The prototype setup

The setup is adapted to a future where the driver has more free time to do other things than navigating. The driver might want to sit in a more comfortable position and focus on another task, but there is still a need for the driver to be in-the-loop and keep a track of what is happening. For these two arguments it was decided that the navigation system should have a screen that is close to the windshield to quickly be able to relate the interface on the screen to the environment. It was also decided that this would need to be controlled from an external control of some sorts.

5.3.2 Technical details

The final prototype was developed using Unity 3D and Mac OS X as the main software developing platform and XCode and iOS as the platform for the remote.

The map data was downloaded offline from openstreetmap.org, a crowdsourced mapping platform with the possibility to integrate the data into various systems. The data was used in Unity for rendering the roads in a three dimensional world.

The communication between the remote and the screen was done via Wi-Fi wireless technology and UDP connectionless communication using a protocol called OSC that is specifically adapted for real time applications. The remote sends both touch sensor data for gesture recognition, but also GPS data.

5.3.3 Remote

The remote is used to control the interface on the screen. It's controlled using gestures performed on the touch surface.

There are 7 gestures recognized by the remote: Swipe left, swipe right, scrolling up and down, pinching in, pinching out, tap and hold and double tap. Swiping left and right performs various actions. Pinching in and out changes the zoom level of the map. Scrolling up and down moves the "ghost car" to preview a route. Tap and hold confirms a destination change. Double tap cancels a destination selection.

The gestures were chosen to be forgiving and distinguishable so that it works with rough inputs in a bumpy car. The gestures were also chosen in regards to be able to mimic the motion of the interface on the screen, e.g. scrolling up and down moves the "ghost car" up and down.

The reason to use a touch interface instead of tactile buttons were that the touch gestures would allow for a wider variety of inputs on a smaller surface and that the touch surface could be reused for other systems in the car.

5.3.4 Screen

The screen displays all information about the current trip and provides the feedback and changes information according o the user input.

The screen is divided into two main areas of information: A top bar with static information about the current route and the map which displays contextual information. See fig. 5.6 for reference of the different parts of the system.

The map is essentially a standard road map but showing only the roads available for traveling by car, and grassland and water indicated by different colors. The map is oriented in a 3D based perspective view. On the map there are a certain number of destinations that are available to the driver to select. The current route of the car is represented with a turquise line that is drawn out from the start of the trip to the current destination. The current position of the car is represented as a 3d model of a car.

The top bar (5) displays the information of the current trip and destination: A representative picture of the destination, the name of the destination, the address of the destination, the time to get to the destination and the estimated time of arrival. The time to get to the destination is prioritized in terms of size and position. This is a consideration based on the survey results in the previous chapter.

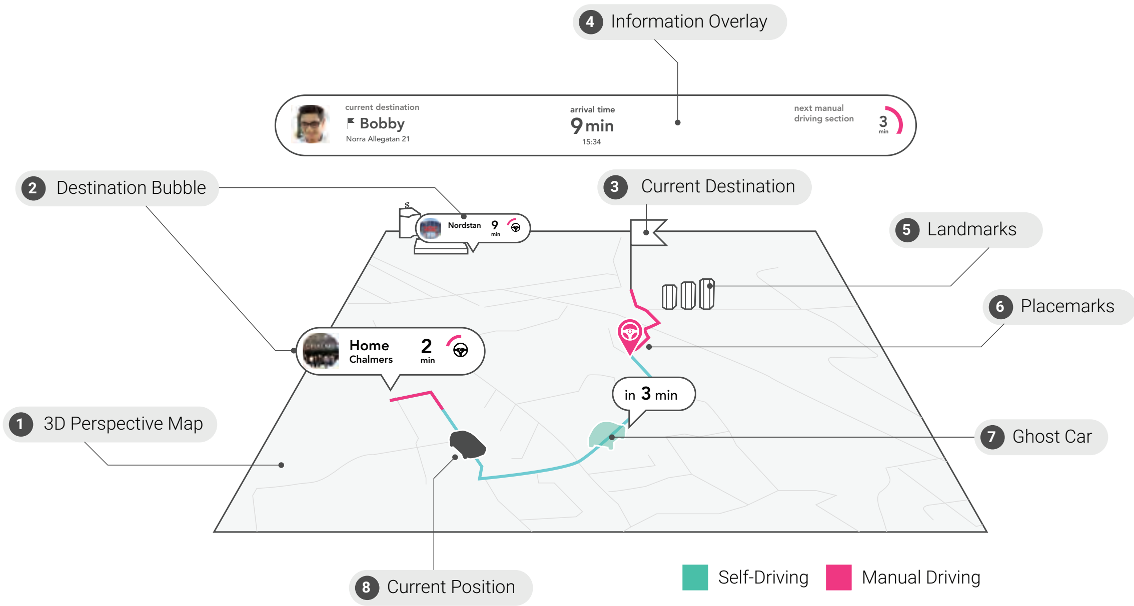


Figure 5.6: Components in the interface on the screen

5.3.5 The Ghost Car

By swiping up on the remote, the user is able to preview the future of the trip and how it will progress. The gesture would spawn a semi-transparent car that spawns from the current position of the car and follows the path of the intended route (2). The appearance and function of this "ghost car" as it will be referred to from now on is so that the user could perceive the function so as it would indicate a future self, meaning that in a certain amount of time the car would be at the position of the ghost car. Next to the ghost car there is information showing how many minutes it will take for the car to get to the current position of the ghost car. The ghost car is also used as a cursor to select where on the route it would zoom in.

The scrolling gesture was chosen for this action for it to create a one to one mapping of the motion of the gesture to the motion of the ghost car in the interface, with the intention of an intuitive interaction.

5.3.6 Current location

The current location of the vehicle is represented by a 3d model of a car that is visible on the map (3). The intention of using a car as the indication for current location was to enable the analogy of a future self in the case of previewing with the ghost car.

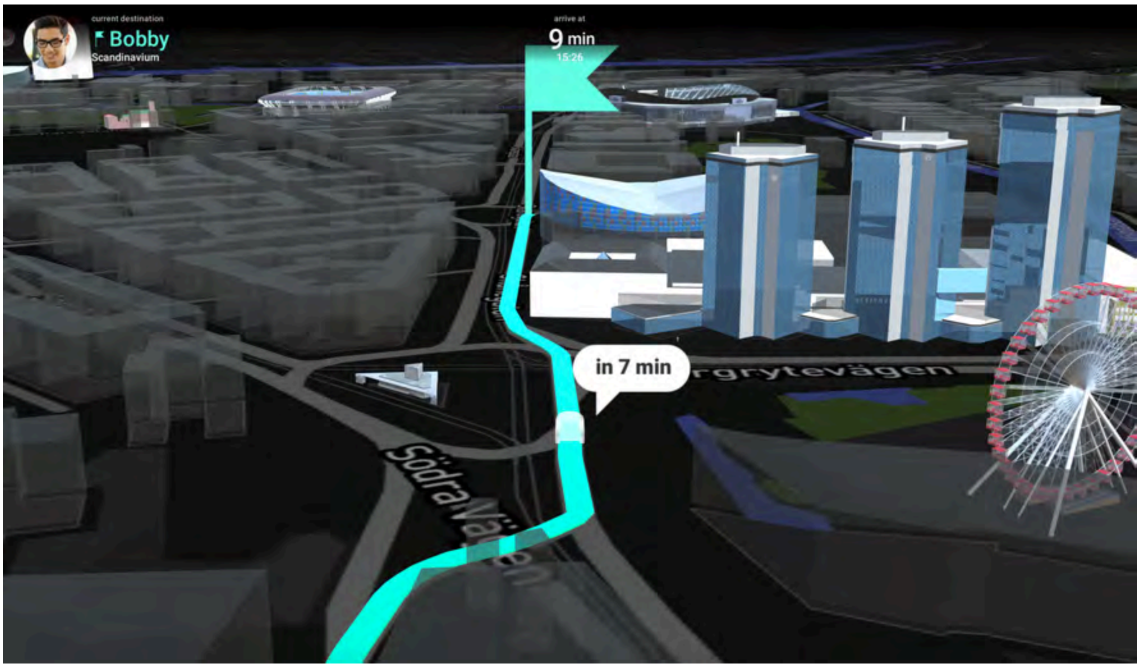


Figure 5.7: The zoomed in view of the interface screen

5.3.7 Choosing destination

Alternative destinations (4) that are available for the user is shown on the map as a "bubble" at the position of the destination. The current destination is indicated with a turquoise flag on the map and the information is on top of the screen. Swiping left or right on the remote will allow the user to preview alternate destinations.

The alternate destinations is thought to be pre-entered into the system. Entering destinations could be done on the users phone before entering the car or the system could intelligently guess based on your information where you would like to go. It could also be a separate system in the car that would allow for entering destinations. Entering destinations is not in the scope of this concept.

When previewing an alternate destination in the interface, the route that the car would take if it were to go there is indicated with a white line in addition to the current route (See 5.8).

If the driver would like the car to drive to the currently previewed destination he would tap and hold on the remote. This would make the turquoise flag appear at the new destination and the information in the top bar would update accordingly.

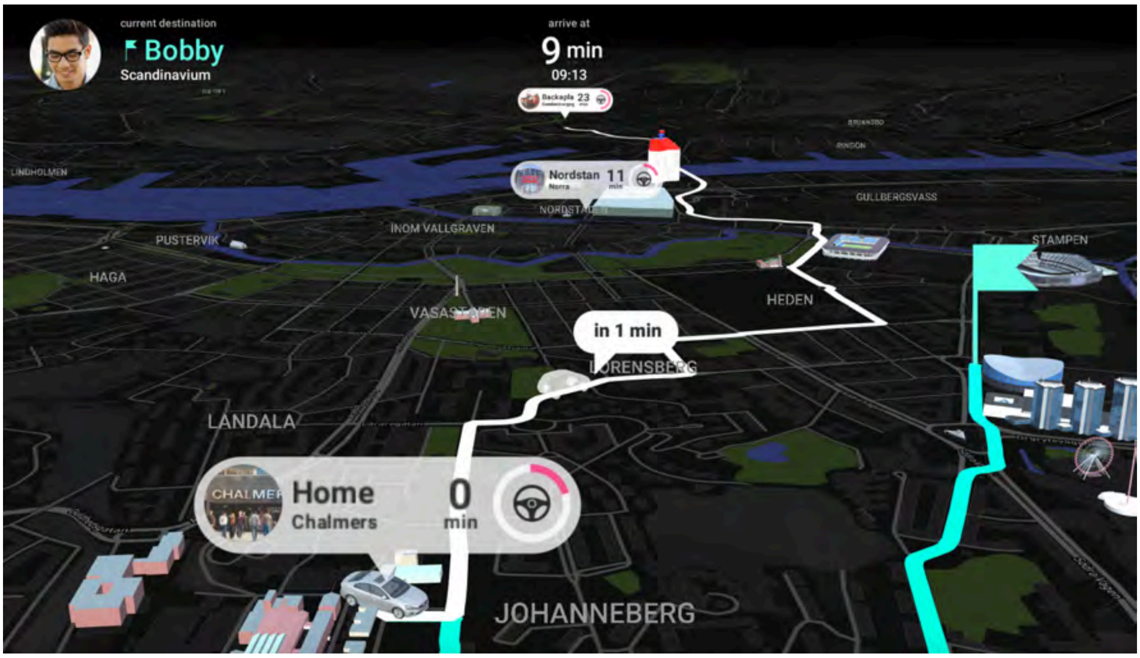


Figure 5.8: Previewing a destination.

5.3.8 Landmarks

On the 3d oriented map there are certain 3d modeled buildings placed out on the map (6). These are landmarks that the driver can use to relate the relative position. Using landmarks for navigation is supported by the multi-point anchoring theory described in the theory section.

5.3.9 Routes

The current route that the autonomous driving is currently driving on is indicated with a turquoise line drawn on the map. If there is a part of the trip where the driver needs to take over and drive manually this part of the route is marked with a pink line instead. The turquoise line will always be shown on the map while the autonomous driving is activated.

5.3.10 Placemarks

Certain route conditions that may be of interest for the driver is presented as placemarks on the route (7). The placemarks could indicate a traffic jam, construction or a point which the car would not be able to handle the autonomous driving but the drive would have to take over and drive manually.

