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User Experience of Electric Vehicle Energy Use and Range

Exploring the User Experience of Range Interfaces in Electric Vehicles’ In-Vehicle Information Systems

Master’s thesis in Computer Science and Engineering

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Department of Computer Science and Engineering
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2025

MASTER'S THESIS 2025

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Cover: The interior of the EX90, featuring the DIM and CSD [1]

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Abstract

Electric Vehicles (EVs) are rapidly gaining popularity, but with the transition from Internal Combustion Engine Vehicles (ICEVs) to EVs comes a learning curve for new users. Through internal surveys, Volvo has discovered a dissatisfaction amongst some of their users when it comes to the range of their EVs. Range in EVs is influenced by both driver behaviour and external factors. Volvo's existing Range Assistant interface is designed to help users understand and optimise their energy consumption, and potentially alleviating range anxiety. However, some users find the interface difficult to interpret, leading to frustration and confusion.

This project therefore aims to identify potential knowledge gaps amongst EV users regarding range estimation and energy consumption. Using a user-centred design approach, questionnaires and usability tests were conducted iteratively to explore user needs and challenges. Based on the findings from the iterations, a list of 10 design recommendations to improve range assistance interfaces has been established. These recommendations cover aspects such as information visualisation, feedback, and coaching, offering guidance for enhancing user trust and understanding in EV range estimation interfaces.

Keywords: EV, range, Range Assistant, energy-efficient driving, UX, design recommendations.

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Contents

List of Figures **xiii**

List of Tables **xv**

Glossary **xvii**

1 Introduction & Background **1**
1.1 Context . . . 1
1.2 Volvo Cars . . . 1
1.3 Electric Vehicles (EVs) . . . 2
1.4 Range . . . 3
1.4.1 Range Anxiety . . . 3
1.5 Goals and Challenges . . . 3
1.5.1 Research Question . . . 4
1.6 Delimitations & Expected Contributions . . . 5
1.7 Ethical Considerations . . . 6

2 Related Work **7**
2.1 State of Charge (SoC) & Range Anxiety . . . 7
2.2 Trust in Digital & EV Interfaces . . . 8
2.3 In-Vehicle Interfaces . . . 9
2.4 Cognitive Load and Safe Driving . . . 10
2.5 Nudging and Safe Driving . . . 11
2.6 Bias in Research for Design . . . 11

3 Theory **13**
3.1 Research Through Design . . . 13
3.2 Interaction Design (IxD) . . . 13
3.2.1 Usability . . . 13
3.2.2 User Experience Design . . . 14
3.2.3 User-Centred Design . . . 14
3.3 Interaction Design Processes . . . 14
3.3.1 Double Diamond . . . 14
3.3.2 Triple Diamond . . . 15

4 Methodology **17**

4.1 Methods for Data Gathering and Understanding the Users 17
4.1.1 Pre-Analysis 17
4.1.2 Questionnaires 17
4.1.3 Interviews 18
4.2 Methods for Defining, Ideation & Developing 18
4.2.1 Scenario 19
4.2.2 User Archetypes 19
4.2.3 Benchmarking 19
4.2.4 Affinity Diagramming 20
4.2.5 Requirement List 21
4.2.6 Brainstorming 22
4.2.7 Prototyping 22
4.3 Methods for Analysis & Evaluation 22
4.3.1 Usability Testing 23
4.3.2 A/B Testing 23
4.3.3 Thematic analysis 23

5 Execution & Results 25
5.1 Understanding the User 25
5.1.1 Volvo Data Pre-Analysis 25
5.1.2 Questionnaire 26
5.1.3 Questionnaire Data Analysis 26
5.1.4 Questionnaire Results 27
5.2 First Design Iteration 29
5.2.1 First Iteration Prototyping 29
5.2.2 First Iteration Testing 31
5.2.3 First Iteration Data Analysis & Results 33
5.3 Second Design Iteration 36
5.3.1 Second Iteration Prototyping 36
5.3.2 Second Iteration Testing 40
5.3.3 Second Iteration Data Analysis 42
5.3.4 Second Iteration Results 42
5.4 Final design recommendations 47

6 Discussion 51
6.1 Results 51
6.2 Execution in Relation to the Literature 54
6.3 Limitations in the Research 56
6.4 Ethical and Societal Considerations 57
6.5 Future Work 58

7 Conclusion 61

Bibliography 63

A Questionnaire I

B Evaluation **VII**

List of Figures

1.1 Volvo Cars' Range Lab found on Volvo's website [6] 2
1.2 Range Assistant app in a Volvo car [18] with the CMA-platform . . . 4
1.3 Position of the DIM (1) and CSD (2) in the EV 5

3.1 Visualisation of the double diamond process [46] 15
3.2 Visualisation of the triple diamond process [47] 16

4.1 The three steps to make an affinity diagram [54] 20

5.1 Illustration of the execution process 25
5.2 Thematic analysis board portraying grouping of themes 27
5.3 The low-fidelity prototype screens made for the CSD 30
5.4 The low-fidelity prototype screens made for the DIM 32
5.5 High-fidelity prototype of the Range and Trip app in CSD: Version 1 37
5.6 High-fidelity prototype of the Range and Trip app in CSD: Version 2 38
5.7 Updated estimated range after R.O. has been activated in the high-fidelity prototype 38
5.8 High-fidelity prototype of the DIM: Version 1 39
5.9 High-fidelity prototype of the DIM: Version 2 39
5.10 The initial set-up of the Buck with simulator 40
5.11 The buck in the (a) second and (b) third test rooms 41
5.12 Thematic Analysis of the final evaluation 42
5.13 Box-plots for the evaluated tips aspect 46
5.14 Box-plots for the evaluated CSD 46
5.15 Box-plots for the evaluated DIM 47

A.1 Image of the R.A. provided in the questionnaire to provide a reference point for the users to clarify questions 5. II
A.2 The Range Assistant provided together with question 13 to clarify what part of the R.A. the question referred to. III
A.3 The Range Assistant with the Range Optimizer circled to clarify question number 19 IV

List of Tables

5.1 Mean, median, and standard deviation values of the evaluated tips aspect 46
5.2 Mean, median, and standard deviation values of the evaluated CSD . 46
5.3 Mean, median, and standard deviation values for the evaluated DIM . 47
5.4 List of final design recommendations 47

Glossary

CMA Compact Modular Architecture.

CSD Centre Stack Display.

DIM Dashboard Integration Module.

EV Electric Vehicle.

GPS Global Positioning System.

HMI Human-Machine Interaction.

ICEV Internal Combustion Engine Vehicle.

ISO International Organization for Standardization.

IVIS In-Vehicle Information Systems.

IxD Interaction Design.

R.A. Range Assistant.

R.O. Range Optimiser.

RtD Research Through Design.

SoC State of Charge.

SPA2 Scalable Product Architecture Version 2.

UCD User-Centred Design.

UEQ+ User Experience Questionnaire Plus.

UI User-Interface.

UXD User Experience Design.

UXR User Experience Research.

WLTP World Harmonised Light Vehicle Test Procedure.

OneVoice OneVoice is a customer feedback service that Volvo does in partnership with Medallia. Customers are able to send feedback whenever and however they want.

Product Quality Study (PQS) is Volvo Cars' own online survey for Volvo owners, and is sent out after two and twelve months after purchase.

UX User Experience.

1
Introduction & Background

The scope of this project is to better understand Electric Vehicle (EV) users knowledge gaps of how different contexts and driving behaviours impact the estimated range, and how this might affect the use and planning when driving EVs. Additionally, this project aims to provide a set of recommendations and a prototype concept that increases EV users' understanding of range, to fulfil their needs and increase their trust in EV range estimations.

1.1 Context

EVs are getting more popular and the sales are increasing [2], [3], largely because of the better greenhouse effects they have on the environment [4], [5] compared to a traditional Internal Combustion Engine Vehicle (ICEV). Even though sales are going up, there is a worry that it might not be fast enough to meet climate targets [4] in reducing global emissions. We should therefore encourage the transition from ICEVs to EVs in hopes to achieve the climate goals.

Aside from the differences in environmental impact, ICEVs and EVs are different when it comes to driving range - as in the distance that can be travelled on a full battery charge versus a full tank. One of the most common concerns when transitioning from a ICEV to an EV is the shorter range available [4], [5]. To help customers, Volvo provides a range calculator (called Range Lab) on their website [6] which provides information about the range for their car models. The calculator provides explanations detailing how some common factors, such as outdoor temperature, might affect the range, see Figure 1.1. To be able to produce these calculations Volvo is performing internal range tests similar to a test called World Harmonised Light Vehicle Test Procedure (WLTP), which nowadays is the global standard for testing vehicles [7]. A WLTP-test is used to determine the consumption and emissions of both EVs and ICEVs. A WLTP-test cycle is a series of starts, accelerations, and stops carried out in a controlled environment [7], [8]. The test cycle is carried out in 23 degrees Celsius [7] and runs over 30 minutes [8].

1.2 Volvo Cars

Volvo Cars is a branch of Volvo, a car company from Gothenburg. Volvo Cars produced their first car, called ÖV4, in 1927 [9]. According to Volvo, their mission

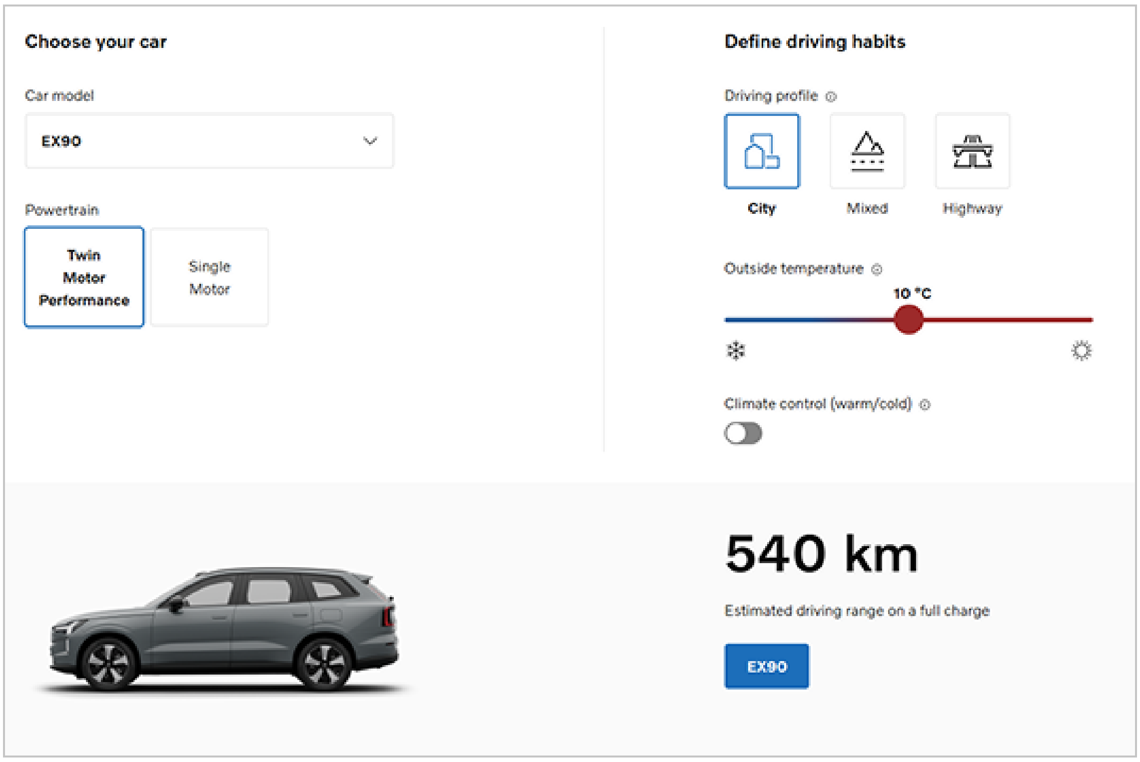


Figure 1.1: Volvo Cars' Range Lab found on Volvo's website [6]

is to make life easier, better and safer for everyone. For example, it was in 1959 that the Volvo engineer Nils Bohlin introduced the three-point belt. Volvo decided not to claim the lone rights to use the belt, making a groundbreaking step in safety for all. It is said that over one million lives have been saved with the three-point belt [9], befitting their motto of:

> "For life. We want to provide you with the freedom to move in a personal, sustainable and safe way." [10]

Volvo released their first production ready fully electric vehicle in 2019 and has the ambition to become a fully electric company by year 2040 [10]. Today, six models are available to the public, EX90, ES90, EM90, EX40, EX30, and EC40, and more are on the way. Volvo cars can be found all around the world and are sold in more than 100 countries.

1.3 Electric Vehicles (EVs)

The general idea for any car is to convert one kind of energy into another; stored energy gets converted into kinetic energy. The difference between an ICEV and an EV is the way and the kind of energy the motor converts. An ICEV uses a gas or a liquid, for example petrol, which goes through a chemical reaction inside the engine to create heat. The heat expands the gases which makes parts of the engine move, which in turn makes the wheels turn. An EV uses electrochemical energy stored in a battery (usually a lithium-ion battery) and sends the energy to an electric engine which turns the wheels. Since no combustion is taking place in the electric engine, an EV has no obvious emissions [11] and is therefore perceived better for the environment.

1.4 Range

Range is an indicator on how far an EV can travel on a full battery charge. The range is shown in numbers of distance, and is the information available to users on for example Volvo's range calculator, see Figure 1.1. For drivers, however, it is usually the estimated range that is more important during a drive. The estimated range is an estimation of distance that the EV is able to travel on the remaining battery, shown as distance (for example kilometres). The estimated range is sometimes confused with the battery charge, however, the battery charge is shown as a percentage number called State of Charge (SoC), similar to how phone batteries are shown today. Worth to note is that different car brands have different formulas to calculate range based on different lengths of historic consumption data for example.

The formula to calculate the estimated range can therefore roughly been explained as follows: [8]

$$range = \frac{usable\ battery\ energy}{energy\ consumption\ from\ the\ battery\ per\ distance\ travelled} \tag{1.1}$$

1.4.1 Range Anxiety

Range anxiety can be described as a fear of running out of electricity for the battery before being able to reach an available charging station when driving [12]. This is a phenomenon associated with drivers' perception of the available driving range. With EVs being the future of the automobile industry in terms of reducing the greenhouse gas emissions [13], there are still some technical challenges like range, charging cost, and range anxiety that have affected the perception of EVs negatively [14].

1.5 Goals and Challenges

Switching to an EV requires time to adapt, and there is a learning curve for getting used to the EV [15]. There are new routines for how to plan the day-to-day driving and charging, especially when going on a longer trip [16]. For new users, it is important to understand what affects the energy consumption, thus also the range available, and the range prediction shown in the In-Vehicle Information Systems (IVIS). Volvo's EVs have a Range Optimiser (R.O.) in an in-car app called Range Assistant (R.A.) [17] (see Figure 1.2) which, when activated, optimises the range in the car by limiting some settings. The R.A. shows the estimated range, consumption, and three elements affecting range: speed, driving style, and (in-car) climate. During the drive, these parameters will update according to the current status of the car and driver behaviour, since the driving styles are different on e.g. highways compared to in the city.

Figure 1.2: Range Assistant app in a Volvo car [18] with the Compact Modular Architecture (CMA)-platform

Through internal surveys, Volvo has discovered a dissatisfaction amongst some of their users when it comes to the range of their EVs. The range is sometimes perceived to change without providing a satisfactory explanation to the user. According to some users, although the R.A. provides the driver with real time data, they still struggle with understanding the information given to them.

With the existing problems in mind, the goal with this project is to better understand EV users knowledge gap of how different contexts and driving behaviours impact the estimated EV range, and how this might affect their use and charging needs of their EVs. This study also aims to provide a recommendation list and a prototype concept of an improved interface that increases EV users understanding that fulfils their needs and trust in the range estimation. From this we present the following research question:

1.5.1 Research Question

> What are some of the features that could be improved in the range interfaces on the in-vehicle information systems to better help the driver understand and trust in the range estimation?

1.6 Delimitations & Expected Contributions

The delimitation factors of this project will include research design, time frame, population size, and recruitment of participants. As the project is a collaboration between students at Chalmers and Volvo as a company, a set delimitation is that the recruitment of participants will be from Volvo EV users only. One of the study's aims is to improve the existing interface which is available to the students, therefore the project will be limited to improving Volvo's EV interface. However, the requirements and recommendations for future designs of such interfaces will be applicable outside of Volvo's EVs as well. As there is already extensive research regarding safety with IVIS as well as the general difference and transition between ICEVs and EVs, it was decided to not focus on road safety and safe driving, but rather use the available research in the pre-analysis to support the project. Additionally, given the time constraints of this project, conducting a full literature review of the existing studies and research regarding the EVs and range is a task that lies outside the scope of this project.

Figure 1.3: Position of the Dashboard Integration Module (DIM) (1) and Centre Stack Display (CSD) (2) in the EV

Through the master's thesis, contributions to the research field are expected within several areas. Firstly, a set of design recommendations for creating a range estimation and assistance-interface in the IVIS, with the purpose of improving drivers' understanding of range, and thus also improve their trust in the estimated range, will be provided. Secondly, a prototype concept of what such an interface could look like will also be provided. It should be kept in mind that this will only be a preliminary concept prototype applied to Volvo's current interface, and the prototype's design should be considered together with the design recommendations when designing a range estimation- and assistance-interface. From the existing IVIS, the project will focus on the DIM- and CSD-interfaces. The DIM is located in front of the driver behind the steering wheel, and the CSD is located in the centre console of the vehicle, see Figure 1.3.

With this project, the overall aim is to provide more research and understanding of the current EV drivers and their understanding of range, so that the possible improvements can be identified. The research area is a highly relevant and newly emerging field as the society is slowly making the transition towards electrification in a global strive for sustainability, and the findings from this project will benefit related research within this field, and hopefully also contribute to further research and development of EVs.

1.7 Ethical Considerations

The goal of this project is to get a better understanding of what users know and understand about range in EVs, then make an improved interface as well as provide guidelines for future work.

This project will consist of phases where different ethical requirements apply. The first phase, data gathering, requires direct contact with users. All participants will be made aware of how their data will be handled in accordance to Volvo's policies, prioritising consent for the data gathering phase. All interviewees will be kept anonymous and they will be free to leave or stop at any time. If at any time a participant withdraws their consent, their data will be removed and destroyed.

The second phase requires less contact with users and has more focus on using the gathered data to create a design. Steps will be taken to minimise bias, by acknowledging and being aware of our position as designers and the gathered user data will be handled with outmost care, ensuring that data integrity is maintained and handled securely.

The third phase will again involve users for the evaluation of the prototypes. For this phase the same will apply as for the first and second phase during interviews and evaluation. User consent will be prioritised for the testing procedures, while also ensuring transparency of how the data will be handled, and the analysis of the data will be done fairly, with the final results from this project accessible for participants to view. We aim to act responsibly for the whole duration of the thesis work, to be transparent and honest with our participants, taking each participant's experience into consideration so as to not put them under any stressful situations, and handle all data with integrity and care.

2

Related Work

There have been studies conducted in related areas which have resulted in relevant findings for this project. This chapter describes studies and the important findings in the topics of range anxiety, trusting interfaces in vehicles, general research about in-vehicle interfaces, cognitive load and nudging in relation to safe driving, and finally biases found in Interaction Design (IxD).

2.1 State of Charge (SoC) & Range Anxiety

The concept of using energy and needing to charge a battery is the main difference between ICEVs and EVs, and for inexperienced drivers one of the biggest concerns is running out of charge in the middle of a trip as a consequence of limited range [19]. The range anxiety obstacle needs to be addressed to ensure the transition from ICEVs to EVs, to better manage the growing environmental concerns [20]. Pevec, Babic, Carvalho, *et al.* [20] employed a survey methodology in their research to assess potential EV owners' perception of range anxiety, with the goal of explaining range anxiety by quantifying it and using key EV parameters when measuring it. They used parameters such as SoC (a relative measure comparing the remaining amount of energy in the EV battery with the maximum capacity of the battery, usually portrayed in battery percentage format) and remaining range (how much distance the EV can still run without having to re-charge the battery, portrayed in kilometres or miles). In their study, Pevec, Babic, Carvalho, *et al.* [20] focused on non-EV owners, with the reasoning that non-EV owners in general have less knowledge about EVs and that they therefore would manifest a higher level of range anxiety [21]. They also reason that non-EV owners' perception of the optimal charging infrastructure is important for the development of future charging infrastructure as well [20]. Their findings show that there is some dissatisfaction amongst potential EV owners regarding the infrastructure of gas and charging stations. They also found that the SoC highly influences range anxiety and charging habits, with more range anxiety at lower SoCs.