5.3.11 Zoom levels

The map can be viewed in two different modes; a strategic view where the camera is further away from the road so that more destinations are visible and a tactical view where the camera is closer to the road and more context information may be displayed. In the strategic view the user is able to make strategic decisions, meaning that he will be able to select which destination that the car will go towards. In the tactical view he will be able to make tactical decisions that regards route changes and traffic situations.

In the zoomed out view the user can use a swipe left or swipe right gesture on the remote to preview how the car would get to an alternative destination.

When zoomed in to the tactical zoom level swipe left or right would be used for tactical decisions. This was not implemented in this prototype since it would not be used in the comparative study.

To switch between the strategic and tactical views the user needs to perform a "pinch" gesture on the remote by using two fingers in an outwards motion.

Golledge and Garling (2002) explains that there are two ways to learn an environment; by having an "overview" and by "experiencing" it. This served as a basis for adding two zoom levels. These are detail levels that are quick to switch between where the first zoom level, the "overview", gives a wider field of view and provides a long-term estimation, while the second zoom level gives a closer look at the immediate surroundings (which could be at a different place). The angle in which the world is viewed on the screen is also changed so that it reflects the purpose of the zoom level. The zoomed in view follows the direction of where the car is going while the zoomed out view focuses on the current destination.

6

Comparative Study

The goal of the third research sub-question is to investigate if a navigation interface employing information designed for semi-autonomous driving increases situation awareness. To answer this, we compare against a current baseline. The baseline of Google Maps was picked for two reasons: it was the only system which could most closely match the features provided in the concept interface, and it could serve as a baseline for future researchers to compare their own systems against. We performed an in-the-wild study comparing the concept we designed in the previous section to Google Maps. The results showed significant differences between the two system in terms of situation awareness and subjective preferences.

6.1 Process

The process for creating and working through the comparative study is summarized in figure 6.1. The experiment design consisted of several steps, starting with building the experimental setup in the test vehicle, creating appropriate routes for a balanced study, and recruiting participants via a website. Once the experiment design was complete, the first pilot studies were carried out, with intensive cycles of integrating feedback. Once the experiment started, all variables, prototype version, and experimental setup was locked down. The study lasted nearly 3 weeks and included 22 participants, with an average time per participant of 1.5-2 hours. The data from the experiment was analyzed with the aid of multiple professionals and researchers. Results include both statistical tests for quantitative measures and qualitative insights based on participant comments and observations. The most salient findings are presented in the results section of this chapter.

6.2 Pilot

A pilot study was conducted to inform about the design of the experiment and to gather feedback on the current prototype design. Four expert participants were recruited: a PhD studying interaction design within the automotive industry, a industry researcher with a background in automotive interaction, and two consultants

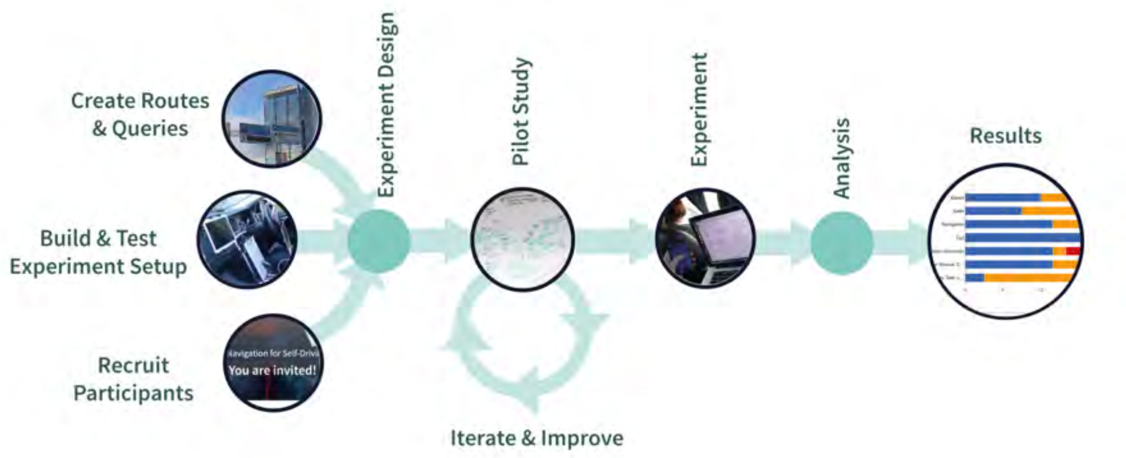


Figure 6.1: Process diagram for comparative study

with experience in designing interfaces for semi-autonomous vehicles. The main feedback concerned the experiment design, which was originally structured using a SAGAT task interruption called a freeze (Endsley, 1995), which was placed before a supposed transition to manual driving. This caused a number of issues for participants, and was thus changed to a real-time probe methodology. This change also worked well in combination with another suggestion to use think aloud as a method to gather more user experience insights. Due to the high novelty factor of both the environment and the interface, all participants felt they needed more training. As a result, a short warm-up round was added at the very start of the experiment to introduce users to the context and experimental procedures. In terms of prototype feedback, participants found it highly intuitive and fast to learn. However, some revisions were made to the remote interface gesture set, mainly 'cancel' gesture which was changed to a double tap based on previous research findings (Hammar and Karlsson, 2015), and the select gesture for which the hold time was reduced to 1 second from 3 seconds. Some participants reported a weak link in the information presented in the map to the information presented in the static overview in the top of the interface. To address this, the coloring of the current destination was updated to match the coloring of the information in the overview area.

6.3 Participants

We recruited 22 (8 females) participants with valid driver's licenses aged between 21 and 36 (mean 26.8, s.d. 4.7) from local universities and industry. Participants had background included 8 interaction design master students, 3 automotive engineering master degree students, 4 students from an engineering background, and 2 professional researchers studying interaction in the vehicle automation domain. Additionally, participants reported their driving frequency (7 weekly, 5 monthly, 12 yearly) GPS usage (7 never, 4 usually, 8 in new areas, and 3 for long trips) familiarity with self-driving vehicles (6 not familiar, 11 somewhat familiar, 5 very familiar) and familiarity with ADAS systems (6 not familiar, 13 somewhat familiar, 3 very familiar). All participants received a movie ticket as compensation for their time.

6.4 Apparatus

In this wizard-of-oz experiment, a special right-hand drive Volvo V40 provided by Volvo Cars was used as the make shift semi-autonomous vehicle. Within the vehicle, technical equipment was mounted and distributed as shown in figure 6.2. The technical components components consisted of:

1. Tablet Display: Samsung Galaxy Tab 10.5 SM-T800 (2560 x 1600 resolution) running Android 6.0, with the following software: Google Maps version 9, Twomon version 1.1.

2. Remote Input: iPhone 6 running iOS 9.3, running the FutureNav Remote application.

3. CPU: Macbook Pro Retina running OSX 10.11.4 with the following software: FutureNav, Twomon version 2.0.42.

4. Immersion Cloth: A black cloth installed between the driver and passenger in the shape of a triangle measuring 37cm wide by 28cm tall.

5. Additional Equipment: USB cabling between tablet and cpu, power supply for the cpu, and usb cables to charge all components during the experiment. GoPros were installed for only some participants and are not part of the core setup or analysis.

6.4.1 Environment and Routes

The experiment was conducted in-situ, set in the city of Gothenburg, Sweden in the area of Chalmers University main campus. An in-situ environment was chosen based on a number of factors as related to our main study objectives: the ability to compare to a real GPS system such as Google Maps, higher believability in the experiment tasks.

The routes were carefully designed to include a similar characteristics in terms number of turns, time to complete, urban density, landmark visibility, and distances to the displayed destinations on the map.

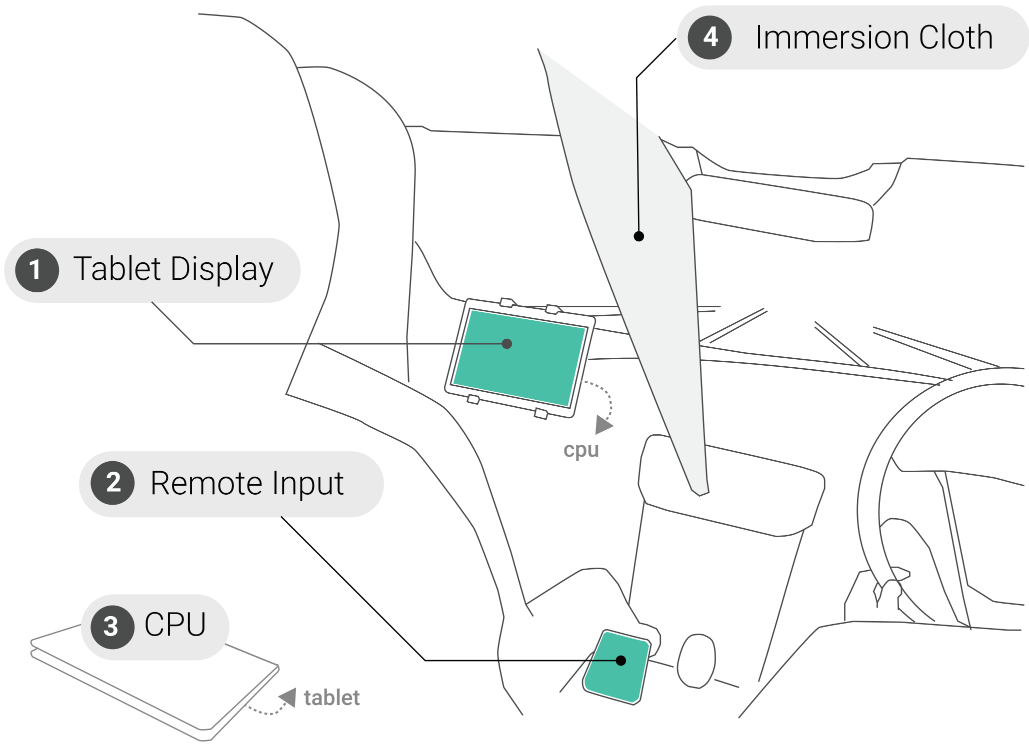


Figure 6.2: The components of the experimental setup

6.5 Design and Procedure

The goal of the experiment was to evaluate map navigation in terms of user experience and situation awareness for semi-autonomous vehicles set in the city. The experiment was a within-subjects comparative study with a single independent variable, the *Navigation Interface*. This variable had two levels: FutureNav as the new concept to be evaluated, and Google Maps, which serves as the nearest comparable baseline. The design uses a full balancing of each condition between the two routes in order to minimize learning effects.

Each participant was introduced to the experiment with a brief overview of the tasks they would need to complete, a tour of the vehicle, the expectations of the study, and were told they would not need to drive at all during any time. After this, a short questionnaire on their background was administered and the experiment began. Before any conditions were instructed on or tested, each subject was given a short warm up ride in the vehicle to familiarize themselves with the environment and the experiment. This practice round lasted between 1 to two minutes, used no navigation interface, and took an established, looped route near the starting location. During this time, a representative question was asked similar in nature to the questions asked in the full route.

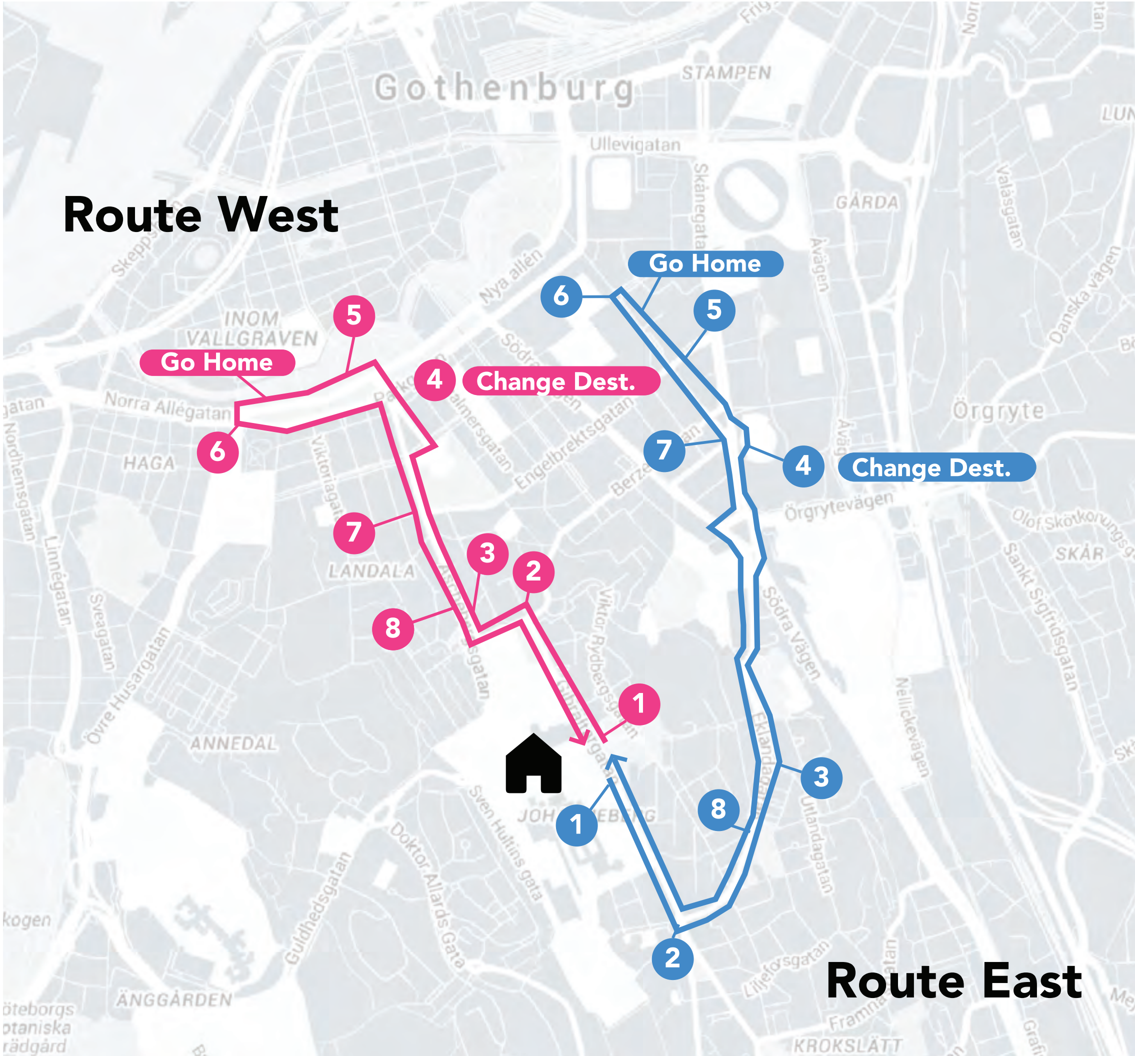


Figure 6.3: The two routes used, displaying the points at which questions were asked, and the points where the tasks were given.

Next, each participant was assigned their first test condition based on the balancing of routes and order.. After this, they received a set of instructions on using the interface assigned to the current condition. The instructions given covered the features across the two interfaces in exactly the same manner, despite some of the participants being very familiar with one of the conditions (Google Maps). It was communicated that using the interface to answer questions during the scenario was optional and up to each participant. To end the training, a scenario was provided which motivated the tasks that lay ahead in the route. The scenario tasks, routes, and questions are described in further detail below.

After each condition, participants filled out a Sustained Attention to Response (SART) questionnaire, followed by a System Usability Scale (SUS) questionnaire. After both conditions were complete, a direct comparison questionnaire was filled out, followed by a semi-structured interview where participants could explain their answers. All questionnaires were prefaced with the line "..in the context of semi-autonomous driving" to encourage feedback based on the desired scenarios and contexts.

6.5.1 Scenario and Tasks

The scenarios were constructed using the same foundation as used in the survey scenario; having to visit multiple destinations in a dense urban environment. There were two scenarios with similar characteristics. In the first scenario, participants were told to navigate to pick up their friend. After this, they could select from two nearby shopping location based on their own preferences. On the way there, they would be told to turn around and go home. In the second scenario, instead of shopping locations, they would choose from two nearby churches, again based on their own preferences. The selected destinations did not affect the routes in any way, as they were designed to have overlap up until the point of receiving instructions to go home.

6.5.2 Measures

Eight questions were formulated based on the SAGAT queries generated for each of the routes (Table 6.1). Each question targets a specific Situation Awareness level aimed to assess a participant's perception (SA1), comprehension (SA2), or projection (SA3). In addition, the questions are centered around the concept of visiting multiple destinations and the information that would be required to do. The answer to each question is evaluated based on a pre-defined scheme, which was generated by driving through the routes several times and measuring the correct answers as well as time to answer. The time to answer is measured by a stopwatch application, where the timer is started as soon as the question is verbally administered, and the timer is stopped as soon as the participant gives the correct answer. Only questions which are answered correctly count towards the results.

During the experiment, participants were encouraged to speak out loud, and comment on their ongoing experience. This data was collected in the form of participant comments for later analysis. In addition, each participant was asked if they answered the question with or without the help of the interface. Due to the time sensitive nature of the route design, the interface usage question was sometimes skipped in order to ask the next question in the sequence at the appropriate time.

Question	SA Level	Motivation
Q1. What is the distance the next turn?	Comprehension	Visual distance estimation.
Q2. In which direction is our current destination?	Comprehension	Spatial orientation.
Q3. How long until we reach (landmark)?	Projection	Accurate time estimation and previewing.
Q4. What is the name of the area on your left?	Perception	Landmarks and precise map placement.
Q5. How long would it take for you to reach (other destination)?	Projection	Visiting multiple destinations.
Q6. How long until we get Home?	Projection.	Orientation and time estimation.
Q7. How long ago did we pass the last intersection?	Comprehension	Information prioritization.
Q8. Which way should we turn next?	Perception	Preparing for takeovers.

Table 6.1: Situation Awareness questions and their assessment motivation.

6.6 Results

6.6.1 Situation Awareness

The first aspects in the data to be analyzed are the real-time probe results. Figure 6.4 shows the comparison in performance of the interfaces in terms of mean time to answer and accuracy for each question. SA analysis normally combines SA level questions together, however, due to the high variances in mean answer times between questions, we will analyze each question separately.

Time
Mean time to answer across all questions was 5.6 seconds for FutureNav ($SD = 3.2$) and 7.6 seconds ($SD = 4.5$) for Google Maps. Paired t-tests for each of the real-time probe questions revealed a significant effect in mean answer times (in seconds) of Q1 ($t = 3.44$, $df = 4$, $MD = 6.48$, $p = 0.026$) where Google Maps ranks better than FutureNav. This can be explained by the fact that FutureNav does not have facilities in it's interface to answer this question regarding distance.

Significant effects were also found in Q2 ($t = -2.54$, $df = 20$, $MD = -3.50$, $p = 0.02$), Q3 ($t = -2.67$, $df = 8$, $MD = -6.64$, $p = 0.028$), and Q5 ($t = -10.96$, $df = 16$, $MD = -12.61$, $p < 0.001$) where FutureNav ranks better than Google Maps. Questions 3 and 5 deal with time estimation where FutureNav provides the ghost car tool for assistance. Question 2 deals with spatial orientation, where FutureNav provides a 3D interface which is always oriented towards the destination.

Accuracy
Accuracy across all questions was 76% ($SD = 0.3$) for FutureNav and 80% ($SD = 0.2$) for Google Maps. Significant effects were also observed on the mean accuracy

of Q1 (t = -3.25, df = 21, MD = 0.41, p = 0.004) where Google Maps ranks better than FutureNav. Here, we offer a similar explenation as for the time variable. On the other hand, FutureNav ranks better than Google Maps in Q5 (t = 2.49, df = 21, MD = 0.429, p = 0.021) where the interface always displays time to reach for all available destinations on the map.

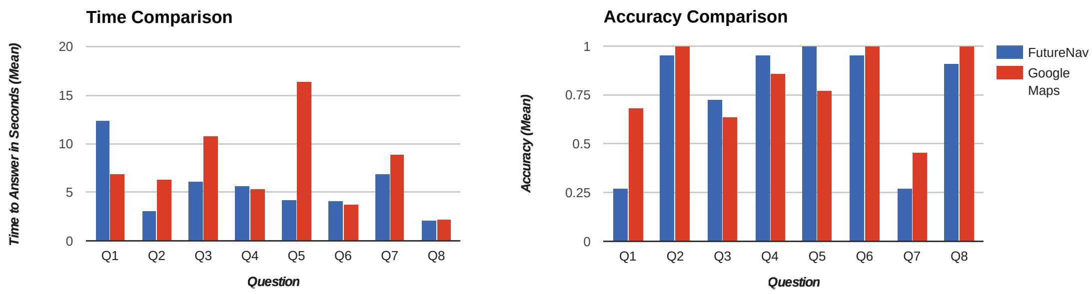


Figure 6.4: Comparing FutureNav with Google Maps: Mean answer time (in seconds) on the left, and Accuracy on the right.

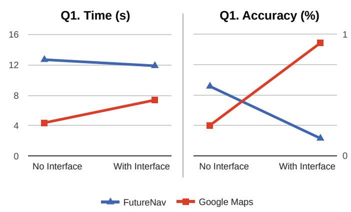
Interface Usage
Interface usage ("Did you use the interface to answer the question?") was recorded for each question, with either a true or false value. Data collection rate across all questions was 90.9%, and by condition, 94.9% for Google Maps, and 86.9% for FutureNav. Interface usage for recorded values was 61.3% across all questions, 60.5% for Google Maps, and 62.1% for FutureNav.

Interface usage was analyzed individually for each question, showing how it influences accuracy and time to answer for each condition. Statistical analysis was not performed on the interaction effect due to the softness of the metric. Future studies could use gaze or touch input to recover better measurements of interface usage. The results of this analysis are visualized as graphs in table 6.2, and are further analyzed individually per question.

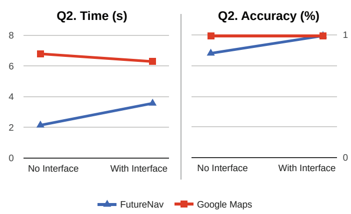
6.6.2 Subjective Measures

SART and SUS Questionnaires
The 3 types of subjective measures used during the study are analyzed in the following section. In the SART questionnaire, FutureNav scored of 19.32, while Google Maps scored 17.36. A paired t-test was performed on these results, but showed no significance. SUS results were 79.1 for FutureNav, and 72.9 for Google Maps.

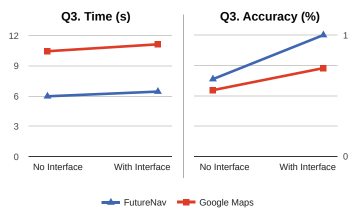
Comparison Questionnaire
The last questionnaire asked participants to directly compare the 2 systems on a number of factors, the results of which are displayed in Figure 6.5. FutureNav was the preferred system for all criteria, particularly in enjoyment (19:0), navigation (14:4), visiting multiple destinations (14:6), preparation for manual driving (14:1),



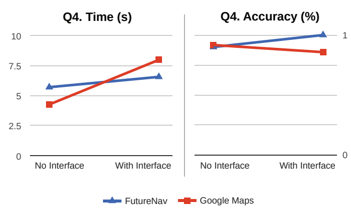
Q1. What is the distance to the next turn? The advantage of providing the distance information is evident in the accuracy plot, which shows a high increase in accuracy when using the interface for Google Maps, and a decrease in accuracy when using an interface that provides only visual distance information.



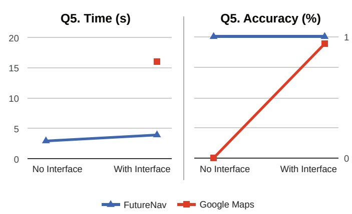
Q2. In which direction is our current destination? Using the interface costs just under 2 seconds to orient in the case of FutureNav, and is negligible in Google Maps. Both conditions exhibit near perfect accuracy, hence there is no effect here of interface usage on accuracy.



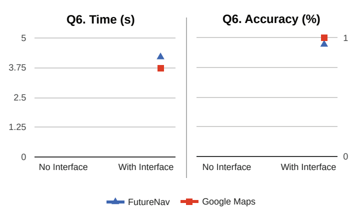
Q3. How long until we reach (landmark)? No interaction effect can be observed in answer times, however, using the preview function in FutureNav increases accuracy by 37% (to 100%), while not having a tool to estimate time increase accuracy by 18% (to 73%) in Google Maps. This is approximately a two-fold increase in accuracy.