Rauh, Franke, and Krems [22] focused on the connection between range anxiety and long-term EV owners versus non-EV owners through their study with test scenarios with predefined SoC and routes. The test scenario was designed to lead to a critical range situation, and they measured range stress on cognitive, emotional and behavioural levels. The study was designed to better understand range anxiety as well as investigate the degree to which practical driving experience predicts the reduction of range anxiety. Their findings supported previous research that indicated that most drivers adapted to the general concept of EV and range within the first 3 months of using an EV [23].

Franke and Krems [24] based their research on participants that were provided EVs for 3 months for test driving. They focused on investigating the factors that might influence range preferences and how these might change over time. The results from their study showed that the range anxiety drivers experienced was associated with higher range preferences, but that range preferences decreased with more EV experience. This indicated that the range anxiety that would occur might reduce with more EV experience, and is in line with the previously mentioned findings from Rauh, Franke, and Krems [22]'s paper.

Another study by Jung, Sirkin, Gür, *et al.* [25] addressed how the user interface in the EV influences range anxiety. They explored the impact of the displayed precision of the range and SoC on drivers' attitudes towards EVs. In their study, participants completed a 19-mile long drive in EVs portraying different remaining range, but also with EVs giving estimates of range with high and low information ambiguity. One of their key findings was that high ambiguity in the EV's user interface for portraying range would result in higher range anxiety as well as feelings of mistrust towards the vehicle in general.

2.2 Trust in Digital & EV Interfaces

Dwyer [26] studied trust in digital interfaces, and she argues that all digital interfaces will have some measure of trust factor amongst its users. That trust is measurable both subjectively (user's feelings when using the system) and objectively (algorithms measuring the usage). It is imperative that system interfaces encourages trust amongst users. Without the trust, it is unlikely that users would continue to use the service. According to Dwyer, trust is not a binary state, rather it is a spectrum where the level of trust ranges from non-existent to fully trustworthy. System interfaces need to continuously work on gaining and keeping the user's trust. One bad occurrence for the user can be enough for them to lose trust in the system [26].

Additionally, Dwyer argues that trust in systems are context dependent, where the trust depends on the level of security needed and the kind of data that is displayed. When the user needs to get exact data, the system requires a higher level of trust from the users, while if the data is more fluctuating users are usually more forgiving and require a lower level of trust. She also introduces that systems require a bit of distrust, which means that the users need to have a sense of when they need to question the information they are given to avoid any unnecessary risk, allowing them to assess the situation and make important decisions when necessary. Users also want to be able to understand the data shown to them, which requires transparency from the designers and companies. Lastly, it is also important to consider the familiarity when introducing something in a system [26]. The familiarity can be from similar shapes or colours of the design, and an example of this is how icons such as the save function in many systems still have a close resemblance to the old floppy disk. The familiarity for new systems is necessary to consider, stressing the need for a universal design [27].

Franke, Trantow, Günther, *et al.* [28] have looked at the level of trust users have about the range in EVs. They claim that the range interface is essential in the EV interface and that the range indicator is what helps users with decision making. Having an accurate displayed range can help diminish users range anxiety and planning for when and where to charge. If the range is perceived to be untrustworthy, users might have a higher level of range anxiety or they might make less efficient choices. Franke, Trantow, Günther, *et al.* argue that the range indicator has the power to enhance or weaken the users' level of trust in the system.

The potential range in EVs is evolving and getting longer, but this might be a cause of concern for potential new users [28]. Franke, Trantow, Günther, *et al.* argue that getting a longer range might make users feel like there is more room for errors and fluctuations in the range indicator, making them lose trust in the system compared to if it showed a shorter range. Being able to trust in the range leads to what Franke, Trantow, Günther, *et al.* [28] refer to as the *comfort zone*, which is the safety buffers users feel they need to keep. The less trust users have in the range, the bigger comfort zone they will likely have, feeling like they need to have more range left when needing to charge. Having more trust in the system will therefore lead to users needing smaller comfort zones and thereby feel more confident in the range. That way users will be okay with charging when the estimated range is lower. When users get more comfortable with range and start to trust the system more, they will minimise their comfort zones and be able to utilise more of the range in their driving [28].

Franke, Trantow, Günther, *et al.* [28] also argue that trust is not only about *how* to display information, but *what* information to display, and how best to translate available data for the interface in an easy and accessible way for the user. This goes together with what Dwyer [26] mentions about having *chameleon interfaces*, which is an interface that adopts settings according to user preferences. Being able to decide what and how to display data might increase the level of trust for the system since the user gets to decide the level of transparency. The findings from Franke, Trantow, Günther, *et al.* [28]'s study also suggest that the designers should focus on making IVIS feel trustworthy and give users the ability to adjust settings and customise the systems.

2.3 In-Vehicle Interfaces

Strömberg, Andersson, Almgren, *et al.* [19] held a study to examine the design of user interfaces and Human-Machine Interaction (HMI) of EVs. By conducting user tests with two different scenarios in a driving simulator, they found that participants sometimes had problems understanding the information on the interface despite trusting that the displayed information was correct. They also discovered that the lack of knowledge and mental concepts regarding electricity and battery usage in EVs influenced how much the users understood from the interface in the car. It was also prominent that the drivers did not understand the factors that caused the range to fluctuate. This led them to express that the range decreased more rapidly than what seemed reasonable, which in turn resulted in the drivers deeming the range information unreliable [19]. The authors also stress how important it is that the vehicle conveys energy related information in a reliable and precise manner to drivers that might be inexperienced with electric energy measurements. Aside from that, drivers should also be aided in developing an understanding of what factors affect the available range to reduce range anxiety [19].

Another simulator study by Gary Burnett and Pickering [29] looked at in-vehicle interfaces, but instead focused on touchpad systems. They discussed what tasks are suitable for in-vehicle touchpad systems compared to touchscreens and a rotary controller interface. Participants carried out a set of different tasks with a prototype using a touchpad system, a touchscreen, or a rotary controller interface, and the results indicated that the preference for type of user-interface was heavily dependent on the type of task that was to be carried out. For example, the touchpad interface was perceived to be easier to use for simple commands, whereas the touchscreen seemed more fitting for complex menu interactions [29].

2.4 Cognitive Load and Safe Driving

According to Engström, Markkula, Victor, *et al.* [30], when it comes to safe driving, driver inattention and driver distraction are the two main factors that are usually discussed. Both of these include activities related to objects that are both inside and outside the vehicle - it could be that the driver is calling or texting on the phone, talking with the passengers, looking at billboards outside the car, or interacting with onboard systems inside the car. One of the three main components of driver distraction is cognitive distraction, which can be described as “withdrawal of attention from the driving task” [30], or “having the mind off road” [31]. Cognitive distraction refers to directing attention towards another activity and thus away from driving [32], and is often discussed together with *cognitive load.* Cognitive load, however, refers to the amount of cognitive resources that is demanded by the driver when they are distracted with a task outside of driving [33]. Engström, Markkula, Victor, *et al.* [30] developed a framework for understanding effects of cognitive load on driving performance, and a way to predict whether a driving subtask is likely to become automatised over time, and thus not have an effect on cognitive load. Engström, Markkula, Victor, *et al.* found that this framework, which they call ‘The cognitive control hypothesis’, suggests that cognitive load impairs driving subtasks that rely on cognitive control, but that automatic driving performance is unaffected. It is therefore implied that a higher cognitive load from tasks like complex navigation or multitasking in the vehicle negatively impacts driving tasks that require cognitive control, such as maintaining lane position and responding to traffic signals. This, however, does not affect automatic tasks such as basic vehicle operation. From the research, it is recommended to minimise cognitive load during driving by reducing complex tasks, and when it comes to the design of onboard system interfaces, it is recommended to provide clear and simple information to the driver [30].

Kountouriotis, Wilkie, Gardner, *et al.* [34] also studied cognitive load and safe driving, focusing on gaze and the task of steering while driving. Their study used simulated driving and gaze-fixation points that had similar properties to real-world road signs or were comparable to IVIS. Results from their study showed that fixating on points far outside the road caused understeering (steering towards the outside edge), while fixating far inside caused oversteering (steering towards the inside edge). Kountouriotis, Wilkie, Gardner, *et al.* also found that when the driver viewed IVIS-type displays, the lane variability decreased. The study concluded that a driver's gaze is critical for safe driving. Additionally, IVIS-type displays might make drivers more vulnerable to cognitive interference, which could potentially affect their steering control. These findings highlight the importance of gaze direction and steering control for safe driving, and suggest that when designing IVIS-type displays both visual attention and cognitive load should be considered to enhance safety while driving.

2.5 Nudging and Safe Driving

Nudging, which is the use of User-Interface (UI) design elements to guide people's behaviour [35], has been studied when it comes to safe driving. Choudhary, Shunko, Netessine, *et al.* [36] conducted a study on nudging and safe driving, to see the effectiveness of nudging to improve driving performance. They sent different types of nudges through notifications to drivers on a smartphone application, indicating how the drivers had performed on the current trip compared to their personal best, personal average, and latest driving performance. The driving performance was measured using telematics technology, such as real-time sensor data from an accelerometer, Global Positioning System (GPS), and gyroscope in a mobile device. The results were also compared to a control group with no nudging received. Choudhary, Shunko, Netessine, *et al.* found that nudges showing the driver's personal best and personal average performance were most effective in improving their driving performance. These findings suggest that personalised nudges can be a cost-effective approach to improving driving safety by influencing driver behaviour through personalised feedback.

2.6 Bias in Research for Design

When it comes to User Experience Design (UXD) and User Experience Research (UXR), biases are not discussed much [37]. In Interaction Design (IxD), **cognitive bias** is the most commonly mentioned bias. In their literature review, I. Saygı and Y. B. Saygı [38] discuss how cognitive biases are systematic errors in human reasoning and decision-making, and that these biases are suggested to affect interactions of users with computers. The most commonly discussed cognitive bias was **confirmation bias**, which is the tendency to actively seek out and interpret information in a way that confirms one's already pre-existing beliefs, while dismissing the information that might contradict one's beliefs. I. Saygı and Y. B. Saygı [38] concluded that to minimise negative effects of cognitive biases, the designers should focus more on UXR to understand the needs, behaviours, motivations, and pain points of users, or try nudging.

Aside from cognitive bias, **participation bias** which is also known as non-response bias, is also a common source of error in studies where participants might give inaccurate answers for a variety of reasons [39], [40]. According to Elston [39], survey studies are more prone to participation biases, especially if the response rate for the survey is below 60%. However, Fowler [40] argues in his handbook for survey research methods that the real problem lies in the lack of good information about *when* participation biases are likely to seriously affect the results. To reduce these types of survey errors, Fowler therefore recommends thorough evaluation of survey questions, and to pair the survey with focus groups or interviews if possible.

Despite the many biases that exist, the effects and implications from using biased and unreliable data are often overlooked or simply not mentioned when it comes to UXD. From the study done by Purdy [37], it was recommended to UX designers and researchers to try to minimise and address biases by:

- Educating themselves and others on cognitive and personal biases, and to work to understand bias as they apply to design and research
- Document assumptions and applicable biases in the context of the work
- Actively work with others that have different lived experience
- Actively seek the opinions of others that disagree with oneself
- Balance openness to new ideas and critical thinking about decisions and actions

3

Theory

This section introduces the relevant theories, frameworks and processes used in the research of interaction design in this project.

3.1 Research Through Design

Gaver [41] has done research about Research Through Design (RtD). He argues that RtD is less about problem-solving and creating a solution, and more about the process itself which makes it stand out from other practices. According to Gaver, the most important part of a project is not necessarily the end product but the learning outcomes and key aspects achieved. An example of outcomes when using RtD are guidelines or requirements. RtD is a tool used as a complement to other methods such as empirical studies and often in correlation with interaction design projects [41].

3.2 Interaction Design (IxD)

Interaction Design (IxD) is a broad subject, and focuses on “the specification of digital behaviours in response to human or machine stimuli”, as explained by Goodman, Stolterman, and Wakkary [42]. Below are the relevant frameworks and theories in interaction design used in this project.

3.2.1 Usability

An important aspect in IxD is the usability of an interface. International Organization for Standardization (ISO) presents a comprehensive explanation as to what usability means and provides a list of where usability is relevant, such as efficiency to achieve set goals, teach users to evolve from beginner to experienced, and minimising errors and undesirable consequences [43]. Additionally, ISO also mentions that usability is an important tool used in other practices such as UX design and User-Centred Design (UCD).

3.2.2 User Experience Design

UX is the user's perceptions and/or responses that result from them using and/or their anticipated use of a system [43]. The responses can vary in theme but can include emotions, beliefs, preferences, perceptions, comfort, behaviours, and accomplishments. These responses can occur before, during, and after use. Sharp, Preece, and Rogers [44] talk about UX as "going beyond usability". This means designers need to not only check if a system is easy to use and accomplish the basic needs of the users, but to also make sure the quality of the overall interaction is high.

3.2.3 User-Centred Design

UCD processes are necessary for forming a good understanding about the actual users intended of a system [44]. By focusing on the use of a system, UCD aims to make interactive systems more usable by factoring in the user factor throughout the design and development process. UCD is also known as human-centred design, and aims toward including a broad set of stakeholders and not only the ones typically considered as users. Additionally, an important factor in UCD is having users take part throughout the design process, to not only design for users but *with* them as well. Creating usable systems leads to multiple benefits such as improved productivity, enhanced user well-being, avoidance of stress, increased accessibility, and reduced risk of harm [43].

3.3 Interaction Design Processes

The interaction design process consists of several stages. The designer needs to discover the user needs and analyse them, design a potential solution, prototype, and then also implement the suggested design solution [45]. There are different frameworks that help the designers walk through these different stages, and in the following section the Double Diamond and the Triple Diamond process will be explained in further detail.

3.3.1 Double Diamond

The double diamond process is divided into two phases: problem and solution, which in turn are divided into the sub-phases: diverging followed by converging. The process is usually represented by two diamonds, the first diamond for problem, and the second for solution, see Figure 3.1, which is were the name comes from. The diamond illustrates the diverging and converging phases, where the designer first needs to broaden the view about the subject and scope, and then define and narrow it down into one problem. To optimise the process, Sunsunwal and Agarwal [46] mention four guidelines for using the double diamond process. (1) Collaboration: to work with others and get inspired by others work. (2) User-centred: make sure to understand the intended users and their needs. (3) Iterate: it is important to continuously improve, double check to make sure the users are understood, and make changes/updates when needed. (4) Communicate: make sure to be in contact

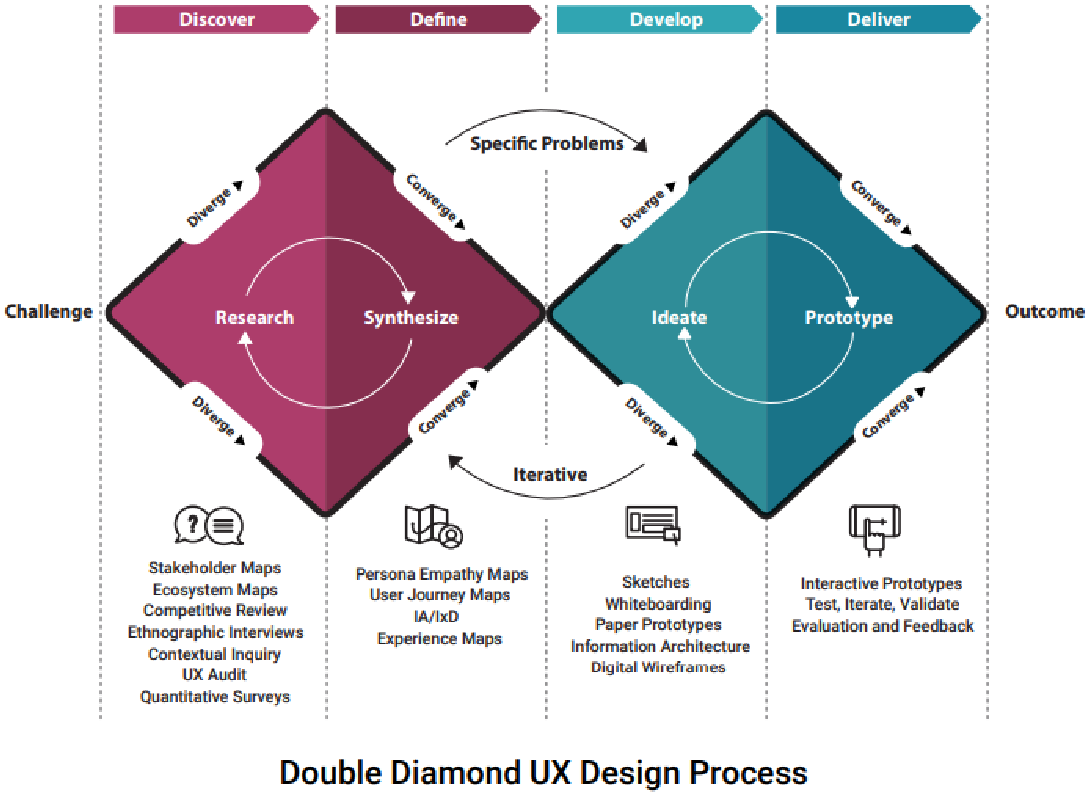


Figure 3.1: Visualisation of the double diamond process [46]

with users throughout the process and use terminology they understand to make them feel included in the process.

3.3.2 Triple Diamond

The triple diamond process is similar to the double diamond process but with one additional diamond. In this process, the diamonds are divided into discover, define, and deliver (see Figure 3.2) [47]. The triple diamond process puts a big focus on learning about users and defining the problem space. Both the first and second diamond (discover and define) focus on the users and the problem, to make thorough research about who the target audience is, what other products already exist, and what can be learnt from studying them - all to define the problem space. Then the final diamond's focus is to make prototypes and to evaluate them together with users. Therefore, the difference between the double diamond process and the triple diamond process is the bigger focus on users and the problem space in the triple diamond process [47].

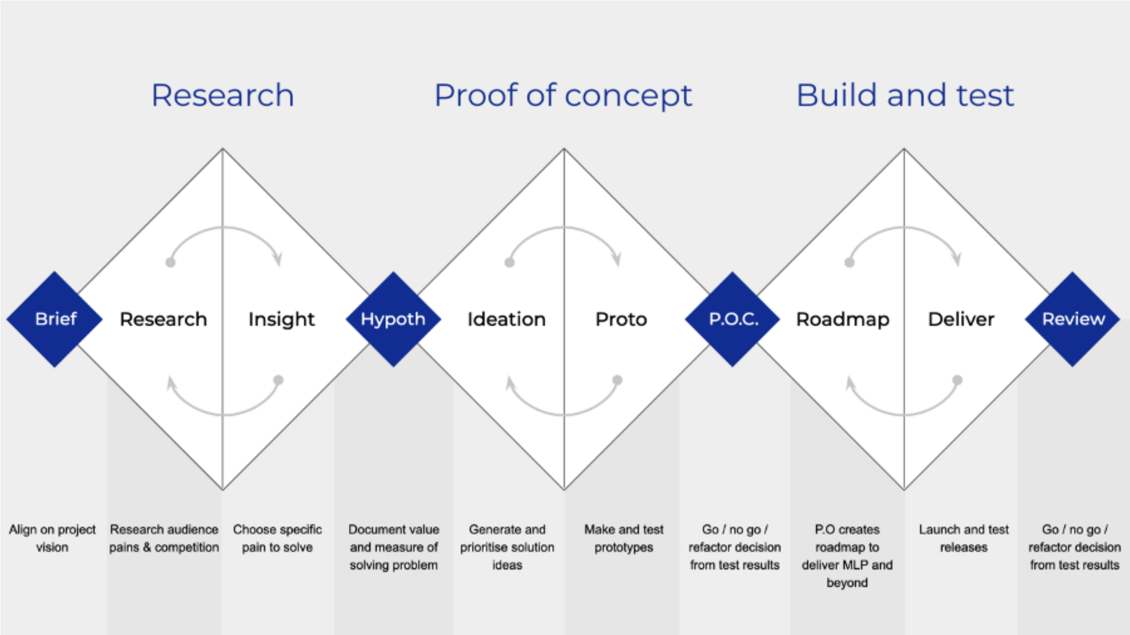


Figure 3.2: Visualisation of the triple diamond process [47]

4
Methodology

This chapter will present an overview of the methods in interaction design that are relevant for the project. The methods for data gathering and understanding the users will first be explained in detail, followed by methods for defining, ideation and developing. Lastly, the methods for analysis and evaluation will be explained.

4.1 Methods for Data Gathering and Understanding the Users

As mentioned in Section 3.3, the interaction design process consists of several stages. The first stage of the interaction design process focuses on understanding the users together with researching and gathering insights about the problem [44]. The data gathering is an important part of UXR and understanding the users, and can be divided into two categories: exploratory research and evaluative research. This phase of understanding the users focuses more on exploratory research, which aims to understand the needs, preferences and behaviours of the users [38]. Therefore, this section presents the methods suitable for the data gathering stage in the interaction design process.