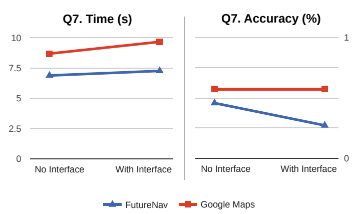
Q4. What is the name of the area on your left? Time to answer increases with interface usage for Google Maps, while staying constant when using FutureNav. The interface of FutureNav displays recognizable landmarks with labels, while Google Maps only provides labels. The accuracy of Google maps decreases 5% with interface usage while it increases by 10% in the case of FutureNav.



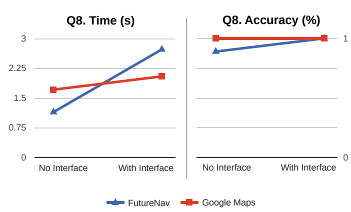
Q5. How long would it take for you to reach [other destination]? No interaction effect can be observed for time to answer, and no participants could answer the question without the support of the interface in the case of Google Maps. Using the interface in the case of Google Maps increased the accuracy to 100%.



Q6. How long until we get Home? No participants attempted to answer the question without the support of the interface. Results are comparable for both systems.



Q7. How long ago did we pass the last intersection? There is an interaction effect in terms of accuracy in the case of using the interface in FutureNav. This may be because FutureNav does not provide a backwards time estimation tool, and thus the question itself may be confusing to participants.



Q8. Which way should we turn next? An interaction effect exists in time to answer, where the differences are 1.58s and 0.3s increases in answer time for FutureNav and Google Maps respectively.

Table 6.2: Interaction Effect of Interface Usage

and ease-of-use (12:5). Participants were not sure which system is safer (11 ties), and which system allows for better secondary task usage such as using a phone (17 ties). Furthermore, each participant could write a comment for each criteria, on why they chose one over the other.

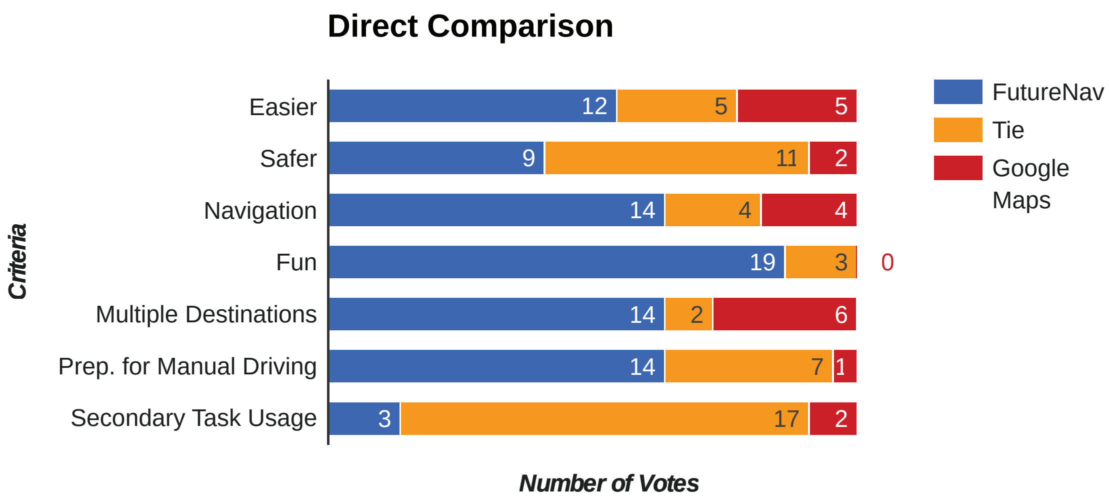


Figure 6.5: Comparing the participant preferences between FutureNav and Google Maps.

Ease of Use: Participants favoured FutureNav because it was "more specific to the task", whereas many people reported they very familiar with Google Maps and thus find it easier to use.

Safety: In terms of safety, most people agreed that "Both of them get the job done, so they should be equally safe.", while some participants commented on the effect of divided attention: "The first one [FutureNav] is safer because it took less time to change and during that time I am more focused on the screen than on the route".

Navigation: The navigation support offered by FutureNav was preferred for a number of reasons pointed out above, and best summed up as "Better overview of the whole situation", while some participants thought the depth of available information in Google Maps is better "Google offers information if you want to get it.".

Enjoyment: The high enjoyment factor was most commonly attributed to the novelty of the interface, in particular the ghost car feature: "The interface looks nicer and there are a few novel features like the ghost car.".

Multiple Destinations: On visiting multiple destinations, participants were more divided than the numbers suggest, with the main influencing factor being the number of destinations to choose from: "If there were a lot of destinations, then maybe its better to use Google Maps because the list is easier. But if the system is smart then it can manage it.".

Manual Driving Preparation: Participants felt that FutureNav prepared them better for manual takeovers party due to the 3D View that "Could go into that mode where you are facing the same direction as the car". Participants also found salience in the color coding of the route: "Nice with color indication (for manual driving)".

Secondary Task: Many participants found this questions confusing. This was perhaps a poorly worded question, since performing a task while in autonomous mode would imply that it should be a primary task. One participant observed that "My attention is split, so I would have to direct my attention to 2 devices [FutureNav]. With Google Maps you just touch it."

6.6.3 Participant Comments

Participant comments were gathered through several avenues: transcribed think-aloud comments made during the experiment, written feedback from the questionnaires, and transcriptions from the post-experiment semi-structured interview. Presented below are themes extracted from the comments:

Interface Features and Control
The first thing many participants noticed is the separation of the input and output devices. This yielded comments regarding the ease-of-use, specifically in the context a moving vehicle: "With Google Maps I can't tap certain things. If its bumping sometimes I cant hit it.".

The size of the tablet display in both systems created some attention blindness, particularly towards the corners: "Since its bigger, I didn't notice the information in the corner. I was just paying attention to the map, the road". Many participants exhibited a strong preference towards information embedded in the map versus information contained in static overlays, and would look there first as an instinct: "The placement [of the static overlay] is good, but you're focused on the map, so its easy to miss it or forget. I looked for the bubble first. It wasn't there."

As a whole, we observed a high variance in questions which asked for time estimation. Some users were not naturally good at time estimation, and thus appreciated the ghost car tool: "I generally feel I don't have a good perception of time. I'm happy if I can get some technical support.", and "The ghost car is helpful for projection".

Distances to locations were on the whole less needed, with several participants noting that an autonomous car should be able to handle these type of calculations: "If I trust the car, then I wouldn't care about the distance". This implies that the need for distance information decreases as trust in automation increases.

Visual Components of the Interface
Regarding the visual components of the interface, in most cases, participants showed a strong preference for the 3D map representations of FutureNav over the 2 dimensional top-down view of Google Maps: “The Birds-eye view by itself helps a lot, it shows the destination, and the next crossing. I can see a building I recognize and it gives me a feeling of where I am."

The combination of the 3D view with the ghost car tool, allowed participants to ‘experience’ future points in the map “You get a view of what you should see at some point, seeing it as you would in driving", and “I prefer FutureNav for the graphics because it was more realistic for the buildings. You can more easily assimilate the real thing that you see outside."

There was a strong tendency in participants to lock in on their preferred viewing angle throughout the journey. One participants said they would value a system that can switch contextually in some situations: “In the city I want more zoomed in so I get better information about what the car is planning.".

The top-down view of Google Maps was more useful in estimating distances visually than the perspective view of FutureNav: “In FutureNav, to go to [destination] it took 23 minutes, meanwhile on the map it looked like a lot less. With Google Maps it is easy to estimate the distance."

Patterns of interface use
Two interesting patterns emerged regarding modes of interface use. One frequent way to use the interface was to get confirmation for information that the participant already knew. In these cases, the interface is used to verify and increase the accuracy of known information: “I know Svenska Messan starts over there, I tried to look at the map to see if it’s the same building or another building".

Participants also liked to preview and memorize the route ahead. This could be done in one of two ways, studying the information before the trip or through the use of the interface during the ride: “I remembered how many turns there were on the route, because I was zoomed in".

Overall Experience

The final comments section summarizes reflections on the study itself, and new ways of thinking about navigation interfaces in semi-autonomous cars. Most participants agreed that the experience of being in a semi-autonomous vehicle was reasonably well simulated, specifically commenting that “The immersion cloth did work in some way", and “It felt a little bit autonomous".

Feedback regarding the driving style included comments on trust: “When we waited at the crossing here, you can feel the car wanted to go, I think an autonomous car would decide to go and just go.".

The lack of steering wheel was perceived as normal by some, while at the same time, this created a new kind of setting where the navigation interface functioned as direct control to the car: “The car starts driving as soon as you set a location. Its very effective, but then you feel less in control".

Although not investigated in this thesis, trust issues cropped up frequently if the car deviated from the route shown on the map. We noted 2 different attitudes, one of close supervision: “If it doesn’t do as I told it to that would probably freak me out. I would think that something is wrong with it. I would try to take over.", and another in showing trust: “If its rerouting correctly its fine by me, sometimes its impossible to make a turn at some point. It depends on where you are."

6.7 Discussion

Looking at the quantitative results, we see that FutureNav is on average 2 seconds faster than Google Maps and 5% less accurate. It is difficult to conclude whether or not this is due to the usage of the interface or not, however, table 6.2 provides some clues. If we assume the null hypothesis, that SA levels are the same for both interfaces, then ‘No Interface’ should have an identical or similar response time and accuracy. However, there are surprising results which show the opposite. In question 1, without the use of interface support, FutureNav shows 32% higher accuracy than Google Maps, despite that we have shown Google Maps is significantly more accurate when using the interface. In question 2, when looking at only the no-interface usage, there is a large separation of 4.65 seconds in mean answer times. This indicates that FutureNav provides better spatial orientation (SA Level 2: Comprehension). In question 3, there is a difference of 4.46 seconds in time to answer, meaning FutureNav allows participant to estimate time faster without the use of an interface (SA Level 3: Projection). In question 5, we can make no inferences about projection since only one participant did not use the interface to answer the question. The interaction effects are analyzed in more detail in the table themselves, but already we can see the benefit of measuring interface usage during situation awareness testing. While interface usage may not provide hard evidence regarding the system itself, it starts to reveal inconsistencies and highlights features of the interface that could be responsible for increasing situation awareness.

The qualitative data gives us insights on the differences in performance between the two interfaces. In particular, we can see that the SART results show that FutureNav is indeed better (although, not significantly better) than GoogleMaps. Making claims based on the real-time probes as a single measure of situation awareness may difficult, however, with in combination with the SART result, we can be more more confident in our results.

The participant comments serve two purposes. One, they explain some of the quantitative results, in particular, there are good points made regarding time estimation and spatial orientation, two key aspects that link navigation and situation awareness. For example, the ghost car was valued positively as a time estimation tool, and 3D landmarks, combined with a destination facing viewpoint helped participants in answering SA queries faster. The participant comments also reveal new facets related to navigation interfaces for semi-autonomous cars. We find that there is a wider spectrum of usage than simply yes or no, where the interface can be used to confirm or pre-memorize certain sections of the route. More importantly, we received valuable feedback regarding the use of the interface as main nexus of control between the driver and the participant. These comments hint at the deeper complexities of using a navigation interface to actually steer a car. How does one trigger an action? When does the action begin? What happens if the car cannot follow a route? How and when should the car alert me if it cannot follow the said route? We do not address these questions in our evaluation, however, they are valid questions raised by our participants as a result of the scenario and context of the experiment.

6.8 SA Aspects of a Navigation Interfaces

By linking together the quantitative results of the real-time probes with the qualitative results of the participant comments, we attempt to answer research sub-question 4: Which aspects of the navigation interface concept raise situation awareness?

Let's focus on SA question 2: "In which direction is our current destination?". This is the strongest candidate in revealing these connections at the comprehension SA level. First, it has been shown that the mean answer time is significantly shorter in the case of FutureNav, and focusing in on the 'No Interface' answer time only widens this gap. We see from the chart that the it takes over 3 times as long for participants to respond to the question in the case of Google Maps. From this we can infer that FutureNav is increasing the orientation ability of participants, and it is doing so in a 'passive' manner, without the need to refer back to the interface to answer the question. According to the qualitative data, this can most readily be explained by the 3D viewpoint that always keeps the destination visible on the map in strategic view mode. In addition, since the destinations are placed in relation to landmarks, a participant only needs to know the direction of a landmark to be able to answer the question. Thus, the FutureNav interface provides 2 alternatives that enable orientation without interface usage. This process can also be intuitively explained as the opposite of dead-reckoning, requiring as little orientation and triangulation on the users part as possible.