4.1.1 Pre-Analysis

A pre-analysis of already existing data is one way to understand users, which is needed for the early stages of the interaction design process. By using existing data from for example surveys, an understanding of the users and the current situation can be formed by making a basic qualitative data analysis. After the pre-analysis, the following steps in the data gathering stage will further complement the understanding of the topic and the context of the problem space.

4.1.2 Questionnaires

According to Hanington and Martin [48], questionnaires are designed for collecting users' self-reported information. It could be anything from their thoughts and feelings to their perceived behaviours and attitudes, all of this typically in written form. Questionnaires can include both open-ended questions to provide an opportunity for more in-depth responses, but close-ended questions can also be used to get more quantifiable data [48]. Questionnaires are similar to interviews, but one big difference between the two is that once a questionnaire is produced, it can be distributed to a large number of participants, without the time constraints that interviews might have. This way, questionnaires are better in collecting more data that otherwise could have been collected through interview studies. Another advantage with questionnaires is that the requirement for users' locations is not as high as it might be for interviews that are conducted in-person [44]. One important thing to keep in mind when designing questionnaire questions, however, is to keep the questions clear and specific, since the researcher will not be able to explain each question to all respondents [44].

4.1.3 Interviews

Interviews are another method for collecting data. There are several types of interviews: **unstructured**, **structured**, **semi-structured**, and **group interviews** (also known as focus groups) [48].

Unstructured interviews are also called open-ended interviews, and are typically exploratory and very similar to conversations about a specific topic. The questions are usually asked in a way where there are no particular expectations about the format or content of answers [48], making it easy to go more in-depth about the topic and generate rich and complex data.

Structured interviews typically consist of close-ended questions, where the answers need to be short and clearly worded. The questions that are asked need to be the same for all interviewees as well, and should always be asked in the same order [48].

Semi-structured interviews are a combination of structured and unstructured interviews, and include both open- and close-ended questions. Usually the interviewer starts with a basic script to keep the topics and themes consistent with each interviewee, but the interviewer can sometimes probe the interviewee for a more elaborate answer if they think it is needed [48].

Group interviews, or focus groups, allow diverse or sensitive issues to be raised, and enable people to put forward their own perspectives. A group consisting of 3-10 people are usually interviewed at the same time, and sometimes they are asked to complete an activity together as well [44]. Group interviews are efficient in providing more natural conversations, and participants will sometimes remind each other about details that otherwise might have been left out during individual interviews [48].

4.2 Methods for Defining, Ideation & Developing

After understanding the users, it is important to also understand the users' needs. An understanding of the problem space can then be formed after getting to know the users' needs. In this stage of the interaction design process, it is important to define the problem clearly so that the next steps can be carried out, namely, ideation and developing [44]. This section presents various methods that are suited to define the problem and understand the users' needs, together with methods for ideation and developing a solution for the problem that has been identified.

4.2.1 Scenario

Scenarios are informal fictional narratives that describe how a user might interact with a design or a product. The general purpose of creating scenarios is so that the design team can refer to it throughout the development process as a way to envision the possible ways the product or concept might be used in the future [44], thus being able to identify requirements and needs. With scenarios, the design team can focus more on how both normal and extreme users would handle the product, and not risk putting too much time in refining technical details. The key to successfully writing good and useful scenarios is to be able to empathise with the future users, and envision a successful interaction between the user and the product [48].

4.2.2 User Archetypes

According to Nielsen [49], using user archetypes is a way to describe users based on their behaviours and needs. User archetypes are similar to personas, and they often visualise the same kinds of insights, but they are different in the way they visualise the users. Both user personas and user archetypes are representations of user clusters where there can be overlaps in e.g., user behaviours, attitudes, pain points, motivations, and goals. The clusters of users that are identified help the designer in identifying needs amongst the users, and the designer will often end up with a small set of key characteristics that differ across different user types [49].

The main difference is that user archetypes are not presented as a specific (usually ficitonal, made up) human character. User archetypes are more abstract, and sometimes a better way to identify and visually describe general patterns which are repeated in different contexts [49]. These archetypes can then also be applied to scenarios, where they represent users and their behaviours. User archetypes can also make it possible to find different solutions to the same problem depending on the perspective of the user, they might have different reasons for the same problem which requires different solutions. Additionally, archetypes are a good tool for communication as they often use simple terminology and they break down problems into smaller problems that are easier to understand [50].

4.2.3 Benchmarking

One important step between defining and evaluation is to measure, compare, and identify the best practices across an industry. Companies have to strive to be faster, better, and cheaper than their competitors, and benchmarking can be seen as a tool to attain or even exceed the performance goals in the industry [51]. According to Anand and Kodali [51], there are many definitions of benchmarking, but one of the most commonly quoted definition is:

> "Benchmarking is the search for the best industry practices which will lead to exceptional performance through implementation of these best practices." [52]

Benchmarking is essentially when the design team continuously tests a product over an extended period of time, allowing them to track the progress of the product as development is iterated. At the same time, it's used to compare the product with competitors' products [53]. It is important to discuss the stakeholders when benchmarking, to capture different expectations [44]. Benchmarking begins with planning precisely what one intends to measure of a product. Usually, it's the areas most critical to the users and sales. Then, through completing different tasks with the various products, the design team can evaluate the performance of each product and thus identify the most important features to help the user complete the task [53].

4.2.4 Affinity Diagramming

Affinity diagramming is a process used to help designers capture observations, concerns, or requirements on sticky notes to easier consider the implication of each trait on its own [48]. It could be answers and transcripts from interviews, notes from observations, or other survey data that needs to be sorted. The notes are clustered based on affinity, see Figure 4.1 as an example. It is important to note that these sticky notes should not be grouped into predefined categories, but rather reveal categories *after* grouping them [48].

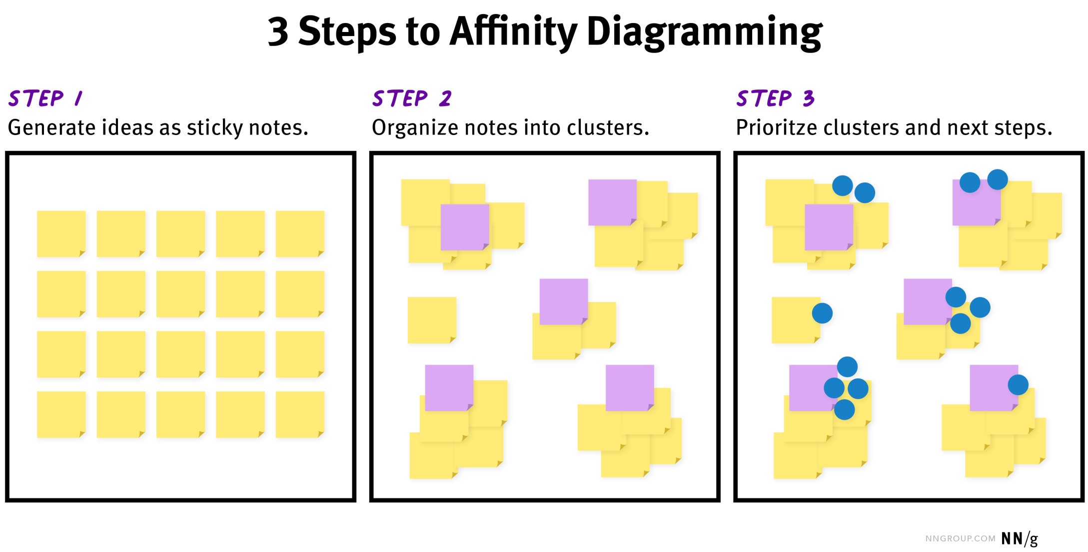


Figure 4.1: The three steps to make an affinity diagram [54]

Affinity diagrams are a great tool for externalising and making sense of qualitative data that sometimes can seem rather dissimilar. In IxD, affinity diagrams are most commonly used in prototype evaluations [55]. As seen in Figure 4.1, there are steps when creating affinity diagrams. The designer should write down all the qualitative data and create separate notes, then cluster notes and organise them into groups of similar themes, then finally prioritise groups of notes. Affinity diagramming can be done individually or collaboratively, and traditionally on paper sticky notes or on digital platforms as well. One software used for digital affinity diagramming is Miro [56], and is often utilised by designers in collaborative design workshops and brainstorming sessions.

Affinity diagramming is sometimes compared to thematic analysis (see Section 4.3.3), but there are some differences between the two evaluation methods. While thematic analysis also is a method to analyse qualitative data, affinity diagrams are often used in the earlier stages of design and research, and is often quicker and more immediate compared to the longer and more detailed process of a thematic analysis [57].

4.2.5 Requirement List

A requirement refers to what a product is expected to do or how it is expected to perform [44]. Design requirements can be seen as guidelines that outline the necessary characteristics and functionalities of a product to ensure that it meets the users' needs and expectations [58].

Two different types of requirements are usually discussed: **functional** and **non-functional** requirements. **Functional requirements** describe what the product will do, what actions it can execute [44], and it is fundamental to understand the functional requirements for an interactive product. The **non-functional** requirements describe the characteristics and constraints of the product [44]. Beside these types of requirements, there are five other types of requirements that are commonly discussed amongst designers: **data requirements**, **environmental requirements**, **user characteristics**, **usability goals** and **user experience goals** [44].

Interactive products handle data, and **data requirements** capture the type, unpredictability, size, accuracy, and value of the required data. Sharp, Preece, and Rogers [44] explain that for **environmental requirements**, the design team needs to consider the circumstances in which the interactive product will be used. Physical environment like lighting, noise, and movement in the operational environment are important factors that the designers need to consider. They also need to consider the social environment, such as collaboration and coordination, especially if the product will be used by several users. There are also requirements for organisational environments and technical environments, which focus on areas like user support, resources attainable by the users, and also what technological limitations might be relevant for the product [44]. **User characteristics** are about the attributes of the intended user group, for example users' skills and abilities, their educational background and so on. For the requirements in this group it is especially important to consider the level of interaction that the user might be able to execute, if the user is a novice then the product might need more step-by-step guidance etc. For **usability goals** and **user experience goals**, the requirements are typically decided early in the development process, which ensures that the usability and the user experience goals are priorities that facilitate progress tracking [44].

By listing all these different types of requirements, the design team can use them as a guideline to refer to throughout the design process, and make sure that all important aspects are considered when developing a product.

4.2.6 Brainstorming

Brainstorming is when the design team comes up with ideas to solve design problems, and is also where they start working on the conceptual design of the product. Brainstorming typically starts with the design team discussing the background and parameters, as well as agreeing on the goals of the ideation process [59]. It is essential that the team defines a clear problem statement as the purpose for the brainstorm, this way it will be easier to bring the focus back to the main topic if needed throughout the idea discussions [60]. There are a lot of ways to brainstorm, some methods include brainstorming in smaller breakout groups or pairs, to have intense rapid interactions to produce a large number of ideas quickly. It is common practice to use post-it notes or whiteboards to sketch and take notes during the brainstorming process, and it is important that the process is democratic, that all ideas are valued equally [59].

4.2.7 Prototyping

Prototyping is a way to provide a concrete manifestation of an idea, to better communicate with the users and the design team of one's concept. A prototype should emphasise the important characteristics and features that the designers wish to test or convey to the user testers, but it does not necessarily need to be a fully functional product [44]. It can be anything from a paper-based outline of a display, a video simulation of the concept, a three-dimensional mock-up model or even a simple paper-based storyboard, as long as it can convey the important traits that the designers want to test and evaluate [44]. Low-fidelity prototyping is usually common in the early stages, whereas later stages can have more refined high-fidelity prototypes, to more accurately portray the functions and features of the final product [48].

There are many programs and software that can be used to create higher-fidelity prototypes. One such program is Figma [61], a collaborative interface design tool. With Figma, people can create, share and test designs for websites and apps, or other digital products. It can be used both by solo designers and larger design teams, making it popular for interaction design and user experience projects.

4.3 Methods for Analysis & Evaluation

There are various methods for analysing data, whether it is quantitative or qualitative data, or a combination of both types [44]. Analysing the gathered data is also a type of user research, and falls under evaluative research, which aims to evaluate the usability and effectiveness of a product or service [38]. The following section therefore focuses on usability testing, A/B testing, and thematic analysis, which are relevant evaluation methods for this project.

4.3.1 Usability Testing

Usability testing is a method that allows the designer to evaluate and observe a user's experience with a product, as he or she walks through the steps of a task that is given by the designer [48]. Digital.gov [62] explains usability testing as:

> "Usability testing refers to evaluating a product or service by testing it with representative users. Typically, during a test, participants will try to complete typical tasks while observers watch, listen and take notes. The goal is to identify any usability problems, collect qualitative and quantitative data and determine the participants satisfaction with the product." [62]

Usability testing allows the designer to clearly identify the parts of the product that frustrate or confuse the users, so that the designer can focus on improving or fixing that specific part of the design. Usability tests are meant to reveal problems and areas that need improvement, as well as provide insight for how normal users might use the product differently compared to the designers [48]. Typically, usability tests follow the 'think-aloud protocol technique', which is a method that requires the participants to verbalise their thoughts and feelings as they are using the product to complete a task [48]. Usability tests are also often paired with surveys that can take place prior to, or in tandem with the test itself. The results from the surveys are often analysed together with the results from the usability tests, to properly uncover potential design flaws or problems with the product [63].

4.3.2 A/B Testing

A/B testing is a technique that is often applied to evaluation tests, to compare two different versions of a design [48]. With two different designs, it is important to make sure that the sample sizes are equally big, and that the participants are randomly assigned to either test A or test B. After using A/B testing, the researcher should be able to determine which design is better suited to help them reach their design solution goal. Although A/B testing is great for determining which design gives better test results, the method itself is not enough to help the researcher understand the reasons for why one design is better than the other. A/B testing should therefore not be a replacement for qualitative methods, but should rather be used as a supplement for qualitative methods to help the researcher gather insight and deeper understanding of why one design might be preferred over the other [48].

4.3.3 Thematic analysis

Thematic analysis is an umbrella term for methods used to identify themes in qualitative data. The themes that are found could be about the behaviour of the user, a new unexpected user group, places or situations where the product is used, and so on [44]. In general, a theme should represent a pattern or a topic found in the data, which is important and relevant to the development of the product or the aim of the study. Qualitative data will usually be paired with thematic analyses, however, themes and patterns can emerge from quantitative data as well [44]. There are different types of analyses, **inductive** and **deductive**. When a study is exploratory, an inductive analysis is more suitable to let the themes emerge from the data. For deductive analyses, the designer will usually have a set of predetermined categories to easier identify detailed patterns and themes that are important for the research [44]. According to Caulfield [64] there are six steps you should follow when doing an inductive thematic analysis:

1. **Familiarisation**
   This stage is about getting familiar with the data. There has to be a general knowledge about the data before it can be divided into themes.

2. **Coding**
   During this stage, sentences and phrases should be coded and labelled. Generally this means that important sentences are highlighted and then a label and colour-code is set to describe the content.

3. **Generating themes**
   During this stage, the labels are used to create bigger themes from patterns found amongst the labels. In general, multiple labels are used to create one theme.

4. **Reviewing themes**
   This is a step where the themes created are double checked with the original data to make sure that they are relevant and accurate representations of the data. This is to make sure that all aspects of the data is covered and make sure that the themes are appropriately named. During this step, themes can be split up, combined, deleted, or created depending on what benefits the most.

5. **Defining and naming themes**
   In this step the themes are named and defined. When naming a theme, it is important that it is succinct and easy to understand. Defining themes includes to give a short explanation of the theme and what is meant with the theme and how it helps to understand and represent the data.

6. **Writing up**
   The final step is summarising the data and write it up in the report.

After identifying themes, it is also common to review the themes to make sure they are not overlapping and that the topics support the found themes [65]. Thereafter, the themes are defined and described. The design team will usually note why the themes are important for the development process as well, to easier go back to the developing phase in the interaction design process and improve the product.

5

Execution & Results

This chapter will cover the execution process and results of the project starting with the phase of getting to know the users (collecting data). Thereafter, two iterations of a prototyping and evaluation phase will be presented, ending with the final design recommendations from this research. The execution process has followed iterative methods such as the Double Diamond framework [46], see Figure 5.1.

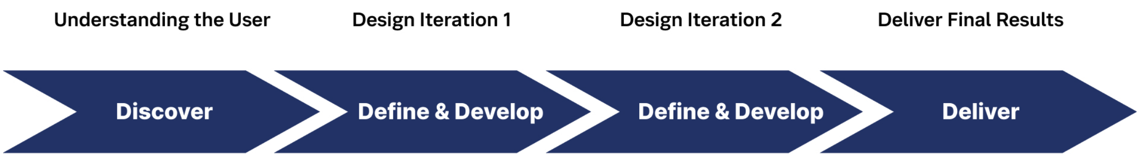


Figure 5.1: Illustration of the execution process

5.1 Understanding the User

The first phase aimed at getting to know the users by gathering a wide range of data, both qualitative and quantitative, and to understand the problem space as well as the behaviours, wants, and needs of the users. The execution of each method used to collect data in this phase are explained in the following sections.

5.1.1 Volvo Data Pre-Analysis

The pre-analysis study has been done on data found from two main sources: Product Quality Study (PQS) and OneVoice. PQS consists of survey data from Volvo Cars' own online surveys that are sent out to customers from after they have had their car for 2 and 12 months. OneVoice is a feedback program at Volvo Cars, where customers can send in feedback whenever in different forms, such as through the Volvo mobile phone application or email. The collected data from these sources were sorted into themes of bigger problem areas. Another part of the pre-analysis of existing data has been on benchmarking studies that Volvo Cars has conducted [66]. From the previous benchmarking studies, some inspiration was gathered for the brainstorming session later. Although a benchmarking study for this project was initially considered as well, it was ultimately not pursued due to time constraints associated with the master's thesis project timeline.

Volvo Cars has also researched user archetypes for different types of EV users when it comes to charging behaviour. The archetypes related to charging habits are relevant for the UX of range and how to plan future energy consumption. From analysing the existing data at Volvo Cars, it was decided to put the focus on long distance driving, since controlling range and energy efficient driving behaviour is especially relevant during those scenarios.

5.1.2 Questionnaire

To better understand the current users and the usage of the range applications in the EVs, a questionnaire was sent out through an internal team at Volvo, to Volvo employees. The authors had little control over whom the questionnaire would be sent out to, but received the demographical data of the respondents afterwards. The questionnaire received 132 respondents in total, of whom 118 were viable for further analysing. The questions for the survey were inspired from previous surveys done at Volvo and a previous master's thesis which had a similar research topic [66]. The demographic questions were therefore reused from previous questionnaires.

The main focus of the survey was to learn about the users' knowledge of the range information and their usage of the R.A. interface and the R.O. (for the full questionnaire, see Appendix A). An important aspect of the questionnaire was to investigate whether there exists a knowledge gap amongst the users, which may be one of the elements affecting the UX of EVs. Therefore, questions about users' understanding of the current R.A. application were included in the questionnaire, to check the current knowledge level.

5.1.3 Questionnaire Data Analysis

To analyse the questionnaire, the data was divided into qualitative and quantitative data. A thematic analysis was used on the qualitative data and diagrams and charts were used to compile the quantitative data.

As mentioned above, the thematic method described in Section 4.3.3, which is based on the article by Caulfield [64], was used to analyse the qualitative data. The thematic analysis was carried out in Miro [56]. An inductive approach was more relevant for this study, which includes a latent approach where the designer reads into the subtext and makes assumptions from the underlying data [44]. Each question was represented by a colour of post-it notes, which in turn have been grouped into themes, see Figure 5.2. For all open-ended questions, each participant could only provide one answer, which ensures that the data is not biased towards representing one respondent more than any other, and thus prevent skewing the results in the analysis.

The quantitative data was visualised with the built in feature in Microsoft Forms [67], which was the tool used to create the questionnaire. The quantitative data

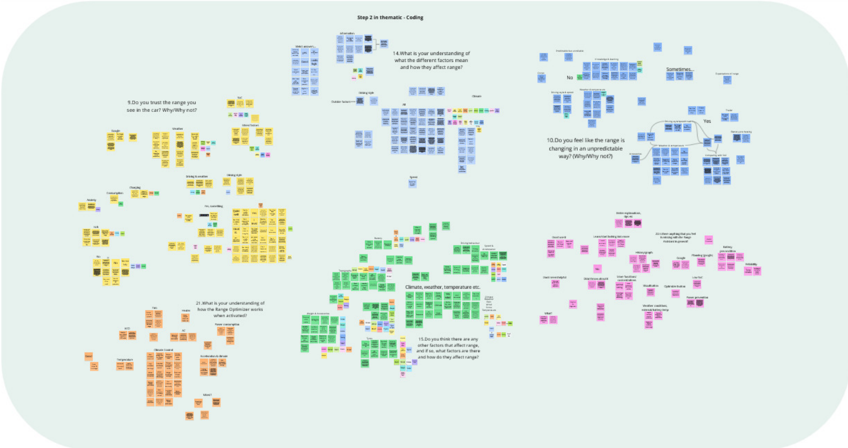


Figure 5.2: Thematic analysis board portraying grouping of themes

showed user demographics, and the most common usages of the Range Assistant application. In order to reduce the risk of bias and to avoid skewed results due to advanced subject knowledge, responses from participants whose professional roles were directly related to the topic of the questionnaire were excluded.

5.1.4 Questionnaire Results

The survey had a response rate of 43% with a total of 132 responses. 14 responses had to be excluded, 12 because of their professional roles, and 2 for not driving an EV with the relevant system or for not having the correct apps, resulting in a total of 118 valid responses. Of the respondents, 92 were male, 25 female, and 1 preferred not to say. The majority of the respondents were from around the Gothenburg area, with a few exceptions from Stockholm. The age of the respondents ranged from 30 to 60+, M = 53,3 and SD = 7,53. As mentioned previously, all respondents were Volvo employees. Potential knowledge, gender, and age biases will be discussed further in the Discussion 6.

As mentioned in Section 5.1.3, the data from the questionnaire consists of both qualitative and quantitative data. From the qualitative data, two main categories of themes were found regarding users' view of range: (1) knowledge about range and (2) trust in range. For knowledge about range, the following five themes were found, labelled Q1-Q5.

Q1: **Driving Behaviour**
Driving behaviour was mentioned by the respondents to be one of the bigger factors affecting range. How they handle the car, such as acceleration, breaking, speed, and their driving style are included under driving behaviour.

Q2: **Tyres**
The tyre type, size, and pressure were mentioned as factors affecting the estimated range.

Q3: **Topography**
Respondents mentioned that topography (such as hilly roads) affect the range.

Q4: **Towing & Accessories**
Respondents mentioned that weight affects the range, that a number of different things contribute to increased weight, such as towing and accessories. Towing trailers or optional accessories like roof boxes or bike racks were mentioned to affect range through added weight and wind resistance. Respondents were aware that they can control how much these factors affect range.

Q5: **Weather & Road Conditions**
Respondents showed an understanding of how weather and road conditions might affect range. Wind, snow, rain, and temperature were mentioned by the majority of the respondents to affect the estimated range.

On respondents' trust in the range estimation, the five themes that were found are summarised in Q6-Q10.

Q6: **Charging for Peace of Mind**
Some respondents showed trust in the estimated range. However, to avoid getting range anxiety, they either chose to charge extra or made sure to charge whenever the SoC would drop below their personal comfort threshold.

Q7: **Learning to Trust the Estimated Range**
Some of the users found there to be a learning curve associated with the degree of which they trust the indicated range. More experience with the EV leads to a better understanding of range, which equips the driver with the knowledge to trust and interpret the shown range information in the IVIS.

Q8: **Impact of Weather Knowledge**
The knowledge about weather was found to affect respondents' trust in the estimated range. The influence of this knowledge on their trust in range varies between drivers. Some respondents trust the estimated range less because they know that weather affects it, and that the estimated range will therefore likely be inaccurate. Other respondents used the knowledge of how weather affects the range to make their own estimations, whereby they also stated that they trust the estimated range.

Q9: **Omission of Topography in Estimations**
Respondents' belief that the EV does not include topography in its calculations negatively influenced their trust in the range estimation.

Q10: **Uncertainty in Driving Behaviour Feedback**
The respondents found that it is unclear as to why and how the estimated range updates according to the driver's driving behaviour. They were discontent with the speed at which the estimated range updates and its mismatch with their current driving behaviour, which further fuelled their mistrust in the estimated range.

A small number of respondents mentioned battery and pre-heating as something that affects range, while the majority did not mention it at all. It was therefore not widely named as a factor influencing trust in the estimated range, nor was it brought up enough times to warrant its own theme.

From the quantitative data it was found that the drivers use the range information to plan their charging, plan their trips, and to assure their mind to reduce range anxiety. When it comes to the usage of the R.A., 46% of the respondents answered that they actively use the R.A.. Out of the drivers that do not use the R.A., 59% answered that they do not understand the information shown on the R.A.. It was also found that 86% of the respondents sometimes make longer trips that usually require charging along the way. In total, 58% of the respondents found that the R.A. was most useful on trips longer than 30 minutes.

The questionnaire also investigated the usage of the R.O.. It was found that 19% of the respondents do not know what the R.O. is, 43% actively use the R.O. feature, while 38% choose not to. Out of the respondents who answered that they know of the R.O., 36% do not know what changes it makes in the car when the user activates the feature. Despite this, some drivers still chose to use the R.O. feature.

The key take-aways from the questionnaire results are that (1) the dissatisfaction with range is *not* because of a knowledge gap of what elements affect range. (2) A part of the mistrust about range comes from the drivers' knowledge about outside elements that might affect range, of which they believed the EV's estimated range does not account for (see [Q8] and [Q9]). (3) With the current CMA version, there is a lack of understanding for what the R.A. shows, and how the R.O. works. It was therefore decided that the next step should focus on exploring different ways of relaying range information.

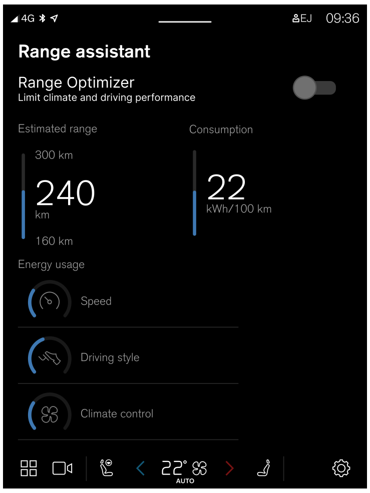
5.2 First Design Iteration

This section will go through the first design iteration, which will cover the prototyping and evaluation phases, and finishing with a list of findings.

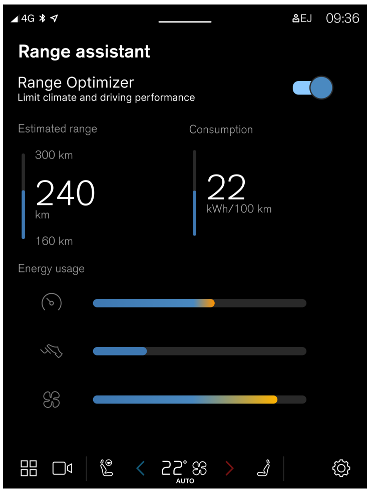
5.2.1 First Iteration Prototyping

From the findings of the questionnaire, it was decided that the first design iteration should focus on exploring different ways of relaying information on the range interfaces in the IVIS. The first step was to brainstorm a prototype concept. The authors brainstormed together, using various IxD brainstorming methods. From the brainstorming session, it was established that the following focus areas would be the main components to be tested.

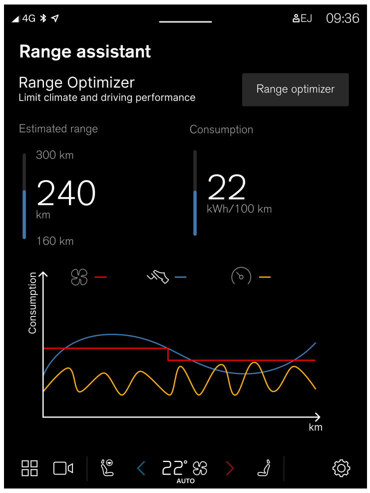
- Range Assistant layout
- Range Optimiser
- Range elements included in the Range Assistant application
- Range information in Dashboard Integration Module
- Tip-feature



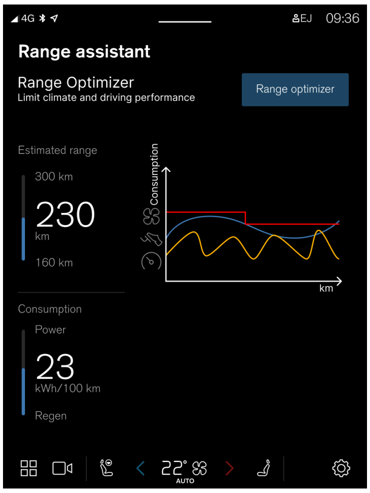
(a) Toggle button R.O. on top, radial bars beneath



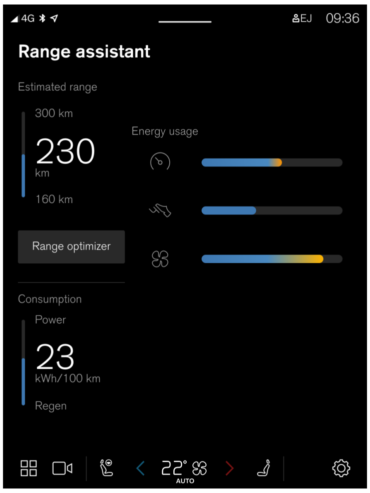
(b) Toggle button R.O. on top, horizontal bars beneath



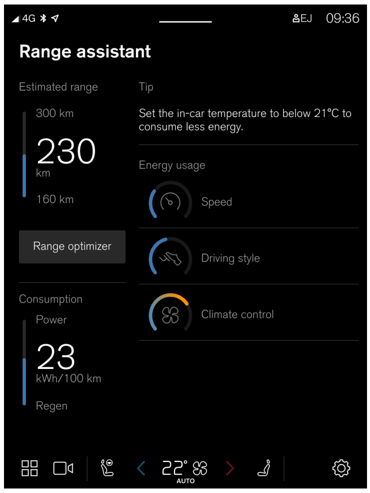
(c) Square button R.O. on top, graph beneath



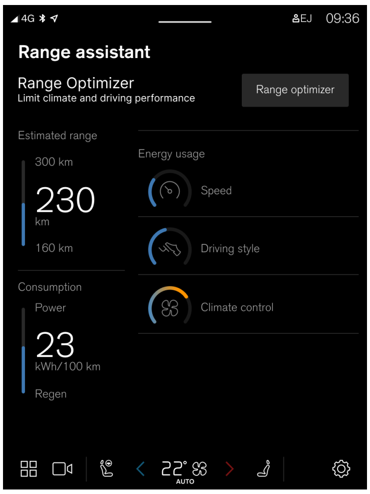
(d) Square button R.O. on top, graph to the right



(e) Square button R.O. to the left, horizontal bars to the right



(f) Square button R.O. to the left, tips and radial bars to the right



(g) Square button on the top, radial bars to the right

Figure 5.3: The low-fidelity prototype screens made for the CSD

A tip-feature was introduced in the focus areas mentioned above, despite not being explored in the previous phase. The tip-feature is something that does not exist in any of Volvo's cars today. Drawing on insight from the literature on nudging and driving safety [36] (see Section 2.5), it was desirable to inquire as to whether this feature is something that drivers would appreciate. The tip-feature was therefore implemented in the prototype (see Figure 5.3f) as a form of nudging aimed at encouraging more energy-conscious driving behaviour.

The low-fidelity prototype was created in Figma [61]. The prototype concept was based on the CMA-system. All design elements and graphical language followed Volvo's current elements and graphical language, and the components used in the Figma prototype were reused from Volvo's design library. The values shown on the prototype screens is only for a visual representation, and should not be seen as a representation of real world values. To fully cover the different aspects, several screen views were created and used in the testing.

Two types of layouts were used to investigate the preferred layout for the R.A. application interface, see Figure 5.3b compared to 5.3e. One version had the range elements positioned in the lower half of the screen, while the other version had the range elements placed on the right side of the screen.

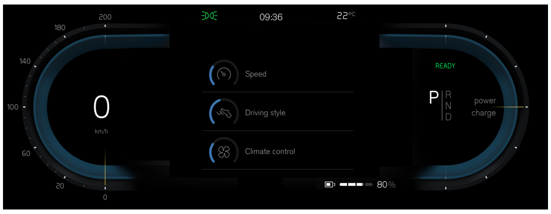
For the R.O., two aspects were investigated - placement of the interactive button for turning on/off the feature, and the type of UI button. There were two types of placement variations of the R.O., one at the top of the R.A. application (see Figures 5.3a, 5.3b, 5.3c, 5.3d, and 5.3g), and the other version had the R.O. placed on the left side of the screen, between the estimated range and current consumption metres (see Figures 5.3e and 5.3f). Two UI button variants (square button versus toggle button) were included in the prototype to test the preferred type of buttons, see Figures 5.3a and 5.3b compared to 5.3c and 5.3d.

The range elements shown in the R.A. cover three factors affecting range: speed, driving style, and climate. These factors were visualized in three different ways: radial bar (see Figure 5.3a), horizontal bar (see Figure 5.3b) and graph (see Figure 5.3c).

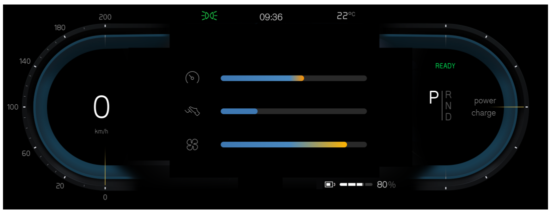
In Volvo's current EVs, the DIM is not used to communicate any other range related information aside from the estimated range. Different variations of the tip-feature and how to portray range elements in the DIM were tested, see Figure 5.4. To portray the range elements in the DIM, two variations were tested (1) a full screen view of the range elements (see Figures 5.4a and 5.4b), and (2) a combined view of map and range elements (see Figure 5.4c). The reason for testing two variations was to learn what level of information drivers want while driving. Additionally, two different ways to display the tip were tested (1) as a pop-up (see Figure 5.4d), or (2) as a full screen view (see Figure 5.4e).

5.2.2 First Iteration Testing

Seven participants tested the low-fidelity prototype, 4 male and 3 female, with an age span of 24-28 years old, M = 24,7 and SD = 1,50. All participants were interaction

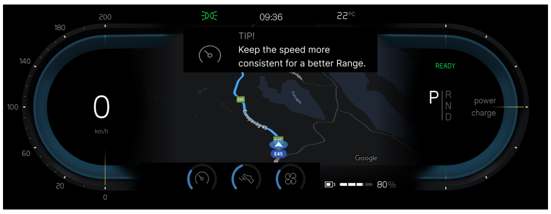


(a) Range view portraying range elements as radial bars

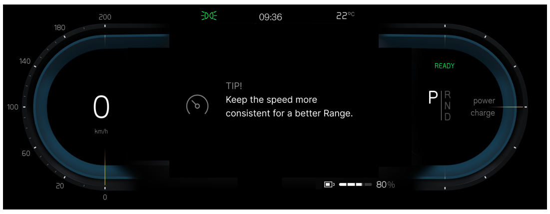


(b) Range view portraying range elements as horizontal bars

(c) Combined view of map and range elements as radial bars



(d) Combined view of map and range elements (radial bars) with tip pop-up



(e) Tip view as full screen

Figure 5.4: The low-fidelity prototype screens made for the DIM

design students. Six out of the seven participants have driving experience while the last participant had tried driving but had no extensive experience at the time of testing.

The prototype was placed in front of the participants for them to interact with, and an unstructured interview was held throughout the duration of the test. Participants were encouraged to think aloud while using the prototype, during which they were also asked specific questions about the layout, shape, and colour of different components of the interface to gather concrete feedback. As mentioned earlier in Section 4.3.1, the think aloud method is a common process used in user research activities, in which participants are prompted to speak what they are thinking as they complete a task or interact with a product [68].

To minimise bias, the order in which the prototype screens were shown for each participant was decided through block randomisation. Block randomisation is a common procedure to carry out random assignment in testing [69]. This is important to ensure that the order of the screens does not have an effect on the participants' opinions. Throughout the whole test, participants' comments and gestures were recorded as notes.

5.2.3 First Iteration Data Analysis & Results

The data was analysed using affinity diagramming with the Miro tool [56], as described in Section 4.2.4. The key points from the data were highlighted and written down on sticky notes, which were then grouped into clusters of connecting themes. The themes from evaluating the low-fidelity prototype were interpreted into the following list of findings, labelled L1-L11:

- L1: Information should be clear and easy to understand without distracting the driver.
- L2: It is appreciated to have range information in the DIM, and not only in the CSD.
- L3: The colours of the bars can give either binary or non-binary information (changing colour for the whole bar, or having a gradient), but should still be discrete so as not to distract the driver.
- L4: The shape of the metre (horizontal or radial bars) does not matter too much to the user.
- L5: It is appreciated to have a graph to show the history of the energy usage.
- L6: The history graph should be either in the CSD or in the mobile app, or even both.
- L7: The history graph should show the different factors and the energy usage, as well as the total energy usage for easier comparison.
- L8: The users should be able to toggle between map view and range view in the DIM.
- L9: Tips are appreciated, but not during drive if it is in textual form.
- L10: Tips in form of icons with visual elements (light/blinking) were brought up as a suggestion to have while driving. Dynamic real-time feedback is still appreciated.
- L11: Tips in textual forms could be appreciated after drives instead. The tips should not include factors the user cannot affect.

L1 Clear and easily understandable information

Participants wanted the information displayed in the interfaces to be clear and easy to understand. Because the test participants all had a background in IxD, some design related concerns were raised, such as visual clutter. Five participants also preferred when the R.O. was positioned at the top of the screen with an easily understandable button indicating whether the feature was activated or not. Additionally, as can be read in the quotes below, the most important information should be at the top and/or left side of the screen, as that was found to be the most accessible place to find information while driving.

> “I prefer when it (the R.O.) is positioned higher up, it is reasonable that the only interaction you have on the screen is on the very top, so you don’t have to search for it. I also like the toggle-button more, because everyone knows what a toggle-button looks like. The other button doesn’t indicate as well if it is on or off, you would have had to have used it before to have seen that it changes colour. It’s valuable to have the R.O. text which indicates what it does.”

> “It is good that the range is more to the left, then it is closer to the driver. It is visually better having it (the R.O.) high up on the screen, but it might be too far away from the driver?”

L2 Non-exclusive information

Participants were positive when presented with the option of having range information in the DIM. They liked that it made relevant information easily accessible by reducing the amount one needs to turn their head to look at the CSD. Utilising the DIM to show more range information was appreciated by the participants, see quote below.

> “Having the range information in the DIM is useful. I’m unsure if radial bars or horizontal bars fit best. It doesn’t matter what they look like, as long as they are included somewhere. You’d want to see the fuel consumption even in normal ICEVs, and usually that information is in the DIM. The idea is pretty smart. When I drive I look at the consumption metre too see how much fuel I consume, it’s pretty similar with range. It’s better to have the information in the DIM than in the CSD, so you don’t have to look at the CSD as much to get information.”

> “I like the idea of utilising the DIM to have range assistant information.”

L3 & L4 Shape and colour of the range elements

The feedback on both the colouring of the range factors and their shape suggests that the participants did not really prefer one over the other. They could see the potential use of both ways. One participant put it this way:

> “I think it works either way, both radial bars and horizontal bars work.”

Having the range elements change colour when energy consumption is high indicates to the driver that they would benefit from changing their behaviour to consume less energy. This was done either by changing the entire colour of the visualisation or having the bar as a gradient changing colour dynamically, but the participants did not show a preference. When it came to having radial or horizontal bars, five of the participants had no preference at all.

L5-L7 History graph

The graph was not a preferred visualisation of the range elements in the R.A. interface. However, a recurring suggestion was to have a graph showing a historic view of the energy usage instead. Two participants suggested that the historic graph should be available in a different tab on the R.A. interface, or on the Volvo phone application instead.

> "I'm imagining my mum driving - if she were to look at that (the range elements in a graph), she would not immediately understand what shes looking at. It would be interesting to check them out after a drive, but I think only people who are really interested in maximising their range would do that. Having a graph option is good still, just not during drive, I think it could cause visual overload."

One participant also mentioned that it depends on what kind of historic view the graph would be used for when considering whether it should be in the EV or in the Volvo phone application.

> "If you want to have history, not only from the latest drive but longer history, it could be good to have in a phone app in that case. Then you can see that you are generally pretty bad at speed for example, otherwise if it is just the history of one trip, then it might be better to have in the car."

L8 Toggleable information

As for the DIM, three participants stressed the importance of having the option to change between the different views available, such as the map view, and range view (see Figure 5.4). As one participant mentioned:

> "Think it could be good that you can decide yourself what it is you want in the DIM and CSD. You maybe might want to check sometimes, so it can be good that you can toggle what it is you can see in the DIM."

L9-L11 Form of tips

Tips were appreciated by the participants. They liked how tips support a better understanding of what the range factors mean and how to interpret and incorporate them into their driving. It was, however, brought up that the tip-feature would be more appreciated either pre- or post-drive, as one of the participants said:

> "The text, maybe you don't need to see it while driving, but it might be good to press and see what they mean before driving off."

The participants felt like reading longer tips while driving would draw too much of the driver's attention away from the road and therefore found that it could be a hazard. Still four participants liked having tips, which they felt could help them with their driving style:

> “I like the tips, but it is too long to be readable while driving. I like that you have the tip. You can glance at it so you know what it is you are doing "wrong". Tips are good - as long as they are not too long.”