At the projection level, questions 3 and 5 (How long until we reach (landmark, other destination)?" both show significance, and can each be linked to a specific feature in the interface. We can see that the ghost car, which was most often used in question 3, has a very low cost-of-use, but provides tangible benefits in terms of accuracy. Because of the novelty and enjoyment of the feature, participants frequently used the ghost car before actually being asked the question on time of arrival. Thus, they were able to answer question 3 much faster than participants using Google Maps. Showing multiple destinations on the map was hypothesized to assist projection ability. This could not be answered by question 5, and despite the strong significance in answer time, we conclude that the time advantage of FutureNav is due purely to the speed of using the interface. It should be noted that we also found no evidence of increased SA level 1, perception, which is a logical given the focus on providing long term information for strategic navigation.

To summarize, there is strong indication that speed of orientation ability, speed of spatial awareness, and accuracy in projection ability can be increased by designing navigation interfaces incorporating the corresponding features described by FutureNav.

7

Designing Navigation Interfaces for Semi-Autonomous Vehicles

7.1 Discussion

In the closing discussion, we restate the initial research questions, summarize our findings with references to previous sections and figures, and suggest how our findings can be used by future researchers and designers. Our primary research question was:

How can we design a navigation interface to support strategic level situation awareness during semi-autonomous driving?

This was further split into 4 sub questions:

- What are the associated navigational information needs of drivers in this mode?
- In which scenarios of the future are drivers likely to use this type of navigation interface?
- Can we design and build a navigation interface that raises situation awareness when tested under common usage scenarios?
- If so, can we identify aspects of this interface which raise situation awareness?

7.1.1 Challenges and Opportunities

To address our overarching research question, we identified a main challenge, *keeping drivers in the loop*, and an opportunity, *providing valuable information to drivers*. In looking at the literature, we identified a gap in strategic level control, and situation awareness at the comprehension and projection level. By providing this kind of information, we could prepare drivers 'in the long term' so that they could still meet their navigational goals. In addition, they would still have information about the current situation, such as heading, and the names of the areas or landmarks which are surrounding them. Rather than focusing in on any particular feature which enhances only a single type of information, we built a navigation interface which is from the ground up designed to function primarily during semi-autonomous driving, and provides information according to the current trip purpose.

7.1.2 Information Needs for Semi-Autonomous Driving

To answer our first 2 sub-questions regarding the information needs of drivers, we investigated likely scenarios of semi-autonomous operation. Scenarios were built-up from literature (Mackett, 2003; Krumm, 2012), future trends (Arthur D Little Future Lab, 2013), and ethnographic studies, resulting in the concept of the *Trip Purpose* centered , non A-to-B type city driving scenario (see fig. 7.1). The most common trip purposes are *Social*, *Shopping*, and *Home*. We envision that this scenario is fully re-usable under future studies examining semi-autonomous driving in the city, and we further argue that our methods can be used to create new scenarios for contexts which fit the object of study. In a more current example, Google Maps has very recently added a feature which allows users to add multiple destinations to a single trip (see fig. 7.2).

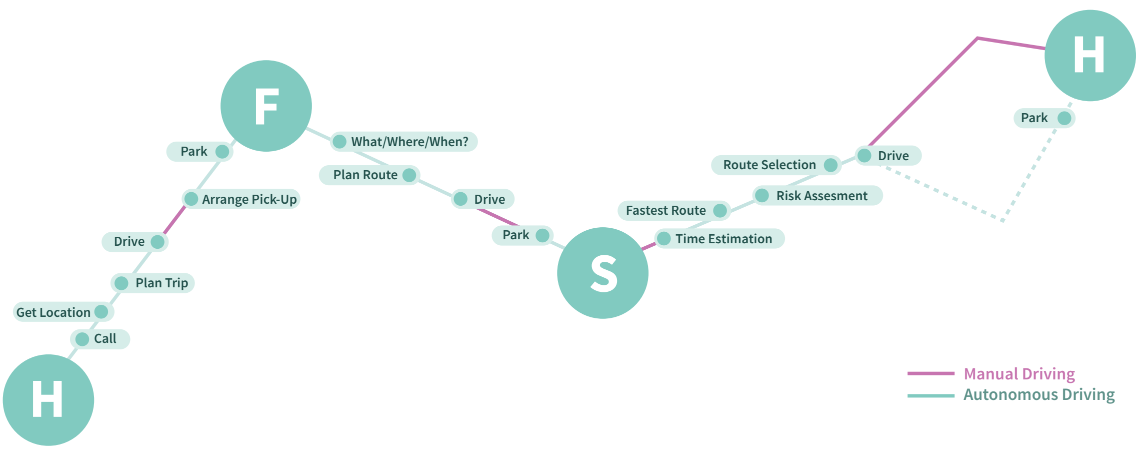


Figure 7.1: A dynamic city type scenario constructed to test navigation interfaces for semi-autonomous vehicles. H = Home, F = Friend (Social Trip Purpose), S = Shop (Shopping Trip Purpose). Manual driving sections are represented in pink.

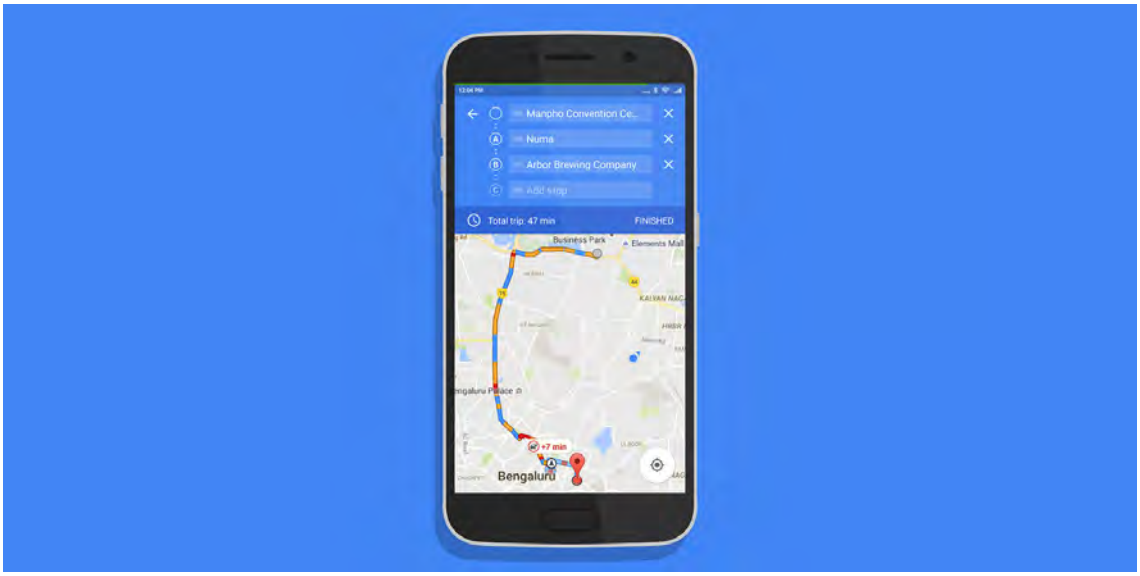


Figure 7.2: Google Maps Multi-Destination Trips Feature

Based on a 3-stop *Trip Purpose* city driving scenario, we investigated navigational information needs under semi-autonomous driving conditions. The results of a 50-person online survey showed 4 primary information need categories: *Time*, *Trip Conditions*, *Self-Driving Parts*, and *Location*. On their own, these results may not be too interesting, however, we further break them down into specific information types (see fig. 7.3), for example, differentiating between estimated time of arrival, and time remaining; distance to location, and location on a map, etc. We also show that these information types vary by trip purpose.

This information may be useful for a future interface designer who may choose to show the information type which is accepted in the *most common* use-case (i.e. static interface), or the information type which is the *best-fit* for a particular trip purpose (i.e. adaptive interface). In our evaluation of FutureNav, we have to implemented using the *best-fit* method, with the caveat that the scenario itself is static.

7.1.3 Navigation Prototype

In following a research-through-design methodology Zimmerman et al. (2007), we created a prototype-artifact (FutureNav, as shown in fig. 7.4), which satisfies 2 requirements: 1) a fully realized tangible representation of the knowledge gained from studies and evaluations, and 2) a fully working and testable interface that can be used to evaluate that knowledge. FutureNav implements 3 key features which are representative of the knowledge gathered in the information needs studies and co-design workshops, and are further refined based on the findings of the evaluation. The first feature is a *Ghost Car* which is able to traverse upcoming trip areas along the line of travel. Again, this feature has also recently appeared in Google Maps,