An alternative to having the tips in textual form could be to use a light, a haptic, or a visual element, as suggested by three participants. In this way, the dynamic, real-time feedback the tips provide would still be conveyed. One participant commented on this during the interview:

> “I don’t want tips while driving, no text to read. Maybe otherwise an icon to indicate that there is a tip?”

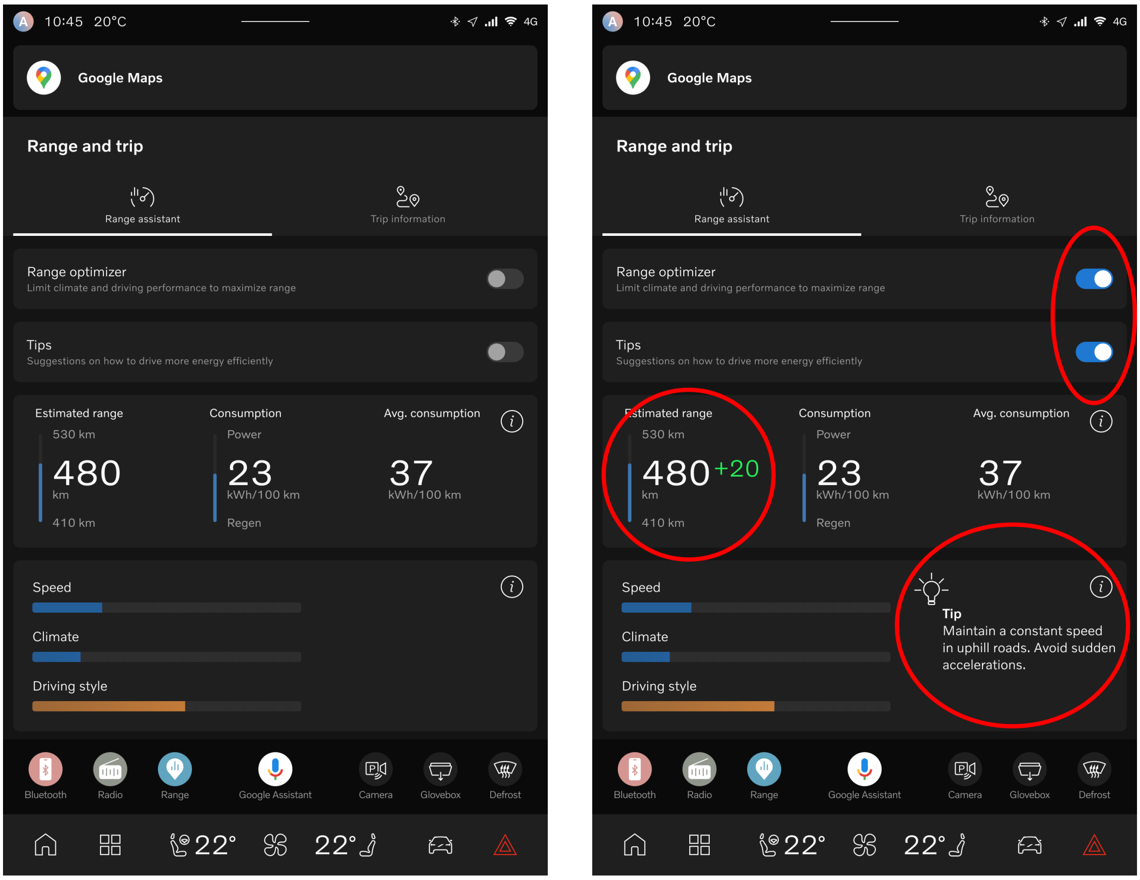
The findings from this iteration was not seen as a strict requirement list, however, it was used as recommendations and guidelines for the second iteration.

5.3 Second Design Iteration

This section will go through the second design iteration. Starting with utilising the findings from the first iteration to create a high-fidelity prototype, the evaluation process will then follow, and lastly the final results will be delivered as a list of design recommendations.

5.3.1 Second Iteration Prototyping

From the findings of the first design iteration, it was decided that the second iteration should focus on refining the low-fidelity prototype, with the end goal of delivering a high-fidelity prototype along with a list of design recommendations. Brainstorming sessions were held, and it was established that the final prototype should focus on incorporating (1) range information in both the DIM and the CSD, and (2) a tip-feature that reminds the driver to opt for a more energy-efficient driving behaviour. Inspired from the R.O. feature, it was decided that both the range information in the DIM and the tip-feature should be toggleable, giving the driver control over the amount of information they would be shown. Although some feedback from the first design iteration suggested removing the tip-feature during driving, and only having it available for post-drive scenarios, it was decided to test nudging [35] through a toggelable tip-feature in an interactive prototype in this second design iteration before making further decisions on this aspect. To minimise visual clutter, and to maintain a balanced visual attention and cognitive load according to the suggestions by Kountouriotis, Wilkie, Gardner, *et al.* [34] and Engström, Markkula, Victor, *et al.* [30], all these features were to be incorporated while maintaining a clean and simple interface.

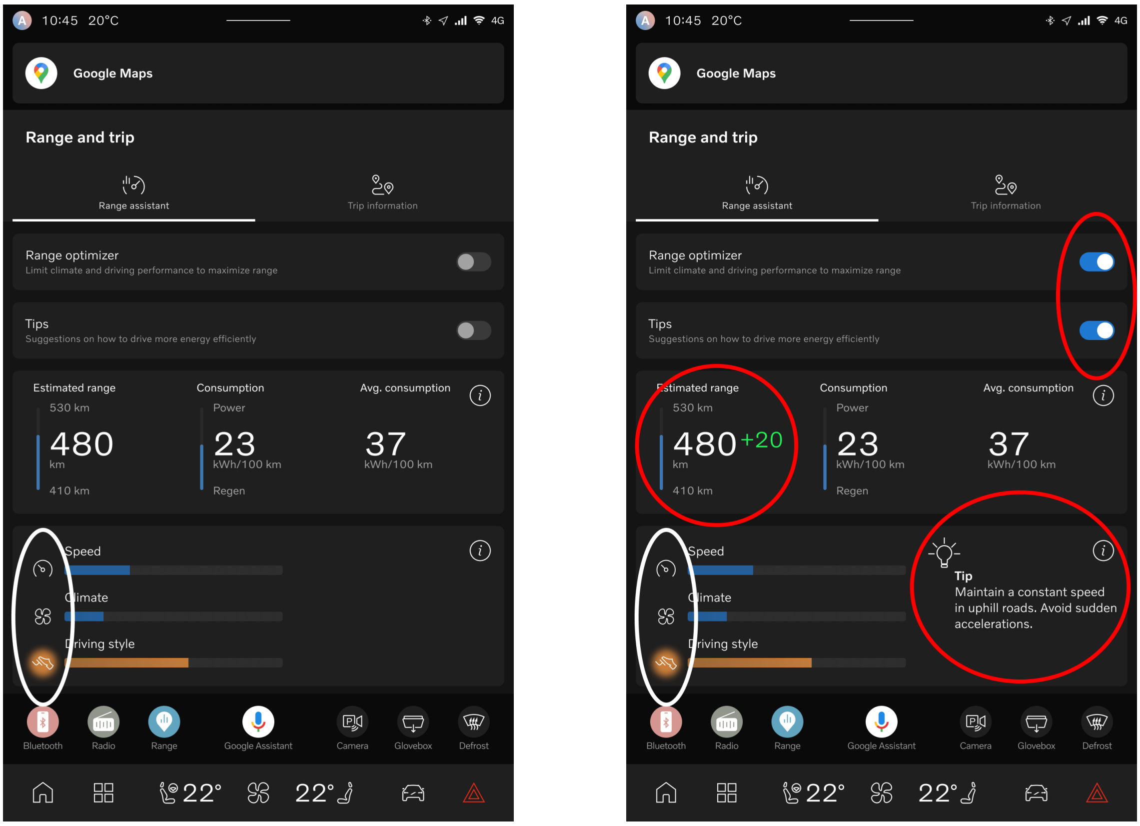


(a) Default view

(b) Activated R.O. and tip view

Figure 5.5: High-fidelity prototype of the Range and Trip app in CSD: Version 1

The high-fidelity prototype was also created in Figma [61]. The prototype was designed for the Scalable Product Architecture Version 2 (SPA2)-system using already existing components from both the CMA- and the SPA2-system. All design elements and graphical language followed Volvo's current elements and graphical language, and the components used in the prototype were taken from the Volvo design library. The values shown on the prototype screens is only for a visual representation, and should not be seen as a representation of real world values. The reason behind the decision of combining elements from both the CMA and SPA2-systems was because the equipment at Volvo that would later be used in the evaluation was only compatible with the SPA2-system. In order to cover as many focus areas as possible, two versions of the prototype were created. One version showed the range elements through only horizontal bars in the CSD, see Figure 5.5, while the other version showed the range elements through both icons and horizontal bars, see the white circles in Figure 5.6. Both versions included a toggleable R.O.- and tip-feature, and visual feedback was given when the functions were activated, as shown with the red circles in Figures 5.5b and 5.6b. A few seconds after activating the R.O., the estimated range would be updated with the added range gained from the R.O. feature, see Figure 5.7.



(a) Default view

(b) Activated R.O. and tip view

Figure 5.6: High-fidelity prototype of the Range and Trip app in CSD: Version 2

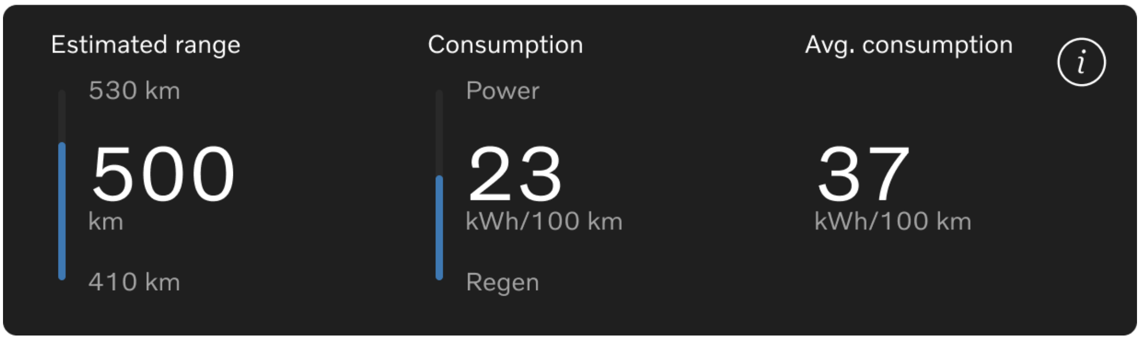
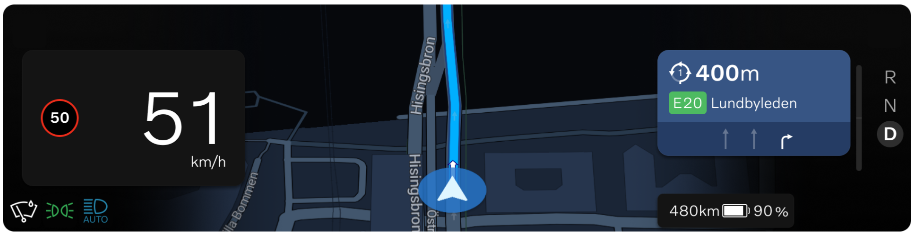
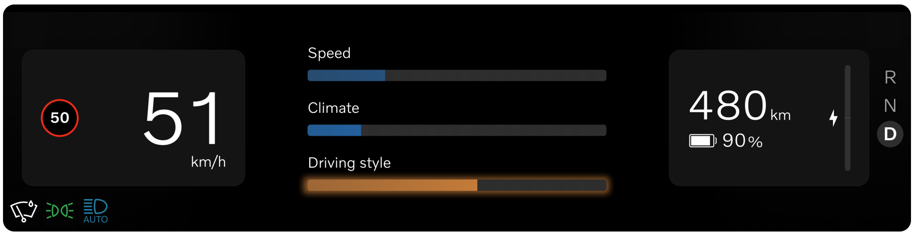


Figure 5.7: Updated estimated range after R.O. has been activated in the high-fidelity prototype

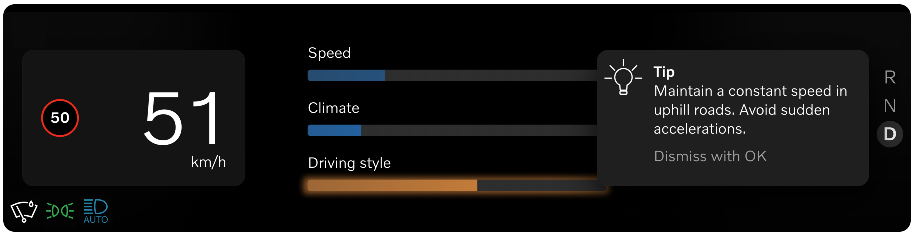
Views for the DIM were also created to complement the CSD views. As such, the DIM prototype also includes two design versions. The first version, shown in Figure 5.8, features separate views for the map (see Figure 5.8a) and driving factors (see Figure 5.8b). When the tip function is enabled, the tip will pop up in a window beside the factors view to provide helpful suggestions for a more efficient energy usage (see Figure 5.8c).



(a) Current map view in DIM



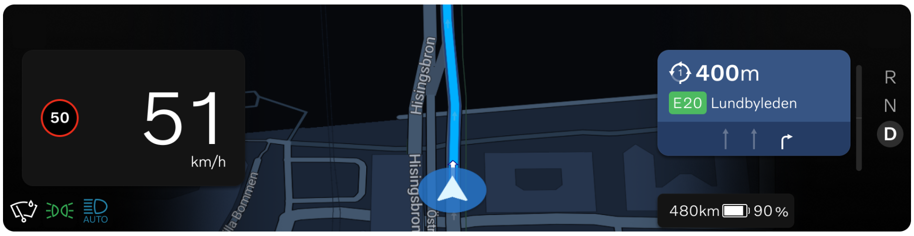
(b) Range elements view in DIM



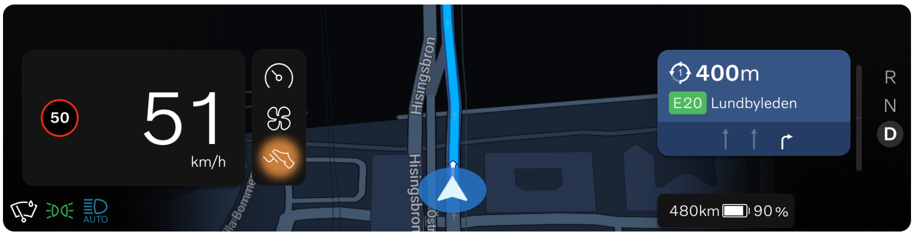
(c) Range elements view with tip pop-up in DIM

Figure 5.8: High-fidelity prototype of the DIM: Version 1

The second version shares the same map view as the first (see Figure 5.9a), but integrates the driving factors directly into the map view, allowing the driver to access relevant information on a single screen without needing to switch between views (see Figure 5.9b).



(a) Current map view in DIM



(b) Combined map and range elements view in DIM

Figure 5.9: High-fidelity prototype of the DIM: Version 2

5.3.2 Second Iteration Testing

Because two versions of the prototype were created, the A/B test model was applied to the evaluation of the second design iteration. The participants were divided into two groups, one for each version of the prototype. The Figma prototype was uploaded to a car rig equipped with the SPA2-system, which was used during the tests. This rig, known as *the Buck*, replicates the interior and systems of a Volvo EX90 (see Figures 5.10 and 5.11).

Participants for the test were recruited from respondents to the prior questionnaire (see Section 5.1.2) who had indicated a willingness to take part in further testing. In total, 16 participants were involved in the testing, 11 male and 5 female. Their ages ranged from 35 to 64, M = 53,8 and SD = 6,29. Their experience in driving EVs ranged from 8 months to 5 years, with one outlier having 13 years of experience. Most participants primarily drove Volvo EX40 or EC40. None worked within energy efficiency, range optimisation, or UX of range in EVs. All participants reported taking at least one long trip per year, with the majority taking between 3 to 5 long trips annually.

The tests were originally planned to take place in a UX Lab with a driving simulator, where participants would sit in the Buck which was placed in front of a large simulator screen displaying a road driving simulation, see Figure 5.10. However, due to a last-minute issue with room availability, the location had to be changed. Finding a suitable space to accommodate the Buck proved difficult, resulting in the tests being conducted in three different locations. To maintain consistency across test sessions, it was decided that none of the participants should use the driving simulator. Instead, a computer was placed on the dashboard of the Buck (see Figure 5.11), playing a video of a recorded road drive to simulate the experience of driving for the participants.

Figure 5.10: The initial set-up of the Buck with simulator

Audio was recorded during all sessions. Prior to starting the test session, all participants signed a consent form and filled in a demographic survey (see consent form and demographic survey in Appendix B). The test was structured into three parts, conducted in the following order: usability test, User Experience Questionnaire Plus

(a) (b)

Figure 5.11: The buck in the (a) second and (b) third test rooms

(UEQ+), and a semi-structured interview (the UEQ+ and interview questions can be found in Appendix B). Before the usability test began, participants were presented with a scenario that they were asked to keep in mind throughout the session.

The scenario was designed to provide a consistent context for all participants, simulating a longer trip where the ability to charge the EV was limited. The aim was to encourage participants to consider how best to manage and extend the estimated remaining range, potentially through the use of the R.O.- and tip-functions. The scenario was presented as follows:

> You are going on a trip to visit friends or family, with a few passengers in the car. The journey is approximately 470 km, and your current estimated range is 480 km. There are no charging opportunities along the route, but you will be able to charge as soon as you reach your destination. Your task is to reach your destination without running out of range.

During the usability test, participants imitated driving the Buck while a road drive video played to simulate a real driving experience. They were instructed to use the 'think aloud'-method, verbalising their thoughts and and reactions to the prototype in real time. As mentioned previously, all spoken feedback was recorded and later transcribed for analysis.

After the usability test, participants filled out the UEQ+ to provide quantitative data to allow for comparison between design versions 1 and 2. This was then followed by a semi-structured interview, which gave participants the opportunity to provide more open-ended feedback while still maintaining consistency across participants.

5.3.3 Second Iteration Data Analysis

The analysis was divided into two parts; a thematic analysis was conducted for the qualitative data, while box-plots and means, medians, and standard deviation were calculated to illustrate the quantitative data.

Thematic Analysis

The thematic analysis was carried out in Miro [56], as described in Section 4.3.3. The analysed data included qualitative data from both observations and interviews. Pre-defined categories are represented by colours, such as DIM, CSD, and tips. For each category, themes were found as shown in Figure 5.12 from which conclusions could be drawn.

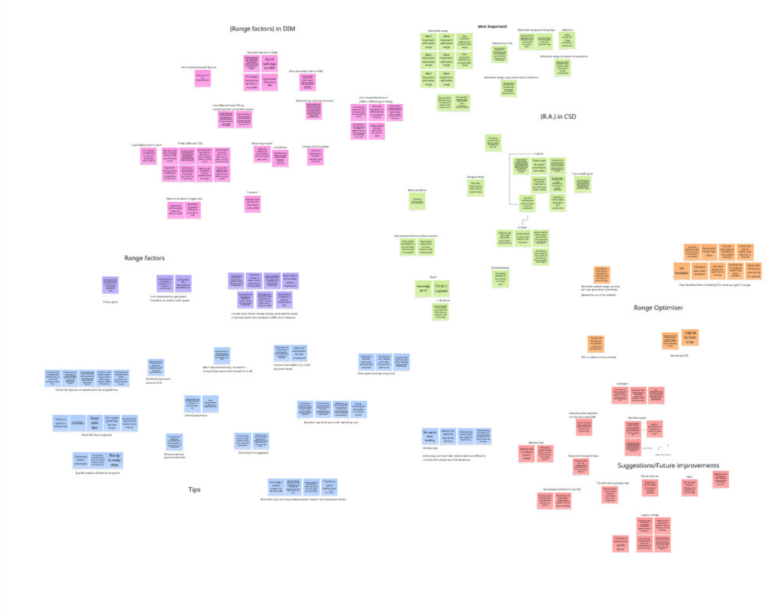


Figure 5.12: Thematic Analysis of the final evaluation

UEQ+

The questionnaire used was based on the UEQ+ method [70]. The UEQ+ measures UX utilising six scales, which are relatively long. Therefore, for this project, the questionnaire was shortened to only include three scales for assessing tips (usefulness, perspicuity, and attractiveness), two scales for CSD (perspicuity and efficiency), and two for DIM (perspicuity and efficiency). All scales were measured through different adjectives rating from 1 to 7 (low to high), see Appendix B for the full questionnaire.