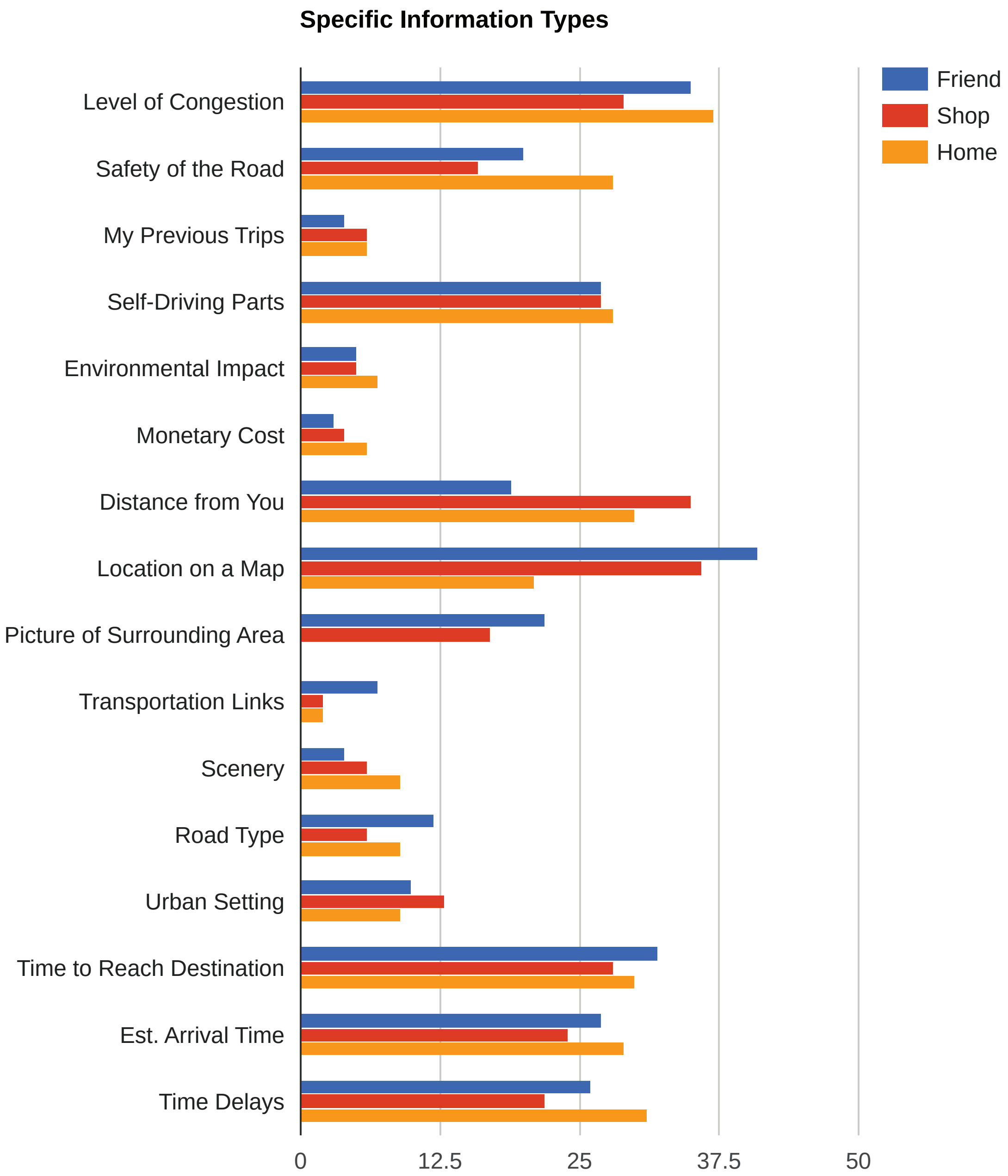


Figure 7.3: Specific Information Types

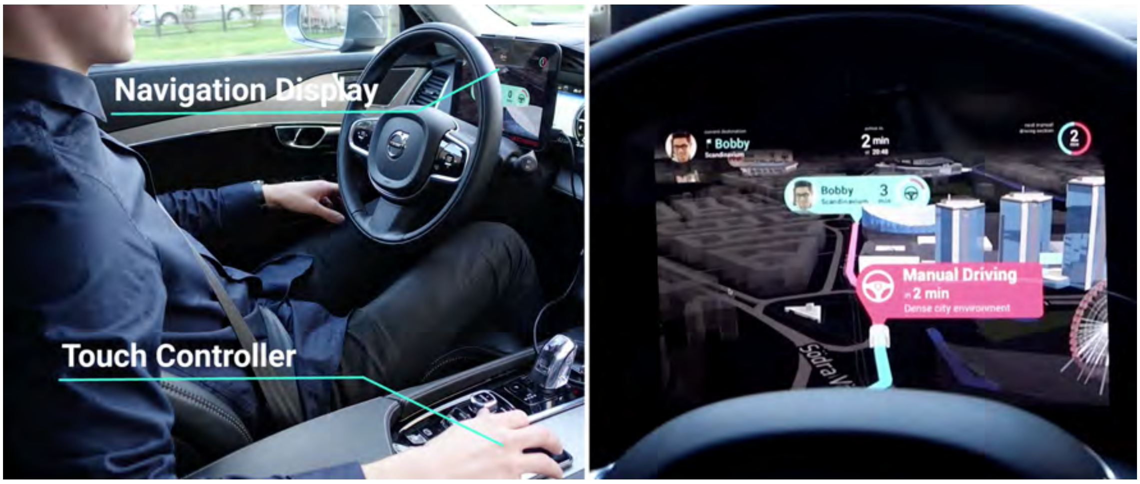


Figure 7.4: FutureNav: The working prototype interface. On the left is the layout, including the remote input. On the right, an example of what the driver sees.

however, their implementation is not locked during traversal, which means the view can become unlocked from the car. Furthermore, as a user scrolls up into future areas, there is no further information gleaned outside of topography, whereas we report the time to reach the currently selected areas and allow the user to zoom in with a double-click to gain a 3D sense of their future surroundings. The second feature is the *3D, landmark driven map* itself. This feature is gleaned from literature, and we hypothesized that it would enable users to get better orientation and spatial awareness if they can 'anchor' themselves to known landmarks. The last main feature is *Fast destination switching*. While Google Maps has added multi-destination trips (see fig. 7.2), an easy way to switch between them is still missing from that interface. The final prototype also includes a haptic touch interface to remotely control an arbitrarily mounted display, thus enabling a mode of operation which is compatible with portable devices, as well as built in vehicle touch interfaces such as on-steering-wheel controls.

7.1.4 Time and Accuracy

The resulting FutureNav interface is a fully functioning GPS-enabled interface with actual routing. This enables us to conduct experiments in the wild, thus providing strong external validity when comparing the interface against a baseline - Google Maps. Overall results for time to answer and accuracy found that FutureNav is 2 seconds faster across all real-time probes, and 5% less accurate (see fig. 7.5). Subjective comparisons and comments support these results, with participants favouring FutureNav, particularly in segments which are coupled to features that increase situation awareness: *Navigation*, *Preparation for manual driving*, and *Switching to multiple destinations* (see fig. 6.5).

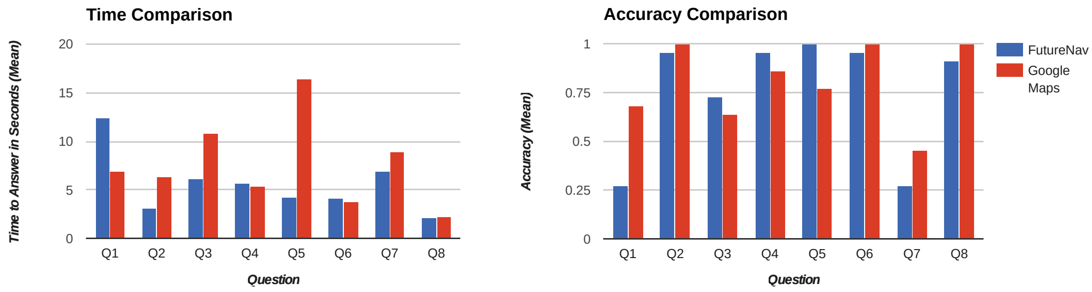


Figure 7.5: Comparing FutureNav with Google Maps: Mean answer time (in seconds) on the left, and Accuracy on the right.

7.1.5 Connecting to Interface Features

We performed question-by-question analysis which breaks down the interaction effect of interface usage by asking participants if they had used the interface to answer our real-time probe questions. Based on these results, we found that when the interface is not used, FutureNav tends to exhibit faster response times, especially when looking at spatial orientation and time estimation (see table 6.2). In the case of time estimation, we provide the ghost car tool, which is a type of active information processing. Active information processing has been suggested to enhance situation awareness (Endsley and Kiris, 1995), and thus, in the time information category, we found this to be true. Regarding the spatial orientation, the birds-eye view combined with the 3D landmarks provide a passive interface, and yet we found that this type of feature still increased comprehension level situation awareness. While Endsley's SA model cannot sufficiently explain this, navigation theory, specifically an interface which provides both survey and experiential ways to gain route knowledge, may be able to account for these increases in situation awareness.

7.1.6 Real-time Probes

As mentioned in literature, measuring situation awareness in the wild is a still yet unsolved problem. The approach we have taken in our experiment expands the knowledge in this area by showing that interface usage can add value to the analysis of SA. Our main finding concerns the framing of the measure. Rather than yes or no framing, we suggest a scale which allows the measurement of the *degree* to which an interface supports SA. For example, some participants used the interface to confirm an answer, while others said they used it to plan ahead and memorize routes. These can be offered as possible selections, rather than 'yes/no'.

7.1.7 Strategic Level driving

Previous work in the AIMMIT project looked at providing support for drivers at the tactical level. This thesis focused strongly on the strategic level driving. One key feature which allows this level of driving is the gestural interface which allows very quick destination switching. This is accomplished simply by a swipe to the left or the right. In addition, all the numbers regarding time and destination information are always displayed on the map. The SA question which most readily connects to this level of driving asks ‘Q5. How long would it take for you to reach(other destination)?’. In this metric, FutureNav was significantly faster than Google Maps, where participants had to shuffle through the interface to find destinations and do time estimation. However, this may just be a case of faster interface usage, and thus, it is difficult to equate to this to better situation awareness. This is even more evident when looking at the interaction effect graphs for Q5, which show that every single participant had to use the interface in the case of Google Maps to answer the question. Furthermore, many participants preferred to look at the map first when looking for information, rather than going through dialogs and menus. Thus, FutureNav is able to provide better strategic level control for semi-autonomous driving, although the features allowing this cannot be linked to higher situation awareness.

7.1.8 Navigation as the Nexus of Control

The steering wheel is the tangible interface that steers the car, and is often thought of as the metaphor for controlling the vehicle. With the invention of drive-by-wire, the steering wheel is one step removed as being in direct control of a vehicle. Just this year, Tesla has introduced a feature which allows the changing of lanes by using a turning indicator, further moving the steering wheel to simply reflect the status of the vehicle. In this experiment, we saw evidence that the participants can feel comfortable even with a total lack of steering wheel, and more interestingly, they began to appropriate the navigation interface as the new metaphor for vehicle control. The implications of having the navigation interface as the new center of control are broad, ranging from trust issues, new control mechanisms, expectations of communication, and operational performance, as recorded in our qualitative results. Although semi-autonomous vehicles are already on the road, there are none such that use the navigation interface as input to control the vehicle. This could be next step in the semi-autonomous driving experience, and one that should be studied from a number of different angles, including, but not limited to situation awareness and user experience. FutureNav provides one example with its trip-purpose based navigation, but it is possible to image others, for example, based on a personalization algorithm, or based on crowd-sourced data for local destination suggestions.

7.2 Concept Iteration

The comparative study gave us a lot of insights of the experience using the prototype, positive and negative aspects of the concept and usability issues. These insights supported an iteration of the prototype after the evaluation. The final prototype serve as a representation of the result and insights of the thesis work.

We noted that some participants did not intuitively make a connection between the turquoise flag in the 3d map and the current destination info at top of the display. We also noticed that many participants wouldn't find the distance to the next turn provided by the Google Maps application, also located in the top bar. Participants tend to search for information on the map primarily and other spaces secondarily. The screen size and location could be an affecting factor. Our interpretation is that location information should stay contextual if possible. The prototype was altered to also display an information bubble in the same format at alternate destination bubbles at the location o the current destination instead of a flag. Redundant information about the current destination in the top bar was still kept for readability and consistency.

Figure 7.6: Strategic zoom level in final prototype.

The behaviour for the 3d oriented map in the original prototype was so that browsing alternative destinations would move the map close to the alternative destination while always also rotating the map to face the destination from the car. This result in having the map move a lot when browsing between different alternative destinations. This would make many users slightly disoriented. It was also concluded that from the results of the comparative study that Google Maps performed better in calculating distances when not using numbers on the screen. We interpreted this to be primarily because of the top down viewpoint in Google Maps. It was also noted from the survey results that information about distance seemed relatively important when deciding on a next destination. As an improvement to the prototype we introduced a third zoom level that would serve as the strategic decision zoom level when deciding on a destination (see fig. 7.6). This zoom level is a top down view similar to Google Maps. Swiping left or right will zoom out to this view and activating a new destination or swiping back to the current destination would return the view to the normal 3d zoom level.

Figure 7.7: Tactical decision placemarks in final prototype.

For demonstration purposes we also added placemarks for manual drive and construction which show extended information when zoomed in to the tactical zoom level. The proposed idea is that the zoomed in view would allow for discovery and more detailed information and tactical decisions. A placemark could serve as a decision point where a tactical decision could be made in advance (see fig. 7.7).

7.3 Reflection

7.3.1 On Research-through-Design Methodology

Research Through Design, explained in section 3.1 served as a foundation in the works of this thesis and it's outcomes. It was a new approach for us and it opened up an opportunity to make use of the design artifact as a central point in conducting research in the field. The reason to use this methodology was that since we could not perform research on users in the context of a semi-autonomous journey we could represent our insights in the face of the prototype and its iterations and utilize user studies on the usage of the prototype to contribute to research. By reading the publications by Zimmerman et.al. and using the guidelines provided there gave the thesis a solid foundation to stand on in terms of contributing to research while at the same time leveraging our skills as designers. The categories Process, Invention, Relevance, Extensibility helped us structure the thesis and think about what to do in order to contribute to research.

When creating a concept and a prototype, we noticed we had to balance our design to be a good product, a "preferred state", or to create a design that was delimited enough for "Extensibility" and adapted for quantitative studies. The design produced in this thesis in some ways reflects the process of using Research Through Design. The design is in one hand an attempt to show the preferred state, in one hand to demonstrate the findings of our research and in one hand to support further research. We think our outcome works well in these three aspects, but we suggest for future work to clearly establish in the early stages of the process what the the purpose of the design artifact.

In our opinion Research Through Design is a good way to utilize practical design knowledge to contribute to research and it has been shown good to use in terms of discussion about the results, being able to refer to the artifact as the basis for discussion. It also challenged us as designers to take an extra step in terms the product of the thesis in order to have something that future research would benefit from, and for the research to explain a broader perspective than in traditional research.

7.3.2 Designing for Future Interfaces

In the standard process of most research endeavours, the first step is to identify a problem that can be solved. More precisely, we are identifying a gap in knowledge that can be informed by research. However, in the case of conducting research into what may be in the future, it is not possible to simply observe a problem as it is, and it is difficult to find gaps, since most of the area is unexplored and undefined. This creates a very steep hill to climb over in the beginning of the research effort, especially for a junior researcher like a masters student. In our master thesis work, much of the first month was spent not studying the problem, but rather coming up ways to study the problem, for example, immersion studies, and field studies that can shed light on future problems. This step is often not mentioned in design handbooks; the process usually starts in our current time-line, and somehow, through some effort, it is possible for the researcher to approach the problem head-on. This type of exploration informs much of the later research, and is easily validated - simply refer to the time that 'this happened' or the time that you observed 'X doing Y'. In addition to not having a target audience, the technology that we are targeting also did not exist. At best, we could simulate approximations through metaphors and wizard-of-oz techniques. This is all not to say this type of research is impossible, but that the researcher should come with an creative mind, and to be prepared to deviate from the standard process or create their own.