5.3.4 Second Iteration Results

This section begins with presenting the results from the thematic analysis. Thereafter, the conclusions drawn from the UEQ+ are presented.

Results from the Thematic Analysis

The following list presents and elaborates on the findings of the thematic analysis, labelled H1-H7.

H1: The most important factor in the R.A. interface is the estimated range.

H2: Drivers want to be able to toggle and choose between what is visible in the IVIS.

H3: The majority prefer having range information in the DIM rather than the CSD.

H4: The idea of having tips is good but the driver might not want them when they are more experienced.

H5: Tips need to be easy to read and show a good connection to the range elements.

H6: It is important how the features in the R.A. are grouped and that the features have a position that matches their level of importance.

H7: It is important to have clear, visual feedback when activating a function such as the R.O..

H1 Most imprtant information in R.A.

When asked about what they think is the most important feature in the R.A. app, the participants were in agreement. Everyone answered that the *estimated range* is what they care about most. The second most important feature the participants mentioned is the range element *driving style*. They wanted to understand how driving style affects energy consumption and what they can do to drive more energy efficiently.

H2 Toggleable information

One aspect that was important to many of the participants was the ability to customise what information they can see in the IVIS. This was mentioned mostly when it comes to what information should be visible in the DIM, such as tips and range elements. This is apparent in a participant comment on having tips in the DIM:

> "And as long as you as a driver can choose, I think that it is great. Then you can choose yourself whether you want to see it there or not."

H3 Non-exclusive information

Twelve participants mentioned that they prefer having the range information in the DIM rather than in the CSD interface. One reason that re-emerged amongst the participants was that the DIM has the important information that you want to see while driving. They felt that it makes sense to have the range factor information there so that the driver can get a quick overview of it and change their driving accordingly. Additionally, it was mentioned that there is a risk factor involved in looking at the CSD for too long, as it requires the driver to look away from the road. This was used as an argument by participants as to why they preferred having information in the DIM rather than the CSD. In the following three quotes, participants mentioned that they prefer looking at the DIM interface.

> “I would rather choose to have it here (DIM) than having it here (CSD) when driving. When you want to change something like driving style amongst other things, it is a lot easier to see it there (DIM) than having to glance down (at CSD). So I prefer to have it in the DIM.”

> “It is good. It is good because I can sometimes feel that, it is really good information in the CSD, but at the same time there is a risk when you look down at it (CSD) instead of the road, so it is easier to keep the gaze on the DIM while driving.”

> “...for it is not always that you have this (CSD, Range and Trip) opened.”

H4 & H5 Tips

The general input on the tip function was that participants liked getting tips. They found it good that the content of the tip was dynamically connected to the range elements, which they could use to improve their driving and their understanding of the range elements. It was mentioned by participants that it is important for the tip to be short, so as to not take too much time to read while driving. This also ties back to H3, that it is easier and safer to glance at the tip were it visible in the DIM interface.

> “What I don’t like is that tips are positioned there (pointing towards the CSD). If there should be tips they should be easy to read, and then I don’t want to look away from the road for too long. Short tips but having them higher up.”

In the quote, the participant also mentions that they would prefer having the tip higher up on the screen to make it easier to find and read while driving. However opinions differed between some of the participants. Three participants mentioned that tips is a feature that they might have activated as a new EV driver, or with a new vehicle, but eventually turn it off once they have seen all the tips. Others mentioned that they would like to always have continuous guidance by keeping tips on, as seen in the quotes by these two participants:

> “If it is possible, I want to be guided more as a driver.”

> “If I sit down in a new car it (tips) is really good, and maybe the first couple of months if I am new at driving an EV. Otherwise I can turn it off, so it (the tips function) won’t hurt anyone.”

H6 Hierarchy of information

The R.A. got positive feedback on its layout, especially the clustering/grouping of elements. The participants found it easy to find and understand information since everything was intuitively positioned together. One participant said it in this way:

> “I like that this is grouped together, that you have both instant consumption, average consumption and range gathered like this. And I like the clarity of what affects my energy consumption. Because then you as a driver are given the opportunity to influence the range and such. So I think it is easy to understand, and I like that it is gathered and grouped. I like that it is clear.”

One participant mentioned they wanted to change the placement of the tips. They felt that it was hard to find and therefore also hard to read. Their idea to fix it was to move it higher up in the R.A. to a more "prime" location. Additionally, a concern that arose was that participants do not want too many elements in the application interface, as it can easily get too cluttered. This was especially a concern for the DIM since it is much smaller than the CSD. Two participants said this when it comes to the design of the DIM, that it should be kept clean and only contain the most important information.

> “Because too much information gets too annoying.”

> “You should probably not mix in too much, it should be pretty clean, I like that the DIM is kind of small. It should contain what is most important.”

H7 Visual feedback

The feedback given to the driver when they activated the R.O. was found to be very clear, as expressed by ten participants. For example, one participant mentioned that they liked how the difference in range was highlighted and subsequently updated with the new range estimation, as seen in the quote below.

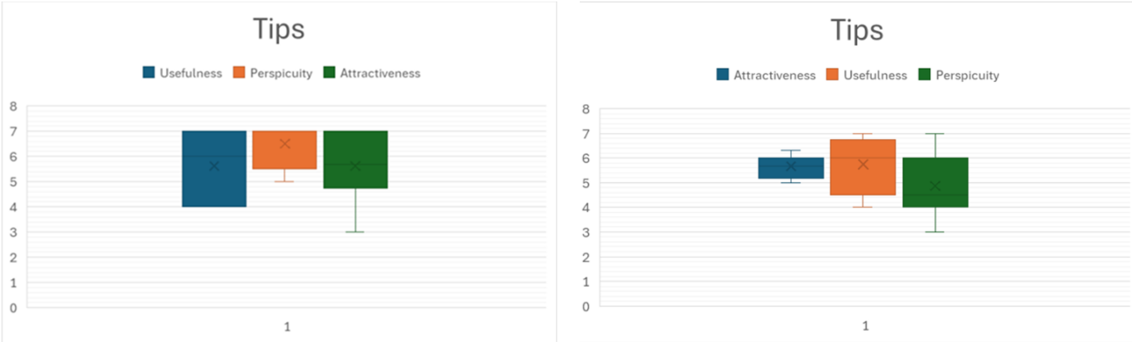
> “What is happening was super clear. That is the difference, and then it updates.”

Participants also liked the fact that they could activate the R.O. and tip-function separately. One participant mentioned that they would like to have the tips function on without the R.O..

> “If you don’t have the Range Optimiser on but you wanted to have tips on. It can still kind of tell you if you are driving a little jerkily right now or if it’s alright.”

Results from UEQ+

The quantitative data was collected in two sets, one set of data from evaluating each version of the second iteration prototype. As mentioned previously, the adjectives for evaluating the different aspects of the prototype were measured through a scale of 1 to 7. Within each set, separate box plots (Figures 5.13, 5.14 and 5.15) and tables (Tables 5.1, 5.2 and 5.3) were made for tips, CSD, and DIM, respectively. These visualisations along with the mean, median, and standard deviation values were used to check for any large differences between versions. As only minor differences were found, it was decided that data from both versions would contribute to the final design recommendations. These recommendations thereby do not enforce any one single solution, but can inspire a range of different yet viable interface designs.



(a) Version 1 (b) Version 2

Figure 5.13: Box-plots for the evaluated tips aspect

Table 5.1: Mean, median, and standard deviation values of the evaluated tips aspect

	Version 1			Version 2		
	Mean	Median	SD	Mean	Median	SD
Usefulness	5,75	6	1,16	5,63	6	1,41
Attractiveness	5,67	6	1,09	5,63	6	1,53
Perspicuity	4,88	4,5	1,36	6,5	7	0,93

(a) Version 1 (b) Version 2

Figure 5.14: Box-plots for the evaluated CSD

Table 5.2: Mean, median, and standard deviation values of the evaluated CSD

	Version 1			Version 2		
	Mean	Median	SD	Mean	Median	SD
Perspicuity	5,63	6	1,67	6,38	7	0,81
Efficiency	5,79	6	1,25	5,83	6	1,09

(a) Version 1 (b) Version 2

Figure 5.15: Box-plots for the evaluated DIM

Table 5.3: Mean, median, and standard deviation values for the evaluated DIM

	Version 1			Version 2		
	Mean	Median	SD	Mean	Median	SD
Perspicuity	5,81	6	1,64	6,19	6,5	1,11
Efficiency	5,33	6	1,71	5,58	6	1,41

5.4 Final design recommendations

The preceding analyses resulted in ten design recommendations. This section will begin by providing an overview of these design recommendations and subsequently go on to explain each recommendation in more detail. The design recommendations bring forward points for consideration when designing a range estimation- and assistance-interface in the IVIS. User characteristics and the level of interaction the users can execute while driving (see types of requirements and guidelines for creating design suggestions in Section 4.2.5) have been considered when creating the recommendations. The overview can be seen in Table 5.4, where each recommendation has a title, a short description and a list of references from which it was derived.

Table 5.4: List of final design recommendations

	Design Recommendation	**Description**	**Source**
R1	Customisation of information	Allow the driver to decide and toggle the type and amount of information shown in the range interfaces in the IVIS.	[L9], [H2], [H3]
R2	Non-exclusive information	The information from the range assistance interface on the CSD should not be exclusive to just the CSD, but should be made available on the other screens in the IVIS as well.	[L2], [H3]

R3	Safe driving and the use of IVIS	To ensure the IVIS do not pose as a distraction to the drivers, the type of information displayed on the interfaces needs to be considered carefully. The driver should be able to get the most important information from a quick glance at the DIM, and if more information is needed, it should be found on the CSD.	[H2], [H3]
R4	Hierarchy of information	The most important elements should be put at the "prime" spots on the screen, where they are visible and easy to locate for the driver. Regardless if it is a function or just information, hierarchy should be considered when designing a range interface.	[H1], [H6]
R5	Minimise clutter	When displaying information on the screens in the IVIS, it is important to consider the amount of visual elements in the design. The screen layout cannot be too cluttered, or else the visual load for the user will be too high.	[L1], [H6]
R6	Clear visual feedback	Feedback from toggling range functions on and off should be clear and visible to the driver, accurately signalling that the action has been carried out.	[H7]
R7	Tips for optional coaching	The driver should have access to optional coaching to achieve a more energy efficient driving behaviour. This coaching could be in the form of tips or recommendations. The tips should be insightful for drivers with little to no EV experience by providing them with new information. For experienced drivers, the tips should serve more as recommendations rather than new knowledge.	[Q2], [L10], [L11], [H7]
R8	Present simple and readable tips during driving	Keep tips short and concise, making it easy for the driver to read and understand the information while driving.	[L1], [L11], [H5]

R9	Relevant tips connected to the range factors	The information in the tips should be directly associated with range elements shown on the range interfaces in the IVIS. The tips should be easy for the driver to comprehend and the terminology in the tips should be relatable to the individual range elements.	[L11], [H5]
R10	Independent control of tips and Range Optimiser	The tips function should not be bound to the Range Optimiser function, meaning the driver should be able to turn on one without affecting the other.	[H2], [H7]

R1-R3 Information

The desired information in the IVIS varies from driver to driver, which makes it difficult to create one design that fits all. Instead, participants mentioned that they would like the option to customise what information they are shown in the IVIS. They also remarked that they would like different kinds of information based on the kind of trip they take, such as commuting to work or longer vacation trips. Additionally, the information should not be confined to one screen, such as the CSD, but made available on whatever interface the driver chooses. This is based on the positive feedback that was received on having the range information in the DIM interface, and the possibility of choosing when it should be displayed.

There is a risk every time the driver needs to look away from the road, which makes it imperative that the information on the interfaces in the EVs is easy to understand and only requires a quick glance to take in. If the driver needs more information than might be available in the DIM, they should be able to find it in the CSD as long as it is safe to do so.

R4-R5 Hierarchy and layout

When designing an interface for an environment such as a car, it is important to make sure that the driver can find the relevant information without adding too much to their cognitive load. Therefore, it is important to rank the necessary elements by importance and place them accordingly. In the first iteration testing, the participants mentioned that it was reasonable to have the interactive element high up on the screen where it is easy to find while driving, so as not to negatively affect the cognitive load of the driver. It is vital that only the elements relevant to the interface are incorporated.

R6 Visual feedback

The participants mentioned that they liked having more visual feedback concerning what actually happens when the R.O. feature is activated. It was also appreciated that the feature had a descriptive text explaining what it does. With the addition of these two features to the R.O., the participants felt that they had a better understanding of its function and why one would want to activate it. Overall, having a range optimising feature like a R.O. was found to be very valuable.

R7-R9 Tips

The tip function in the R.A. interface received mixed opinions from the participants. Some participants remarked that they would use tips once and then likely turn them off, while others felt that they would consistently need it to properly understand the newer features of an EV. Therefore, tips should be an optional function that a driver can turn on or off based on their level of knowledge and comfort of driving an EV. Participants liked that the tips in the prototype were connected to the R.A. elements and thereby indicated how the driver could change their behaviour to maximise their remaining range. It is, however, important to keep in mind that tips need to be kept short, concise, and easily understandable.

R10 Independent control

Connected to recommendation R1, the participants wanted to be able to choose what function they have activated while driving. For example, it was mentioned that they might not need or want the R.O. on, but might want tips to learn more about energy consumption or how their driving style is affecting the range. For this reason, they expressed that they did not want the tips function to be built into the R.O.. It is therefore important to keep the control of these features separate, so that they are not bound to each other.

6
Discussion

This chapter discusses the various aspects of the thesis, starting with the results of the delivered prototype of the range estimation- and assistance-interface in the IVIS, in combination with the design recommendations for such an interface. Thereafter, the execution of the research will be discussed in relation to existing theories and research. Lastly, the limitations and ethical considerations of this project will be discussed, followed by a discussion on potential future work.

6.1 Results

The goal with this thesis project was to explore if there is a knowledge gap amongst EV drivers, the reasons behind drivers' dissatisfaction, and mistrust towards the estimated range in EVs, and to identify the areas needing improvement in the IVIS. The end goal was to deliver a prototype of a range estimation- and assistance-interface alongside a design recommendation list, and in doing so, also answer the research question:

> What are some of the features that could be improved in the range interfaces on the in-vehicle information systems to better help the driver understand and trust in the range estimation?

Through the perspective of UX and RtD, and the application of IxD with a UCD approach, a set of design recommendations and a prototype of a range estimation- and assistance-interface were produced. This was done under the guidance of the stated research question, with the purpose of fulfilling the aforementioned goal of this thesis project.

The Usage and Future of the Prototype & Design Recommendations

The prototype of the range interfaces in the IVIS should not be seen as a future version of the range interfaces that Volvo will be developing and releasing, but should instead be seen as a source of inspiration for designing similar interfaces for range in the IVIS. It should also be noted that, from the final evaluation in the second iteration, it is apparent that the prototype can still be refined and improved. Its main purpose was to confirm the findings from the first iteration, but to also test suggestions from the first iteration. Therefore, it is reasonable to say that not all features and decisions behind the design of the final prototype have gone through enough evaluation for it to be seen as a well-established recommendation or version for a range interface.

When it comes to the design recommendations, they should also be seen as guidelines and recommendations, and not strict requirements. The purpose of bringing forward a recommendation list is to provide a tool for designers when developing a range estimation- and assistance-interface. The recommendations can be used throughout the whole design process, but they are especially valuable in the earlier phases when the designer needs to create an understanding of what features are important and necessary for the EV to relay good and trustworthy range information to the driver. It is important to note that the recommendations do not explicitly state how the information on the range interfaces should be visualised, but rather the type of information that should be included and the aspects the designer should consider when designing such an interface.

Both the prototype and the recommendation list have been created with today's use of the range interfaces in Volvo EVs as a reference point. We are still only at the beginning of the transition between ICEVs to EVs, and it is not unthinkable that the interactions between the drivers and the range applications in the IVIS will evolve and change in the future. Therefore, the recommendations will have to be reviewed and updated in the future, should they be kept as a guiding tool for designers. Although the current recommendations might evolve and change in the future, the general need for a good understanding of range and energy efficient driving behaviour will most likely continue to be a strive, so recommendation lists or general design guidelines for range interfaces in IVIS will remain as a need even in the future. It is, however, important to acknowledge the fact that in the future, when we are further into the transition to electrification, the general knowledge of range and EVs will most likely be higher, resulting in a decreased demand for feedback or information to increase the knowledge. At that time, the recommendation list will therefore need to be updated and tweaked towards perhaps a more experienced user group.

The Prototype & Design Recommendations in Relation to the Literature

The findings from this thesis project are not only based and supported by the user research done throughout the project, but also by the literature. The final prototype and the ten design recommendations developed in this thesis project show strong alignment with findings from the literature on nudging and behaviour-guiding UI design. For instance, recommendations R7-R9 - focused on optional coaching, concise tips during driving, and relevance to range factors - reflect the importance of personalised feedback nudges, as demonstrated by Choudhary, Shunko, Netessine, *et al.* in Section 2.5. Their study showed that the nudges tailored to a driver's performance (such as a personal best-score, or an average-score) led to improvements in driving behaviour, suggesting that feedback grounded in drivers' own data can positively influence safe driving. This principle is reflected in R7-R9, where the goal with those recommendations is to nudge the drivers toward a more energy-efficient driving behaviour through timely, relevant, and easily understandable feedback.

In addition to supporting behaviour through nudging, several of the final design recommendations directly address concerns around cognitive load and driver distraction, as highlighted by Engström, Markkula, Victor, *et al.* [30] and Kountouriotis, Wilkie, Gardner, *et al.* [34] in Section 2.4. For example, R3-R5 aim to reduce the visual and cognitive complexity of the range estimation- and assistance-interface, supporting the principle that clear and minimal displays can help avoid overwhelming the driver's cognitive resources. Engström, Markkula, Victor, *et al.* [30]'s concept of cognitive control suggests that excessive cognitive load impairs driving tasks such as lane keeping and traffic monitoring, which are essential skills for safe driving. By following R4-R5 and placing important information in "prime" screen locations and avoiding clutter, designers can help ensure that drivers do not engage in unnecessary search or processing, which reduces mental effort and distraction when interacting with the range interfaces. Similarly, R1 about customisation of information aligns with the goal of reducing cognitive interference by allowing drivers to control the amount and type of information displayed. R1 supports both novice and experienced users by limiting non-essential data that might otherwise draw cognitive resources away from driving, creating an unsafe driving environment. Moreover, R6 about having clear visual feedback is essential in ensuring that interactions with the IVIS are quick and intuitive, and only require short attention time. This helps the driver maintain gaze direction and reduce off-road eye fixation, which was something that Kountouriotis, Wilkie, Gardner, *et al.* [34] identified as a risk factor for impaired steering control (as previously mentioned in Section 2.4). Together, these design recommendations incorporate cognitive science principles into the design research to support safe and focused driving. One important consideration for incorporating for example a tip-feature in range interfaces, is that although participants might express positive feedback during tests of the product, it is still difficult to conclude whether it will be an appreciated feature in practice. To truly test visual load and cognitive load in relation to the use of nudging, the need of longitudinal studies remain.

The design recommendations also address factors related to trust in digital interfaces and IVIS, as outlined by Dwyer [26] and Franke, Trantow, Günther, *et al.* [28] in Section 2.2. Recommendations such as R1-R2 about customisation of information and having non-exclusive information directly support the development of trust by enhancing transparency and user control. This allows drivers to customise and tailor the range interface to their preferences and access it across multiple screens. This aligns with the idea of *chameleon interfaces* introduced by Dwyer [26] in Section 2.2, which adapt to individual user needs and promote confidence in system reliability through both familiarity and flexibility. Additionally, R6 about visual feedback also ensures that drivers receive immediate confirmation of actions taken within the interface, which is important in maintaining trust especially since even one small confusing or failed interaction can significantly undermine user confidence [26].

From Franke, Trantow, Günther, *et al.* [28]'s perspective, range estimation interfaces play a central role in either building or weakening trust in IVIS (as seen in

Section 2.2). When drivers perceive the estimated range as inconsistent or poorly explained, it leads to increased range anxiety. As research shows, range anxiety (particularly among non-EV-users) is a major psychological barrier to EV adoption [20], [19]. Recommendations like R7-R9, which suggest giving clear, concise and context-related tips, can help reduce this range anxiety by educating drivers on what factors influence range in an accessible format, supporting the drivers in forming accurate mental models of the systems [19]. R3-R4 also address the need to convey important range information without overwhelming the driver, which might help drivers understand the fluctuating range values that occur sometimes.

Overall, the final prototype and the design recommendations aim to build and strengthen interface trust for the drivers, and thus also reduce uncertainty that might exist surrounding usage of range interfaces. This supports a smoother psychological transition to EV usage by directly addressing the cognitive and emotional aspects of range anxiety.

6.2 Execution in Relation to the Literature

This section reflects on the execution process of the study, discussing decisions made during the design and implementation phases. It also discusses how these findings relate to relevant theories and previous research in the field.