Despite these difficulties, there are certain advantages to designing such future interfaces. As designers, it is our job to envision the future, and what better opportunity than to specifically design for it? Envisioning the future is not only fun, but has the strong potential to influence it. The boundaries of what is possible are much looser, and much more bendable. While it is not possible to 'Verify' if your results are indeed solving some problem, since that problem may not even exist in the future, in the end, the results may have even more impact as they form building blocks and give direction for future research.

8

Conclusion

Following research through design as a methodology, we have outlined a clear process for designing a navigation interface to support situation awareness. Along the way we have created artifacts which serve as the basis of this design knowledge. The process consisted of identifying the information needs of drivers in common scenarios of semi-autonomous driving. When it comes to navigation strategically between multiple destinations in the city, we established a set of primary needs: Time, Location, Route Conditions, and Self-Driving Parts. We find that these vary between different trip purposes: social trips, home trips, and shopping trips. As our main artifact, we built a working prototype interface, FutureNav, which employs these information needs. We conducted an experiment which compared FutureNav against Google Maps as a baseline in a real-world test using the scenario elicited in the first steps. We found that FutureNav had a positive effect on comprehension (SA level 2) and projection (SA level 3). In terms of the user experience, our participants overall preferred FutureNav in a number of categories, most importantly navigation, making multi-purpose trips, and preparation for self-driving parts. We also identify the ghost car feature, map landmarks, and the 3D viewpoint as features which could be the source of increased situation awareness. For our future work, we would like to explore the use of navigation interfaces in semi-autonomous cars as the nexus of control.

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A

Appendix

A.1 Survey

Human-Centered Car Navigation in the Future

In this survey, you will be guided through a scenario where you drive the Hubble Car to complete a few tasks. The Hubble Car is a vehicle that can drive completely by itself in most areas, however, on smaller roads it might require manual operation using a regular steering wheel and pedal.

By completing this survey you will help us understand what kind of information you might need while navigating in a self-driving car. What will navigation look like in the world of self-driving cars? You can help us invent the future!

The survey should take about 10 minutes to complete. We will not collect your name or email for this survey, so your data will be confidential. Good luck!

* Required

Meet a Friend

You are in your Hubble Car and it is driving by itself towards the University where your friend Bobby is studying. Today you have plans to go together to buy the Funstation by Macrosoft. As you approach the campus, you call Bobby on your holographic phone and he tells you that he is by the Library. The campus roadways are fairly busy with pedestrians, and parking is limited. There may also be areas of the campus where the car will ask you to drive manually. Your task is to arrange a good place and time to pick up Bobby.

1. **In the situation above, it is important that I am given information regarding... ***

   Mark only one oval per row.

	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree
Friend's Location	◯	◯	◯	◯	◯
Traffic, Weather, Construction, etc	◯	◯	◯	◯	◯
Urban Setting and Scenery	◯	◯	◯	◯	◯
Time to get to your friend	◯	◯	◯	◯	◯
Trip Impact (Cost, Environmental, etc)	◯	◯	◯	◯	◯

2. **What kind of information would be most interesting?**
   Consider your options carefully as you may select up to 7 options!
   Check all that apply.

   - [ ] Estimated arrival time - "You will reach your destination AT 11:30"
   - [ ] Possible connections to other modes of transport
   - [ ] Time in minutes to your friend's location - "You will reach your friend IN 15 minutes"
   - [ ] The parts of the route where the car can drive by itself
   - [ ] A picture of the surrounding area where Bobby is
   - [ ] Any possible time delays - "The trip is going to take 15 minutes longer than usual"
   - [ ] Level of congestion - "Traffic is heavy in this area"
   - [ ] Urban Setting (for example, amount of foot traffic and cyclist routes)
   - [ ] The kind of scenery you might encounter on a particular route
   - [ ] Safety of the road - "There is construction on the highway"
   - [ ] My previous trips (have I driven here before?)
   - [ ] Information about the road type (highway, urban road)
   - [ ] Location on a map - Bobby is a dot on a map
   - [ ] The monetary cost of the trip
   - [ ] The environmental impact of my trip
   - [ ] Distance from you - "Bobby is 12km away"
   - [ ] Other: ....

3. **Comments on your choices**

   ....

   ....

   ....

   ....

   ....

Go Shopping

Ah, you finally found Bobby. He was throwing yo-yo right outside of that old coffee place.

You're both in the car now and you decide to head to a store to buy the Funstation. There is a lot of possible stores that you could go to. You could go to a store in the busy city centre, the big mall in the outskirts, or you could go to a store that is on the way home. You drive the car onto the main road so it can go on by itself as you both decide on which stores you might want to check out. Your task is to find a suitable store and park there.

4. **In the situation above, it is important that I am given information regarding... ***
Mark only one oval per row.

	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree
The Location of the Stores	⬭	⬭	⬭	⬭	⬭
Traffic, Weather, Construction, etc	⬭	⬭	⬭	⬭	⬭
Urban Setting and Scenery	⬭	⬭	⬭	⬭	⬭
Time to get to the stores	⬭	⬭	⬭	⬭	⬭
Trip Impact (Cost, Environmental, etc)	⬭	⬭	⬭	⬭	⬭

5. **What kind of information would be most interesting?**
Consider your options carefully as you may select up to 7 options!
Check all that apply.

- [ ] Distance from you to different shops
- [ ] Level of congestion along the route - "Traffic is heavy in this area"
- [ ] The kind of scenery you might encounter on your route to a shop
- [ ] Any possible time delays - "The trip is going to take 15 minutes longer than usual"
- [ ] The parts of the route or areas where the car can drive by itself
- [ ] Information about the road on your route (highway, urban road)
- [ ] Urban Setting of the shops (for example, amount of foot traffic and cyclist routes)
- [ ] Estimated arrival time - "You will reach your destination AT 11:30"
- [ ] Safety of the road - "There is construction on the highway"
- [ ] A visual preview of the shopping area
- [ ] Time in minutes to destination - "You will reach your destination IN 50 minutes"
- [ ] The monetary cost of the trip
- [ ] The environmental impact of my trip
- [ ] Shop locations on a map
- [ ] My previous trips (have I driven here before?)
- [ ] Possible connections to other modes of transport
- [ ] Other: ....

6. **Comments on your choices**

....

....

....

....

....

Get Home

Exciting! You have bought the Funstation and are ready to get home and play with it!

You drive out on the main road again and tell the car to go Home. It gives you a suggested route, but this time you are very familiar with the roads. You know the way home as well as some alternate routes that might be faster, calmer, or scenic. Your task is to get home in whichever way you deem best!

7. **In the situation above, it is important that I am given information regarding... ***

   Mark only one oval per row.

	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree
The Location of my Home					
Traffic, Weather, Construction, etc					
Urban Setting and Scenery					
Time to get home					
Trip Impact (Cost, Environmental, etc)					

8. **What kind of information would be most interesting?**

   Consider your options carefully as you may select up to 7 options!

   Check all that apply.

- [ ] The environmental impact of my trip
- [ ] My previous trips (have I driven here before?)
- [ ] The kind of scenery you might encounter on a particular route
- [ ] Urban Setting (for example, amount of foot traffic and cyclist routes)
- [ ] Information about road types (highway, urban road)
- [ ] Estimated arrival times - "You will reach your destination AT 11:30"
- [ ] Possible connections to other modes of transport
- [ ] Safety of the road - "There is construction on the highway"
- [ ] The location of your home on a map shown as a place mark
- [ ] Time in minutes to destination - "You will reach your destination IN 50 minutes"
- [ ] Any possible time delays - "The trip is going to take 15 minutes longer than usual"
- [ ] Level of congestion - "Traffic is heavy in this area"
- [ ] The parts of the different routes where the car can drive by itself
- [ ] The monetary cost of the trip
- [ ] Length of the various routes - "Route A is 4.5 km"
- [ ] Other: ____________________

9. **Comments on your choices**

____

____

____

____

____

Wrap Up!

To finish, tell us a bit about yourself.

10. **Gender**
Mark only one oval.

- Male
- Female
- Other: ____________

11. **Age**

____

12. **Driving Frequency** *
Mark only one oval.

- Daily
- A few times a week
- A few times a month
- A few times a year
- Never (Don't worry, we'll still use your data!)

13. **In which city do you usually drive?**

____

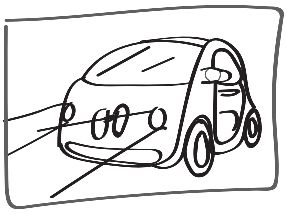
14. **Did this survey give you any ideas? Write them down!**

____
____
____
____
____

A.2 Workshop

Meet a Friend

You are in New Zealand sitting in your Hubble Car and it is driving by itself towards the University where your friend Bobby is studying. Today you have plans to go together to buy the Funstation by Macrosoft. Your task is to arrange a good place and time to pick up Bobby.



As you approach the campus, you call Bobby on your holographic phone and he tells you that he is by the Library.

Event (Destination Choice): Head towards library, or head towards parking?

The campus roadways are fairly busy with pedestrians, and parking is limited. There may also be areas of the campus where the car will ask you to drive manually.

You must drive manually around campus to get exatly to where Bobby is standing.

Visual

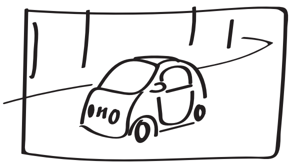
Haptic

Audio

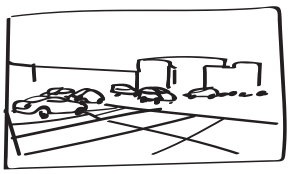
Go Shopping

Ah, you finally found Bobby. He was throwing yo-yo right outside of that old coffee place. You're both in the car now and you decide to head to a store to buy the Funstation. There is a lot of possible stores that you could go to. You could go to a store in the busy city centre, the big mall in the outskirts, or you could go to a store that is on the way home.

Event (Destination Choice): Choose a Shop



You drive the car onto the main road so it can go on by itself as you both decide on which stores you might want to check out. Your task is to find a suitable store and park there.



Event (Manual Driving): Find Parking

Visual

Haptic

Audio

Go Home

Exciting! You have bought the Funstation and are ready to get home and play with it! You drive out on the main road again and tell the car to go Home. It gives you a suggested route, but this time you are very familiar with the roads. You know the way home as well as some alternate routes that might be faster, calmer, or scenic.

Event (Route Choice): Take an alternate route of your choice, or not!

Your task is to get home in whichever way you deem best!