Sampling for User Research

During the thesis project, only Volvo Cars employees were part of the user research, apart from the evaluation of the low-fidelity prototype where interaction design students were recruited instead. The sampling for this project might have created some biases that are worth discussing. Starting with the gender distribution - the majority of the participants involved in the research were men, with the exception of the evaluation of the low-fidelity prototype where the gender distribution was more equal. The recruitment for the evaluation of the high-fidelity prototype was done solely amongst the questionnaire respondents, where there was already an uneven gender distribution. This indicates that the majority of the data used for the research for this project was from men, and it should be noted that the results from this project therefore might not be representative of the general user group of EV users when it comes to gender representative findings. It is also worth to note that the majority of the respondents and participants leaned toward the middle or higher age group, and younger or new drivers were not represented as much. It is therefore possible that the age and gender distribution from the project participants may have created biases, meaning the values and beliefs about energy efficient driving found in this project might not be fully representative of the whole EV user population.

Another aspect to consider is that the majority of our participants were Volvo Cars employees, which might have affected their knowledge level about range and EVs, as well as different factors affecting energy efficient driving. It could be assumed that although the participants for this research were not directly employed at the energy efficiency or sustainability teams, their general knowledge about this field might still be higher than the average user, as it is easy to get information from casual chatting with other employees at the company. An attempt to gather some outside opinions and reviews was made for the evaluation of the low-fidelity prototype, but that specific evaluation also did not focus on user's knowledge about range and EVs, therefore, it is reasonable to argue that it might not have made a big difference to include outside participants there. However, in the end the user data from this project is still more representative of users with a higher level of technical knowledge, potentially biasing the findings toward the experiences and expectations of more advanced EV drivers, rather than the broader user population.

The Utilisation of Research Through Design

Throughout the thesis project, the theory of RtD has been implemented as a tool in the research process. Part of the research focus has been on prototyping design concepts based on user requirements found from user research, along with the evaluation of the design concepts. The research was conducted specifically with the goal of getting user insights and valuable data that could be used as a foundation for the development of design recommendations, which is one of the common outcomes in RtD as Gaver [41] highlights.

The Impact of Interaction Design

The research, high-fidelity prototype, and design recommendations presented in this thesis project have been fundamentally shaped by principles of IxD, particularly those tied to usability, UX, and UCD. Rather than focusing solely on interface aesthetics or functionality, the design process was driven by a deep understanding of user needs, behaviours, and to a certain degree the real-world context in which EV drivers operate. This IxD approach ensured that the design recommendations extend beyond the boundaries of the prototyped interfaces to support broader interaction goals, such as reducing range anxiety, improving the relay of information from IVIS to drivers, and fostering trust in system feedback among EV drivers. This thesis project has been grounded in iterative methods such as the Double Diamond framework [46], including phases of user research, prototyping, and evaluation, all based on real user involvement. The use of questionnaires and evaluative testing sessions with actual EV drivers ensured that the insight gathered was both context-specific and experience-driven, aligning with UCD's emphasis on designing *with* users rather than just *for* users [43].

The application of usability principles contribute to solutions that encourage efficient, learnable and low-error interactions [43]. This thesis project has deliberately tried to follow the usability principles, because these attributes are particularly important in the context of EVs, where especially beginner EV drivers might encounter unfamiliar terminology and system behaviours related to energy consumption and range estimation. By integrating IxD theory throughout the development and execution process, this research emphasises the importance of aligning design outcomes, in this case design recommendations, with real user needs and capabilities.

Bias in the research

Throughout the process of data analysis and development of the design recommendations, bias was taken into consideration. Confirmation bias was one of the most commonly occurring ones in the fields of design according to I. Saygı and Y. B. Saygı [38]. By having more iterations of data collection, the risk of confirmation bias occurring has been lowered, as each iteration revealed new insights and thus reduced the risk of the researchers seeking out information that only confirmed pre-existing beliefs. To minimise bias in this thesis project, more focus has been put on UXR to form a better understanding of the users' needs, behaviours, pain points and motivations. Following the recommendations of Purdy [37], as described in Section 2.6, we have educated ourselves more about the common biases that occur during research in design, and to minimise these we have also tried to keep a balance between openness to new ideas and critical thinking about decisions throughout the thesis project. Purdy also recommends actively working and seeking out others with different experiences and opinions, which has been difficult for this project, as the participant recruitment was done entirely through a separate team at Volvo Cars.

However, despite the many attempts of minimising bias in our research, some bias might still have appeared. Aside from the previously mentioned potential gender, age, and knowledge biases, according to Elston [39], survey studies are also the ones most likely to be affected by participation bias, especially when the response rate is below 60%. To minimise bias in the questionnaire, the survey questions were thoroughly evaluated and reviewed by different researchers. However, the questionnaire survey had a response rate of 43%, which is lower than the recommended threshold level suggested by Elston. This implies that the questionnaire survey might have still been affected by some level of participation bias. More about the impact of this bias and the limitations will be discussed below in Section 6.3. Additionally, having only participants with an IxD background for the evaluation of the low-fidelity prototype in the first design iteration may have biased and affected the later design decisions. For example, the quote in [L1] expressed a preference for the toggle-button for the R.O., since "everyone knows what a toggle-button looks like". One can argue that a design knowledge bias may have affected the evaluation results here, and that the toggle-button is not as intuitive to people as the participants stated. It would therefore have been better include a bigger variety of participants, to minimise eventual design knowledge bias.

6.3 Limitations in the Research

This thesis project is not without limitations, as mentioned in Section 6.2, there might have been some participation bias in the questionnaire that was carried out to understand the users, as the response rate was 43%, which is lower than the recommended threshold at 60% [39]. The questionnaire was sent out through another team at Volvo Cars, and we had no control of how many it would be sent to. Additional demographic data was obtained during the analysis of the data. Having a participation bias would mean that the results from the questionnaire mostly only reflect the knowledge and opinions of EV drivers with an opinion about range and energy efficient driving, and there is a risk that the questionnaire results do not represent all EV drivers in Sweden.

Furthermore, even though the questionnaire did not show a knowledge gap, it is important to consider the fact that a questionnaire study in itself is very limited to only collecting self-reported data. Because of this, there is a possibility that respondents demonstrated a higher knowledge level than they actually possess, potentially resulting in an incomplete representation of their actual knowledge.

As mentioned in Section 5.3.2, there were some last minute changes to the testing procedure room. Therefore, in order to minimise biased differences in the results, the driving simulator was not used in the end. It would have been ideal to conduct all the tests at the same location to minimise the possible effect the difference in rooms might have had on the participants. Aside from the potential effects from using three rooms, another limitation was using only a road drive video, and not the driving simulator, to test the prototype. Additionally, the test was conducted using the Buck for the usability testing, and not carried out in a real car. Had there been possibilities of uploading the range interface prototypes in a real car, the testing would have been much more realistic in putting the participants in a real-life scenario. However, that would have come with safety concerns regarding for example how fast the participant would need to drive to see the range factor metre for speed change, or how high the cabin temperature would have to be set to see the range factor metre for climate change and so on. Therefore, it was decided that opting for a driving simulation method for the usability test would be the most optimal and safe option for both the authors, company, and all participants.

Another limitation for this research is the time aspect. This thesis project has been carried out over the span of one academic semester. As with most thesis projects, there is the argument that more time for the project would have provided better chances for potentially improved results. With more time, more iterations could have been carried out, and the range interfaces could have been polished even more while strengthening and refining the design recommendations. However, improving the UX of energy usage for EV drivers is a need that will always exist as long as EVs are relevant for the society. Because the transition between ICEVs to EVs is still only just starting, one could argue that even if the project for example had been carried out over the span of one year, the findings would still need to be revisited and updated as we progress further into the transition. This is because the findings of this thesis project is directly related to the user population's *current* knowledge, behaviours, needs, and that the *current* status will always be changing as time passes.

6.4 Ethical and Societal Considerations

Throughout the project, ethical principles were carefully upheld to respect participant privacy and data integrity. During the data gathering phase, all participants were informed about the data handling in line with Volvo's policies and provided informed consent. No data was collected before the participants had signed the consent form for data collection. Their anonymity was maintained throughout the whole data analysis, and participants retained the right to withdraw at any point, with their data subsequently removed and destroyed. In the evaluation phases, user data was treated with the utmost care to ensure confidentiality and minimise bias. Transparency was maintained in communicating how participant data would be used, and the data analysis was conducted fairly to accurately represent user perspectives. After this thesis project was completed, participants were provided with the results and findings.

Reflecting on the process, prioritising ethical considerations aimed to build trust with participants and thus enrich the quality of the insights gathered. However, challenges such as ensuring consistent understanding of consent and balancing participant comfort during interviews highlighted areas for potential improvement in future work. Going forward, continued emphasis on transparency, participant well-being, and secure data management remains essential for ethical user research, especially if future work includes usability testing in real road scenarios, where even more safety concerns exist.

Some of the societal considerations for this project could be about the influence and impact of such a project. What impact would the results have on EV users, if the design recommendations were to be taken into account when designing the next range interface? Studies like this project is a crucial part of the transition between ICEVs to EVs. With constant improvement of the UX of range and energy usage, and better coaching possibilities for using the different IVIS in EVs, the threshold for learning about EVs would lower. This would make EVs more accessible to people, and even people who originally viewed EVs as too modern or technological could also easily understand the systems and concept of consuming energy from a battery when driving. As EVs become more accessible to people, there is also a higher chance of reaching the climate targets [4] by reducing global emissions, leading us to a more sustainable future.

6.5 Future Work

Future work should not only focus on further improving the UX of energy use and range for EV usage, but also focus on refining the research methods. As mentioned above, this thesis project is not without its limitations. Consequently, there are a few perspectives and directions that future work in the same field could take.

Further User Research

For user sampling, this project had the limitation of only researching Volvo users who were Volvo Cars employees. The knowledge bar amongst users might therefore not be fully representative or generalisable for the whole EV user population. The study could therefore benefit from further user research, preferably with a broader user sampling across several different brands of EVs to provide representative findings. It is also worth considering that the EV usage might differ across countries and cultures, where driving behaviour is different, and therefore research in that direction could also provide valuable insight regarding energy efficient EV usage.

Coaching & Gamification Approach for Energy-Efficient Driving

While conducting the user research, it became apparent that the drivers believed in the importance of energy efficient driving, both for financial and environmental reasons. Although a knowledge gap regarding range was not found through the questionnaire, many users still wished to learn more about estimated range and how to better control their energy usage, partly for psychological reassurance. This thesis project has mainly been carried out with an IxD perspective, and has therefore not explored much outside the scope of IxD and improving current UIs. One part of this study's findings focus on incorporating tips and guiding users towards a more energy efficient driving behaviour, or at least providing them with the information needed to make a decision regarding their driving behaviour. Future work could focus more on how to better motivate and coach EV drivers to drive more energy efficiently. For that purpose, perhaps coaching and gamification approaches could be considered, and more research about how personal scores affect users' motivation can be conducted, which also aligns with Choudhary, Shunko, Netessine, *et al.* [36] findings.

Expanding the Focus to Applications & Interfaces Outside the Car

The focus of this research has been on range estimation- and assistance-interfaces in the IVIS, and the thesis project has not explored applications and interfaces outside the car. Future research could therefore focus more on systems outside the car, such as the range calculator mentioned in Section 1.1, or the Volvo mobile phone application. Part of the current knowledge gap amongst novice EV users could presumably be tackled by expanding the research focus to applications outside the car, as an attempt to improve the UX from another direction. Some suggested approaches could be to improve the range calculator to educate future EV users before they even purchase their EV, providing them with more examples of real-world range situations, or adding complementary range information in the mobile phone application. It could also be worth to explore interfaces and applications about range across different car brands, similar to conducting a benchmarking study.

Exploring Further Improvements in Regards to Customer Satisfaction

The research question of this project has been focusing on the trust aspect in the UX of EVs. Although the design recommendations and the prototypes developed in this project provided a solid base for research in this area, it is important to discuss the differences between UX and customer satisfaction. With theories and principles from IxD and RtD shaping this project, non-design solutions have not been focused on when answering the research question. As touched on in the previous Section 6.1 about cognitive load and nudging in relation to the findings in this project, the final design recommendations are grounded in both literature and research findings from this project. However, customer satisfaction might not necessarily be the same as UX. Customer satisfaction can be based on factors outside of just the UX of the EV, and future work could therefore also expand and focus on improving customer satisfaction from aspects outside the UX of EVs energy use and range, for example through looking more into customer complaints.

Benchmarking studies

As mentioned in the earlier execution sections, a benchmarking study for this project was reconsidered due to time constraints. Future studies should consider including benchmarking analyses to examine how different car brands design and optimise their range interfaces in EVs. By comparing the various approaches from different car brands, researchers can identify features that are appreciated across different brand users, and better design to enhance user understanding and management of their energy consumption. It would also allow researchers to discover general needs and pain points across EV users that still need to be addressed. Future research could be based on the findings from this study, but could add more benchmarking studies to complement the areas that were not covered in this thesis project.

7
Conclusion

The aim of this thesis project was to research (1) what potential knowledge gaps that EV-drivers have about range factors and the range interface in their EVs, and (2) how the interface could be improved to help the driver understand and trust in the range estimation to encourage a more energy efficient driving behaviour. The findings from the project are a list of recommendations that are based on tests and evaluations from two prototypes at different fidelity levels. The list of recommendations is an answer to the following research question:

> What are some of the features that could be improved in the range interfaces on the in-vehicle information systems to better help the driver understand and trust in the range estimation?

To answer the research question, a process such as the Double Diamond framework has been followed, starting with data gathering to understand users, to then follow up with prototyping and user testing. The data gathered was collected into lists of key findings, which were then incorporated in the design processes of creating prototypes. The feedback from the prototypes was analysed and compiled into a final list of design recommendations:

- R1 **Customisation of information** - Allow the driver to decide and toggle the type and amount of information shown in the range interfaces in the IVIS.
- R2 **Non-exclusive information** - The information from the range assistance interface on the CSD should not be exclusive to just the CSD, but should be made available on the other screens in the IVIS as well.
- R3 **Safe driving and the use of IVIS** - To ensure the IVIS do not pose as a distraction to the drivers, the type of information displayed on the interfaces needs to be considered carefully. The driver should be able to get the most important information from a quick glance at the DIM, and if more information is needed, it should be found on the CSD.
- R4 **Hierarchy of information** - The most important elements should be put at the "prime"-spots on the screen, where they are visible and easy to locate for the driver. Regardless if it is a function or just information, hierarchy should be considered when designing a range interface.
- R5 **Minimise clutter** - When displaying information on the screens in the IVIS, it is important to consider the amount of visual elements in the design. The

screen layout cannot be too cluttered, or else the visual load for the user will be too high.

R6 **Clear visual feedback** - Feedback from toggling range functions on and off should be clear and visible to the driver, accurately signalling that the action has been carried out.

R7 **Tips for optional coaching** - The driver should have access to optional coaching to achieve a more energy efficient driving behaviour. This coaching could be in the form of tips or recommendations. The tips should be insightful for drivers with little to no EV experience by providing them with new information. For experienced drivers, the tips should serve more as recommendations rather than new knowledge.

R8 **Present simple and readable tips during driving** - Keep tips short and concise, making it easy for the driver to read and understand the information while driving.

R9 **Relevant tips connected to the range factors** - The information in the tips should be directly associated with range elements shown on the range interfaces in the IVIS. The tips should be easy for the driver to comprehend and the terminology in the tips should be relatable to the individual range elements.

R10 **Independent control of tips and Range Optimiser** - The tips function should not be bound to the Range Optimiser function, meaning the driver should be able to turn on one without affecting the other.

An important note is that the prototypes created are not meant to be a final correct design, but as a way of testing what should be included in this kind of interface, or potentially as inspiration for what components one should include in such an interface. Another important note is that EVs are still a relatively new technology that is under continuous development, which means that the findings presented in this paper will need to be updated and reevaluated to provide relevant recommendations in designing range information interfaces. The recommendations in this project will contribute to future designs and future recommendations for similar interfaces in EVs. A potential next step would be to look into how coaching and gamification features can be integrated in a range interface within the IVIS.

Bibliography

[1] Volvo Cars. "Volvo ex90, interior design." Accessed: 2025-06-10. (2025), [Online]. Available: https://www.volvocars.com/us/cars/ex90-electric/interior-design/.

[2] B. Honda, *13 reasons buying an electric vehicle (ev) might not be the best choice for you (yes, even a honda ev)*, Accessed: 2025-02-17, 2024. [Online]. Available: https://www.butlerhonda.com/blog/2024/may/7/buying-an-electric-vehicle-ev-cons-hybrid-instead.htm.

[3] J. Wood, "Electric vehicles: The 3 main factors holding back sales," *World Economic Forum*, 2022, Accessed: 2025-02-17. [Online]. Available: https://www.weforum.org/stories/2022/10/ev-sales-charging-infrastructure-transport-sector-sustainable/.

[4] U.S. Department of Energy, *Emissions from electric vehicles*, Accessed: 2025-02-17, 2025. [Online]. Available: https://afdc.energy.gov/vehicles/electric-emissions.

[5] A. Kurkin, E. Kryukov, O. Masleeva, Y. Petukhov, and D. Gusev, "Comparative life cycle assessment of electric and internal combustion engine vehicles," *Energies*, vol. 17, p. 2747, Jun. 2024. DOI: 10.3390/en17112747.

[6] V. Cars, *Calculate your range*, [Online]. Available: https://www.volvocars.com/intl/cars/electrification/range/?model=EX90&profile=mixed&temperatureIndex=2&climate=true&powerTrain=Single, Accessed: February 13, 2025.

[7] P. Point, *What is wltp? a guide to consumption and emissions testing*, Accessed: 2025-02-17, 2024. [Online]. Available: https://pod-point.com/guides/what-is-wltp-an-ev-drivers-guide-to-consumption-and-emissions-testing.

[8] E. Database, *Wltp explained: Range, consumption and efficiency*, Accessed: 2025-02-17, 2025. [Online]. Available: https://evdb.nz/wltp.

[9] Volvo Cars, *Who we are - Our heritage*, Accessed: February 15, 2025, 2025. [Online]. Available: https://www.volvocars.com/intl/our-heritage/.

[10] Volvo Cars, *Who we are - Our story*, Accessed: February 15, 2025, 2025. [Online]. Available: https://www.volvocars.com/intl/our-story/.

[11] C. Woodford, *Electric cars*, Accessed: February 15, 2025, 2007. [Online]. Available: https://www.explainthatstuff.com/electriccars.html (visited on 04/02/2024).

[12] J. Neubauer and E. Wood, "The impact of range anxiety and home, workplace, and public charging infrastructure on simulated battery electric vehicle lifetime

utility," *Journal of Power Sources*, vol. 257, pp. 12–20, 2014. DOI: 10.1016/j.jpowsour.2014.01.075.
[13] S. Verma, G. Dwivedi, and P. Verma, "Life cycle assessment of electric vehicles in comparison to combustion engine vehicles: A review," *Materials Today: Proceedings*, vol. 49, pp. 217–222, 2022, International Conference on Advancement in Materials, Manufacturing and Energy Engineering (ICAMME-2021), ISSN: 2214-7853. DOI: https://doi.org/10.1016/j.matpr.2021.01.666. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S221478532100763X.
[14] H. Yu, F. Tseng, and R. McGee, "Driving pattern identification for ev range estimation," in *2012 IEEE International Electric Vehicle Conference*, 2012, pp. 1–7. DOI: 10.1109/IEVC.2012.6183207.
[15] S. Pichelmann, T. Franke, and J. F. Krems, "The timeframe of adaptation to electric vehicle range," in *Human-Computer Interaction. Applications and Services*, M. Kurosu, Ed., Berlin, Heidelberg: Springer Berlin Heidelberg, 2013, pp. 612–620, ISBN: 978-3-642-39262-7.
[16] A. Lobo, K. Hariharan, S. Sreekumar, and M. N. Shetty, "Time optimal long distance trip planning for electric vehicles," in *2019 5th International Conference On Computing, Communication, Control And Automation (ICCUBEA)*, 2019, pp. 1–4. DOI: 10.1109/ICCUBEA47591.2019.9129188.
[17] V. C. USA, *Optimise the range of your fully electric volvo with new range assistant app in latest over-the-air update*, Accessed: 2025-02-17, 2021. [Online]. Available: https://www.media.volvocars.com/us/en-us/media/pressreleases/289321/optimise-the-range-of-your-fully-electric-volvo-with-new-range-assistant-app-in-latest-over-the-air.
[18] Volvo Cars, *Optimise the range of your fully electric volvo with new range assistant app in latest over-the-air update*, Accessed: 2025-02-20, 2021. [Online]. Available: https://www.media.volvocars.com/us/en-us/media/pressreleases/289321/optimise-the-range-of-your-fully-electric-volvo-with-new-range-assistant-app-in-latest-over-the-air.
[19] H. Strömberg, P. Andersson, S. Almgren, J. Ericsson, M. Karlsson, and A. Nåbo, "Driver interfaces for electric vehicles," in *Proceedings of the 3rd International Conference on Automotive User Interfaces and Interactive Vehicular Applications*, ser. AutomotiveUI '11, Salzburg, Austria: Association for Computing Machinery, 2011, pp. 177–184, ISBN: 9781450312318. DOI: 10.1145/2381416.2381445. [Online]. Available: https://doi.org/10.1145/2381416.2381445.
[20] D. Pevec, J. Babic, A. Carvalho, Y. Ghiassi-Farrokhfal, W. Ketter, and V. Podobnik, "Electric vehicle range anxiety: An obstacle for the personal transportation (r)evolution?" In *2019 4th International Conference on Smart and Sustainable Technologies (SpliTech)*, 2019, pp. 1–8. DOI: 10.23919/SpliTech.2019.8783178.
[21] P. Plotz, U. Schneider, J. Globisch, and E. Dütschke, "Who will buy electric vehicles? identifying early adopters in germany," *Transportation Research Part A: Policy and Practice*, vol. 67, pp. 96–109, 2014. DOI: 10.1016/j.tra.2014.06.006.

[22] N. Rauh, T. Franke, and J. F. Krems, "Understanding the impact of electric vehicle driving experience on range anxiety," *Human Factors*, vol. 57, no. 1, pp. 177–187, 2015. DOI: 10.1177/0018720814546372.

[23] S. Pichelmann, T. Franke, and J. F. Krems, "The timeframe of adaptation to electric vehicle range," in *Human-computer interaction: Applications and services*, M. Kurosu, Ed., ser. LNCS, vol. 8005, Berlin, Germany: Springer, 2013, pp. 612–620.

[24] T. Franke and J. F. Krems, "What drives range preferences in electric vehicle users?" *Transport Policy*, vol. 30, pp. 56–62, 2013. DOI: 10.1016/j.tranpol.2013.07.005.

[25] M. F. Jung, D. Sirkin, T. M. Gür, and M. Steinert, "Displayed uncertainty improves driving experience and behavior: The case of range anxiety in an electric car," in *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*, ACM, 2015, pp. 2201–2210. DOI: 10.1145/2702123.2702479.

[26] N. Dwyer, "Traces of digital trust: An interactive design perspective," Ph.D. dissertation, Victoria University, 2011.

[27] National Disability Authority, *About universal design*, Accessed: 2025-02-19, 2025. [Online]. Available: https://universaldesign.ie/about-universal-design.

[28] T. Franke, M. Trantow, M. Günther, J. F. Krems, V. Zott, and A. Keinath, "Advancing electric vehicle range displays for enhanced user experience: The relevance of trust and adaptability," in *Proceedings of the 7th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*, ser. AutomotiveUI '15, Nottingham, United Kingdom: Association for Computing Machinery, 2015, pp. 249–256, ISBN: 9781450337366. DOI: 10.1145/2799250.2799283. [Online]. Available: https://doi.org/10.1145/2799250.2799283.

[29] L. M. Gary Burnett Glyn Lawson and C. Pickering, "Designing touchpad user-interfaces for vehicles: Which tasks are most suitable?" *Behaviour & Information Technology*, vol. 30, no. 3, pp. 403–414, 2011. DOI: 10.1080/0144929X.2011.553743. eprint: https://doi.org/10.1080/0144929X.2011.553743. [Online]. Available: https://doi.org/10.1080/0144929X.2011.553743.

[30] J. Engström, G. Markkula, T. Victor, and N. Merat, "Effects of cognitive load on driving performance: The cognitive control hypothesis," *Human factors*, vol. 59, no. 5, pp. 734–764, 2017.

[31] T. W. Victor, J. L. Harbluk, and J. A. Engström, "Sensitivity of eye-movement measures to in-vehicle task difficulty," *Transportation Research Part F: Traffic Psychology and Behaviour*, vol. 8, no. 2, pp. 167–190, 2005.

[32] K. Young, J. Lee, and M. Regan, "Defining driver distraction," *Driver distraction theory, effects, and mitigation*, pp. 31–40, 2008.

[33] J. Engström, P. Larsson, and C. Larsson, "Comparison of static and driving simulator venues for the tactile detection response task," in *Driving Assessment Conference*, University of Iowa, vol. 7, 2013.

[34] G. K. Kountouriotis, R. M. Wilkie, P. H. Gardner, and N. Merat, "Looking and thinking when driving: The impact of gaze and cognitive load on steer-

ing," *Transportation research part F: traffic psychology and behaviour*, vol. 34, pp. 108–121, 2015.

[35] M. Weinmann, C. Schneider, and J. v. Brocke, "Digital nudging," *Business & Information Systems Engineering*, vol. 58, pp. 433–436, 2016.

[36] V. Choudhary, M. Shunko, S. Netessine, and S. Koo, "Nudging drivers to safety: Evidence from a field experiment," *Management Science*, vol. 68, no. 6, pp. 4196–4214, 2022.

[37] C. Purdy, "Bias in research for design: Considerations for designers when conducting user experience research," M.S. thesis, NTNU, 2021.

[38] I. Saygi and Y. B. Saygi, "The impact of cognitive biases on user decision making in human-computer interaction: A review of the literature," *of Engineering and Applied Sciences*, p. 69, 2023.

[39] D. M. Elston, "Participation bias, self-selection bias, and response bias," *Journal of the American Academy of Dermatology*, 2021.

[40] F. J. Fowler, *Survey Research Methods*, 4th ed. SAGE Publications, Inc., 2009. DOI: 10.4135/9781452230184. [Online]. Available: https://doi.org/10.4135/9781452230184.

[41] W. Gaver, "What should we expect from research through design?" In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, ser. CHI '12, Austin, Texas, USA: Association for Computing Machinery, 2012, pp. 937–946, ISBN: 9781450310154. DOI: 10.1145/2207676.2208538. [Online]. Available: https://doi.org/10.1145/2207676.2208538.

[42] E. Goodman, E. Stolterman, and R. Wakkary, "Understanding interaction design practices," in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, ser. CHI '11, Vancouver, BC, Canada: Association for Computing Machinery, 2011, pp. 1061–1070, ISBN: 9781450302289. DOI: 10.1145/1978942.1979100. [Online]. Available: https://doi.org/10.1145/1978942.1979100.

[43] I. O. for Standardization, *Ergonomics of human-system interaction part 11: Usability: Definitions and concepts*, Accessed: February 15, 2025. [Online]. Available: https://www.iso.org/obp/ui/#iso:std:iso:9241:-11:ed-2:v1:en.

[44] H. Sharp, J. Preece, and Y. Rogers, *Interaction Design: Beyond Human-Computer Interaction*. Wiley, 2019.

[45] Interaction Design Foundation - IxDF, "What is the interaction design process?" *Interaction Design Foundation - IxDF*, Jun. 2020, Accessed: 2025-02-16. [Online]. Available: https://www.interaction-design.org/literature/topics/interaction-design-process.

[46] S. Sunsunwal and P. Agarwal, *Double diamond design process*, Accessed: February 15, 2025, 2023. [Online]. Available: https://informatics.nic.in/uploads/pdfs/e9eed640_34_35_tu_double.pdf.

[47] Jake Brereton, *The Triple Diamond Design Process: A Comprehensive Guide*, [Online]. Available: https://www.launchnotes.com/blog/the-triple-diamond-design-process-a-comprehensive-guide, Accessed: February 16, 2025, 2024.

[48] B. Hanington and B. Martin, *Universal methods of design expanded and revised*. Quarto Publishing Group USA, 2019.

[49] J. Nielsen, *Personas vs. archetypes*, `https://www.nngroup.com/articles/personas-archetypes/`, Accessed: 2025-05-14, Nielsen Norman Group, 2024.

[50] M. Branz, A. Farrell, M. Hu, W. Liem, and E. Ballard, "System archetypes," *Methods Brief Series 1.07: Systems Thinking Foundations*, 2021. DOI: `https://doi.org/10.7936/c89k-d163`.

[51] G. Anand and R. Kodali, "Benchmarking the benchmarking models," *Benchmarking: An International Journal*, vol. 15, no. 3, pp. 257–291, 2008. DOI: `10.1108/14635770810876593`. [Online]. Available: `https://www.emerald.com/insight/content/doi/10.1108/14635770810876593/full/html`.

[52] R. C. Camp, *Benchmarking: The Search for Industry Best Practices that Lead to Superior Performance*. Milwaukee, WI: ASQC Quality Press, 1989.

[53] "Should we introduce benchmarking for our UX research?" *Interaction Design Foundation*, 2016, Accessed 2025-02-16. [Online]. Available: `https://www.interaction-design.org/literature/article/should-we-introduce-benchmarking-for-our-ux-research`.

[54] Nielsen Norman Group, "Affinity diagramming," *Nielsen Norman Group*, 2024, Accessed: 2025-02-19.

[55] A. Lucero, "Using affinity diagrams to evaluate interactive prototypes," in *Human-Computer Interaction–INTERACT 2015: 15th IFIP TC 13 International Conference, Bamberg, Germany, September 14-18, 2015, Proceedings, Part II 15*, Springer, 2015, pp. 231–248.

[56] Miro, *Miro [computer software]*, `https://miro.com`, Accessed: 2025-05-14, 2025.

[57] Looppanel, *A side-by-side comparison: Affinity mapping vs. thematic analysis*, `https://www.looppanel.com/blog/affinity-mapping-vs-thematic-analysis`, Accessed: 2025-05-14, 2024.

[58] "Design requirements," *Interaction Design Foundation*, 2025, Accessed 2025-02-16.

[59] R. Hartson and P. S. Pyla, "7.6 ideation," in *UX Book - Process and Guidelines for Ensuring a Quality User Experience*. Elsevier, 2012.

[60] T. Kelly, "The perfect brainstorm," in *The Art of Innovation*, T. Kelly and J. Littman, Eds., Doubleday, 2000, ch. 4.

[61] Figma, *UI Design Tool: The modern interface design tool*, Accessed: 2025-02-19, 2025. [Online]. Available: `https://www.figma.com/ui-design-tool/`.

[62] Digital.gov, *Usability*, `https://digital.gov/topics/usability/`, Accessed: 2025-05-14, 2025.

[63] T. D. Abel, "Beyond usability: Methodologies and bias–surveying the surveys," in *Universal Access in Human-Computer Interaction. Theory, Methods and Tools: 13th International Conference, UAHCI 2019, Held as Part of the 21st HCI International Conference, HCII 2019, Orlando, FL, USA, July 26–31, 2019, Proceedings, Part I 21*, Springer, 2019, pp. 3–12.

[64] J. Caulfield, *How to do thematic analysis | step-by-step guide & examples*, Accessed: March 19, 2025, 2023. [Online]. Available: `https://www.scribbr.com/methodology/thematic-analysis/`.

[65] D. H. Mortensen, "How to do a thematic analysis of user interviews," *Interaction Design Foundation*, 2021, Accessed: 2025-03-19. [Online]. Available:

https://www.interaction-design.org/literature/article/how-to-do-a-thematic-analysis-of-user-interviews.

[66] E. Lindgren and L. Silberberg, "Recommendations for designing a cross-device coaching experience," Accessed: 2025-05-21, M.S. thesis, Chalmers University of Technology, 2020. [Online]. Available: https://odr.chalmers.se/items/c90eb68f-e14d-4897-9536-209e56c99458.

[67] Microsoft. "Microsoft forms: Online surveys, polls, and quizzes." Accessed: 2025-05-26. (2025), [Online]. Available: https://www.microsoft.com/en-us/microsoft-365/online-surveys-polls-quizzes.

[68] K. Baxter, C. Courage, and K. Caine, "Chapter 7 - during your user research activity," in *Understanding your Users (Second Edition)*, ser. Interactive Technologies, K. Baxter, C. Courage, and K. Caine, Eds., Second Edition, Boston: Morgan Kaufmann, 2015, pp. 158–189, ISBN: 978-0-12-800232-2. DOI: https://doi.org/10.1016/B978-0-12-800232-2.00007-9. [Online]. Available: https://www.sciencedirect.com/science/article/pii/B9780128002322000079.

[69] J. J. Shaughnessy, E. B. Zechmeister, and J. S. Zechmeister, *Research Methods in Psychology*, 10th ed. New York: McGraw-Hill Education, 2015, ISBN: 9780077825362.

[70] M. Schrepp and J. Thomaschewski, *Ueq+ research project*, https://ueqplus.ueq-research.org/, Accessed: 2025-04-17, 2025.

A

Questionnaire

The following questions were asked in the questionnaire.

1. What model car (BEV) do you drive?
   - EX40
   - EC40/C40
   - EX90
   - None of the above
2. How long have you been driving a BEV? (current + previous BEV)
   - Less than 6 months
   - 6-12 months
   - More than 12 months
3. What is your age?
   - 29 or younger
   - 30-39
   - 40-49
   - 50-59
   - 60 or older
4. What is your gender?
   - Woman
   - Man
   - Non-binary
   - Other
   - Rather not say
5. Do you work with any of the following (functionality and/or design): battery, range, range assistant, range optimizer and other similar functions?

- Yes
- No

6. Do you have the possibility to charge at home or at work?
    - Yes
    - No
7. Do you make any longer trips that require charging along the way (e.g. to another city, summer house etc.)?
    - Yes, weekly
    - Yes, monthly
    - Yes, every now and then during the year
    - No, never
8. In what way do you use the range information? (Multiple answers possible)
    - Plan trips
    - Plan charging
    - Assure your mind/Reduce range anxiety
9. Do you trust the range you see in the car? Why/Why not?
    - Open ended
10. Do you feel like the range is changing in an unpredictable way? (Why/why not?)
    - Open ended
11. Do you use the Range Assistant?
    (The range assistant is an in-car application to optimize range. It provides information on estimated driving range based on current driving behavior and real-time energy consumption data. Further, it gives feedback on the key factors that affect the driving range; speed, driving style and climate control.)

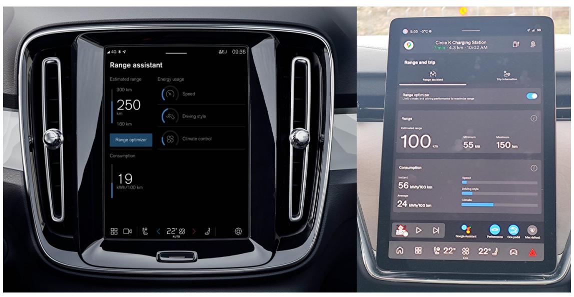


Figure A.1: Image of the R.A. provided in the questionnaire to provide a reference point for the users to clarify questions 5.

- Yes
- No

12. (If no), Why have you not used the Range Assistant? (Multiple answers possible)
    - Didnt know about it
    - I dont understand it
    - It didnt seem useful to me
    - I prioritize other applications
    - I dont like to be distracted while driving
    - Other reason
13. Do you know what the factors that are shown on the Range Assistant mean?

Figure A.2: The Range Assistant provided together with question 13 to clarify what part of the R.A. the question referred to.

- Yes
- No

14. (If yes), What is your understanding of what the different factors mean and how they affect range?
    - Open ended
15. Do you think there are any other factors that affect range, and if so, which factors are there and how do they affect range?
    - Open ended
16. How often do you use the Range Assistant for your trips?
    (a) Never
    (b) Couple of times a year
    (c) Monthly
    (d) Weekly

(e) Very often/Every time

17. When do you typically use the Range Assistant? (Multiple answers possible)
    - Before a trip
    - During the trip, having it open all the time
    - During a trip, glancing at it once in a while
    - After a trip
18. When do you find the Range Assistant most useful? (Multiple answers possible)
    - Short trips (<30 min)
    - Longer trips (>30 min)
    - Very long trips (> 3 h)
    - Never
19. Have you used the Range Optimizer feature in the Range Assistant app?

Figure A.3: The Range Assistant with the Range Optimizer circled to clarify question number 19

- Yes
- No
- I don't know what that is

20. Do you understand what changes the Range Optimizer makes in the car when you activate it?
    - Yes
    - No
21. (If yes), What is your understanding of how the Range Optimizer works when activated?
    - Open ended
22. there anything that you feel is missing with the Range Assistant in general?

- Open ended

23. Would you be willing to participate in a follow-up interview/focus group (on-site in Gothenburg) about Range Assistant?
    - Yes
    - Maybe, if given more information
    - No

B

Evaluation

ID:_________

Research Consent Form

User Experience of Electric Vehicle Energy Use and Range

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Thank you for taking the time to participate in our research. This Usability Testing is part of a master's thesis project at Chalmers University of Technology, Sweden, in collaboration with Volvo Cars AB, Sweden. The study aims to explore the understanding of range and the user experience in electric vehicles (EVs). The test will take approximately 30 minutes to complete.

In this evaluation, we will ask you to fill out a demographic survey about your professional background, experience with driving EVs, and your thoughts and opinions regarding the range interfaces. There are no right or wrong answers, we are just interested in your personal opinions. Please try to respond to the questions as openly and honestly as possible and try to respond to each question. This is very important for our research project. In this session we also encourage you to think aloud, try to say exactly what you think when you think of it. Again, there are no right or wrong answers.

You may withdraw your participation at any time. There will be no negative consequences if you decide not to continue. All collected data will be treated as confidential and stored securely.

The following material will be collected:

- Audio recording of the test
- Notes taken during the test
- Demographic questionnaires

The published research will not contain any identifying information about you. All collected data will be anonymised accordingly. When we write about the study or publish a paper to share the research with other researchers, we will write about the information we have gathered from this testing. Your responses may be quoted in the thesis and scientific papers. However, we will not include your name or any information that will directly identify you. We will only use the collected data to do further analysis for the purpose of education and scientific papers.

We will use the data only if you agree on to this by giving your consent to the following statements:

- I have read and understood the description, and I have had the opportunity to ask questions if necessary and have had these answered satisfactorily.
- I understand that my participation is voluntary and that I am free to withdraw the use of my data without giving any reason. If I withdraw, my data will be removed and destroyed.
- I consent to the publication of the results of the study with the understanding that anonymity will be preserved.

Thank you very much for your valuable input!

Declaration of Consent

I agree to the above statements:

Name (print name):

____

Signature:

____

Date: ________________________

Additionally, by signing below I agree that my data in the study can be used for educational purposes and scientific papers:

Signature:

____

Date: ________________________

ID:_________

Demographics Survey

1. Gender
   - ☐ Female
   - ☐ Male
   - ☐ Non-binary
   - ☐ Prefer not to say

2. Age
   - ☐ 18-24
   - ☐ 25-34
   - ☐ 35-44
   - ☐ 45-54
   - ☐ 55-64
   - ☐ 65 or over

3. How long have you been driving an EV? (Specify months or years)

   ____

4. What model of EV do you typically drive?

   ____

5. What is your current profession or field of work?

   ____

6. Where do you usually charge your EV? (Select all that apply)
   - ☐ Home
   - ☐ Work
   - ☐ Public
   - ☐ Other: _______________________

7. How many longer trips (>3 hours) do you make per year?
   - ☐ None
   - ☐ 1-2
   - ☐ 3-5
   - ☐ 6 or more

ID:_________

Questionnaire

	1	2	3	4	5	6	7	
In my opinion, the aspect of having tips is								
annoying	☐	☐	☐	☐	☐	☐	☐	enjoyable
bad	☐	☐	☐	☐	☐	☐	☐	good
unpleasant	☐	☐	☐	☐	☐	☐	☐	pleasant
confusing	☐	☐	☐	☐	☐	☐	☐	clear
useless	☐	☐	☐	☐	☐	☐	☐	useful
To achieve my goals, I consider the DIM interface as								
difficult to understand	☐	☐	☐	☐	☐	☐	☐	easy to understand
inefficient	☐	☐	☐	☐	☐	☐	☐	efficient
impractical	☐	☐	☐	☐	☐	☐	☐	practical
cluttered	☐	☐	☐	☐	☐	☐	☐	organized
confusing	☐	☐	☐	☐	☐	☐	☐	clear
To achieve my goals, I consider the CSD interface as								
difficult to understand	☐	☐	☐	☐	☐	☐	☐	easy to understand
inefficient	☐	☐	☐	☐	☐	☐	☐	efficient
impractical	☐	☐	☐	☐	☐	☐	☐	practical
cluttered	☐	☐	☐	☐	☐	☐	☐	organized
confusing	☐	☐	☐	☐	☐	☐	☐	clear

Interview Questions

- What's your general impression of the Range and Trip application? (CSD)
- What did you think about the feedback from turning on features in the Range and Trip application?
- What is in your opinion the most important information in the Range and Trip?
- How did you feel about having the added tips feature to the Range and Trip application on the CSD?
- What did you think about having the range factors in the DIM?
- **For scenario 1:** What did you think about having tips in the DIM?