Visual

Haptic

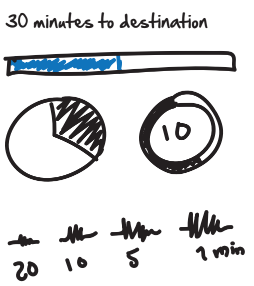
Audio

Time

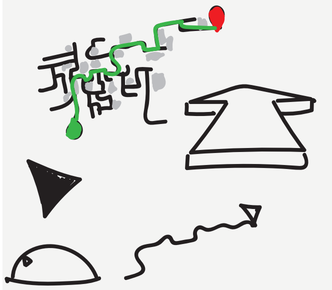
Estimated time of arrival

Time delay

Time to

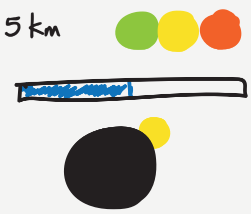


Destination



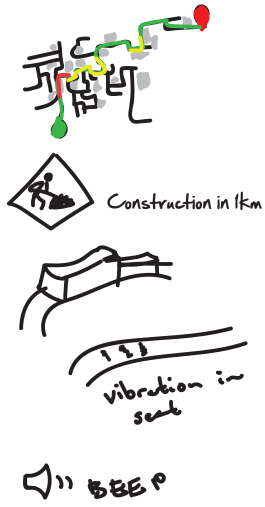
Surroundings

Distance

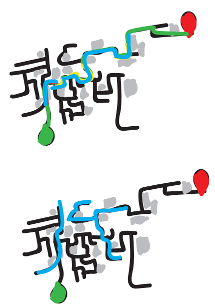


Conditions

Congestion Safety

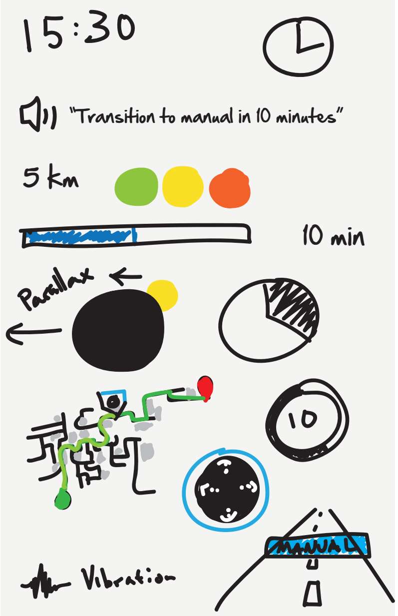


Self driving parts

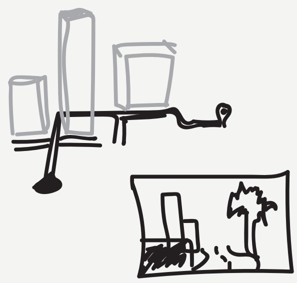


Self driving

When to transition to manual driving

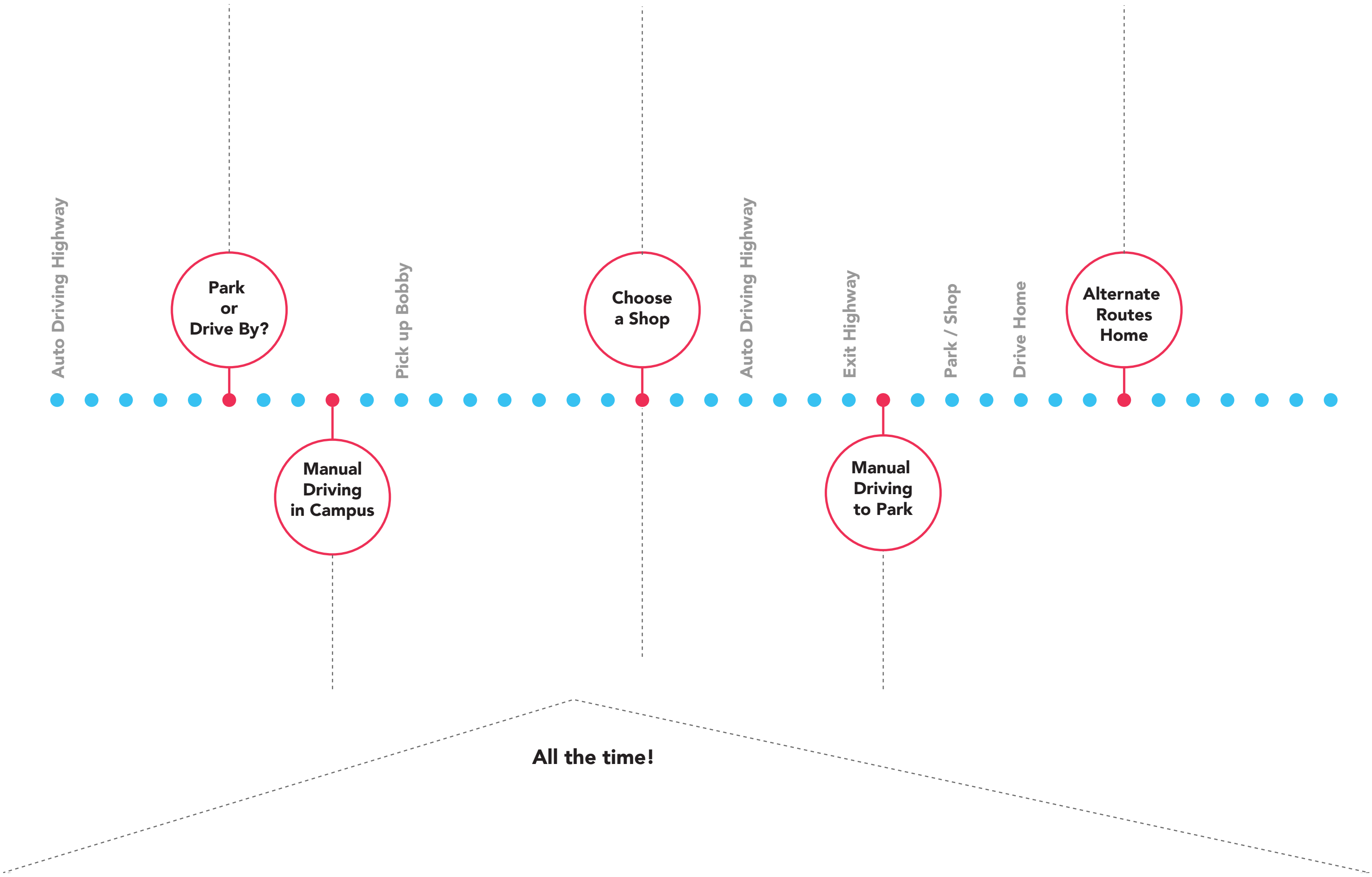


Location



Information Timeline

= 1 unit of ______________



A.3 Questionnaire

1 **INTERFACE:** ☐ SV ☐ GM **ROUTE :** ☐ EAST ☐ WEST

2 **INTERFACE:** ☐ SV ☐ GM **ROUTE :** ☐ EAST ☐ WEST

---

1. ID : .... / Date : ..... / ..... / 2016

2. AGE : ....

3. GENDER : F ☐ M ☐

4. PROFESSION: ....

5. Driving frequency:

- ☐ A few times a week
- ☐ A few times a month
- ☐ A few times a year

6. How often do you use a GPS while driving:

- ☐ Always
- ☐ Usually
- ☐ Situationally, e.g ______________________
- ☐ Never

7. How familiar are you with self-driving cars?

- ☐ Very familiar
- ☐ Somewhat familiar
- ☐ Not familiar

8. How familiar are you with systems such as adaptive cruise control and automated parking?

- ☐ Very familiar
- ☐ Somewhat familiar
- ☐ Not familiar

9. Do you agree to use the collected data, photo and vıdeo recording for our study?

- ☐ **YES**
- ☐ **NO**

1

Please circle the best choice. The situation refers to the context of being in a semi-autonomous car, the environment you perceived, and using the interface to navigate this environment.

Instability of the Situation How changeable is the situation? Is the situation highly unstable and likely to change suddenly (high), or is it very stable and straightforward (low)?	1 2 3 4 5 6 7 Low High
Complexity of the Situation How complicated is the situation? Is it complex with many interrelated components (high) or is it simple and straightforward (low)?	1 2 3 4 5 6 7 Low High
Variability of the Situation How many variables are changing in the situation? Are there a large number of factors varying (high) or are there very few variables changing (low)?	1 2 3 4 5 6 7 Low High
Arousal How aroused are you in the situation? Are you alert and ready for activity (high) or do you have a lower degree of alertness (low)?	1 2 3 4 5 6 7 Low High
Concentration of Attention How much are you concentrating on the situation? Are you bringing all your thoughts to bear (high) or is your attention elsewhere (low)?	1 2 3 4 5 6 7 Low High
Division of Attention How much is your attention divided in the situation? Are you concentrating on many aspects of the situation (high) or focused on only one (low)?	1 2 3 4 5 6 7 Low High
Spare Mental Capacity How much mental capacity do you have to spare in the situation? Do you have sufficient to attend to many variables (high) or nothing to spare at all (low)?	1 2 3 4 5 6 7 Low High
Information Quantity How much information have you gained about the situation? Have you received and understood a great deal of knowledge (high) or very little (low)?	1 2 3 4 5 6 7 Low High
Information Quality How good is the information you have gained about the situation? Is the knowledge communicated very useful (high) or is it not useful at all (low)?	1 2 3 4 5 6 7 Low High
Familiarity with situation How familiar are you with the situation? Do you have a great deal of relevant experience (high) or is it a new situation (low)?	1 2 3 4 5 6 7 Low High

1

Please rate the system you just used as a navigation interface in the context of semi-autonomous driving:

	strongly disagree				strongly agree
I think I would like to use this system frequently					
I found the system unnecessarily complex					
I thought the system was easy to use					
I think that I would need the support of a technical person to be able to use this system					
I found the various functions in this system were well integrated					
I thought there was too much inconsistency in this system					
I would imagine that most people would learn to use this system very quickly					
I found the system very cumbersome to use					
I felt very confident using this system					
I needed to learn a lot of things before I could get going with this system					

Comments:

2

Please circle the best choice. The situation refers to the context of being in a semi-autonomous car, the environment you perceived, and using the interface to navigate this environment.

Instability of the Situation How changeable is the situation? Is the situation highly unstable and likely to change suddenly (high), or is it very stable and straightforward (low)?	**1** Low	**2**	**3**	**4**	**5**	**6**	**7** High
Complexity of the Situation How complicated is the situation? Is it complex with many interrelated components (high) or is it simple and straightforward (low)?	**1** Low	**2**	**3**	**4**	**5**	**6**	**7** High
Variability of the Situation How many variables are changing in the situation? Are there a large number of factors varying (high) or are there very few variables changing (low)?	**1** Low	**2**	**3**	**4**	**5**	**6**	**7** High
Arousal How aroused are you in the situation? Are you alert and ready for activity (high) or do you have a lower degree of alertness (low)?	**1** Low	**2**	**3**	**4**	**5**	**6**	**7** High
Concentration of Attention How much are you concentrating on the situation? Are you bringing all your thoughts to bear (high) or is your attention elsewhere (low)?	**1** Low	**2**	**3**	**4**	**5**	**6**	**7** High
Division of Attention How much is your attention divided in the situation? Are you concentrating on many aspects of the situation (high) or focused on only one (low)?	**1** Low	**2**	**3**	**4**	**5**	**6**	**7** High
Spare Mental Capacity How much mental capacity do you have to spare in the situation? Do you have sufficient to attend to many variables (high) or nothing to spare at all (low)?	**1** Low	**2**	**3**	**4**	**5**	**6**	**7** High
Information Quantity How much information have you gained about the situation? Have you received and understood a great deal of knowledge (high) or very little (low)?	**1** Low	**2**	**3**	**4**	**5**	**6**	**7** High
Information Quality How good is the information you have gained about the situation? Is the knowledge communicated very useful (high) or is it not useful at all (low)?	**1** Low	**2**	**3**	**4**	**5**	**6**	**7** High
Familiarity with situation How familiar are you with the situation? Do you have a great deal of relevant experience (high) or is it a new situation (low)?	**1** Low	**2**	**3**	**4**	**5**	**6**	**7** High

2

Please rate the system you just used as a navigation interface in the context of semi-autonomous driving:

	strongly disagree				strongly agree
I think I would like to use this system frequently					
I found the system unnecessarily complex					
I thought the system was easy to use					
I think that I would need the support of a technical person to be able to use this system					
I found the various functions in this system were well integrated					
I thought there was too much inconsistency in this system					
I would imagine that most people would learn to use this system very quickly					
I found the system very cumbersome to use					
I felt very confident using this system					
I needed to learn a lot of things before I could get going with this system					

Comments:

Please compare the two systems you just used in the context of semi-autonomous driving navigation:

	SV Nav	Don't Know or Tie	GM Nav	Comments
Which was easier to use?				
Which do you think is safer to use?				
Which helped you most at navigation?				
Which was more fun to use?				
Which is better for visiting multiple destinations?				
Which is more helpful in preparing you for manual driving?				
Which is better for performing secondary tasks such as phone usage?				

Comments:

A.4 Icon Attributions

clock by Arthur Shlain from the Noun Project
Location by Creative Stall from the Noun Project
Brain by Cindy Duong from the Noun Project
Home by Calvin Goodman from the Noun Project
Eye by Andrea Mazzini from the Noun Project
Subway by Viktor Fedyuk from the Noun Project
Road by BraveBros. from the Noun Project
anxiety by Emily Haasch from the Noun Project
Steering Wheel by Rohan Gupta from the Noun Project
Water by Alessandro Suraci from the Noun Project
Psycology by Bhasker Sharma from the Noun Project
traffic jam by Felix Westphal from the Noun Project
Target by Creative Stall from the Noun Project
Steering Wheel by Rowan Kelly from the Noun Project
Traffic Cone by Joris Hoogendoorn from the Noun Project
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