CHALMERS UNIVERSITY OF TECHNOLOGY | UNIVERSITY OF GOTHENBURG

Recommendations for Presenting Battery State of Health Information

To enhance in-vehicle experience and understanding for Battery Electric Vehicle Users

Master's thesis in Interaction Design and Technologies

NATTHAMON PONGCHANCHAI

LIINA TUMMA

Department of Computer Science and Engineering
CHALMERS UNIVERSITY OF TECHNOLOGY
UNIVERSITY OF GOTHENBURG
Gothenburg, Sweden 2024

Master's Thesis 2024

Recommendations for Presenting Battery State of Health Information

To enhance in-vehicle experience and understanding for Battery Electric Vehicle Users

NATTHAMON PONGCHANCHAI
LIINA TUMMA

UNIVERSITY OF GOTHENBURG

CHALMERS
UNIVERSITY OF TECHNOLOGY

Department of Computer Science and Engineering
Chalmers University of Technology
University of Gothenburg
Gothenburg, Sweden 2024

A Chalmers University of Technology Master's thesis template for LaTeX
To enhance in-vehicle experience and understanding for Battery Electric Vehicle Users
NATTHAMON PONGCHANCHAI & LIINA TUMMA

Supervisor: Mohammad Obaid, Department of Computer Science and Engineering
Advisor: Micaela Nilsson, Volvo Cars
Examiner: Morten Fjeld, Department of Computer Science and Engineering

Master's Thesis 2024
Department of Computer Science and Engineering
Chalmers University of Technology and University of Gothenburg
SE-412 96 Gothenburg
Telephone +46 31 772 1000

Cover: Description of the picture on the cover page (if applicable)

Typeset in LaTeX
Gothenburg, Sweden 2024

A Chalmers University of Technology Master's thesis template for LaTeX
To enhance in-vehicle experience and understanding for Battery Electric Vehicle Users
NATTHAMON PONGCHANCHAI & LIINA TUMMA
Department of Computer Science and Engineering
Chalmers University of Technology and University of Gothenburg

Abstract

Within the automotive industry nowadays, a significant transformation is currently happening, transitioning from combustion engine vehicles to more sustainable alternatives, including Plug-in Hybrid Electric Vehicles (PHEVs) and Battery Electric Vehicles (BEVs). With more and more consumers coming to the fully-electric vehicle market, the new regulations concerning the battery State of Health (SoH) of Electric Vehicles (EVs) have been regulated and used as a standardisation for automotive manufacturers to implement battery SoH feature by 2026. This new legislation is not only new to the EV drivers but also novel to the vehicle manufacturers in the automotive industry. However, compliance with the regulations does not take into account the user experience. Moreover, the scarcity of research in this area makes it potentially challenging to understand the user needs and goals. This thesis investigates how the information of battery SoH should be displayed from a user-centred perspective, with the aim to improve user understanding of battery health and increase their engagement with the BEV battery health maintenance.

The study takes a user-centred design approach to better understand user needs and develop the most appropriate approach to display battery SoH to drivers. During the process, several research and design methodologies including literature review, questionnaire and focus groups, have been conducted to understand the users, frame the problem spaces, and identify the user requirements for further development. With the defined user requirement list, different resolution levels of prototypes were developed and evaluated in three iterations, with a total of 15 participants involved across these iterations, to ensure that the design concept met their expectations and requirements and that the prototypes were refined efficiently based on their feedback. The findings revealed that simply displaying SoH as a percentage is insufficient to inform users about the current state of their battery health and additional contextual information and actionable guidance are needed. This thesis presents a series of design recommendations as deliverables, derived from research, analysis, and evaluation of the design concept. These recommendations were established with the aim of enhancing the user experience and understanding of battery SoH information displayed in BEVs, also serving as guidance for the implementation of the SoH functionality in the BEVs in the upcoming future.

Keywords: battery electric vehicle, battery health, interaction design, user-centred design, user experience, user interface, information visualisation.

Acknowledgements

We would like to express our sincere gratitude to everyone who has been involved in any way to this master's thesis. First and foremost, we would like to thank Mohammed Obaid, our supervisor at Chalmers University of Technology, for his generous support, guidance, and expertise throughout this thesis. His encouragement was helpful in keeping us motivated and navigating through challenging times.

We would like to extend our sincere gratitude to Micaela Nilsson, our advisor at Volvo Cars, for her continuous support and coordination throughout this thesis. Her dedication and emotional support were invaluable in assisting us to overcome the challenges encountered during this thesis work. With her assistance, nothing was impossible, as she always found a solution or workaround for any issues raised during the project.

We also would like to express our sincere appreciation to everyone at Volvo Cars who supported us for the entire thesis period, particularly the Energy Management, for welcoming us to the team and providing valuable feedback. Moreover, we would like to thank other departments that were involved in the process, such as Car UX Driver Experience, CoDev Fleet, Battery Cell Analytics, Battery Control, and Product Validation, for their collaboration and assistance. Without their support, we would not be able to access insightful information and expert points of view about this thesis. Last but not least, we would like to thank all the participants who were part of the CoDev Fleet and participated in any session to share their ideas, opinions, and feedback with us. Without their assistance, we would not be able to progress our thesis successfully.

Natthamon Pongchanchai & Liina Tumma, Gothenburg, May 2024

Contents

List of Figures

Abbreviations

BEV	Battery Electric Vehicle
EV	Electric Vehicle
GDPR	General Data Protection Regulation
GTR	Global Technical Regulation
HVI	Human-Vehicle Interaction
InfoVis	Information Visualisation
ISO	International Organization for Standardization
IxD	Interaction Design
MOL	Mental Overload
MUL	Mental Underload
PHEV	Plug-in Hybrid Electric Vehicle
RtD	Research through Design
SoC	State of Charge
SOCE	State of Certified Energy
SOCR	State of Certified Range
SoH	State of Health
UBE	Usable Battery Energy
UCD	User-Centred Design
UX	User Experience
ZEV	Zero-Emission Vehicle

1
Introduction

The era of BEVs has begun and is increasingly becoming a significant part of the automotive industry. With more and more BEV drivers coming in, new legislation and guidelines need to be considered along with other factors in the product development process. One of the major considerations in the recent future is battery SoH, which will play a vital role in assessing the resale value of the EV, similar to how the milage impacts the value of combustion engine vehicles. SoH is conventionally shown in percentage and will typically be 100% at the time of manufacture and will decrease over time with the battery's performance. There are several factors that impact battery drainage, such as climate and charging behaviour, and drivers can influence the rate of the battery's degradation. Therefore, it is essential for vehicle drivers to understand key concepts, such as battery SoH, capacity and factors that affect battery health. This knowledge helps them make more informed decisions about using and maintaining their vehicles. However, they should not need detailed technical knowledge of batteries. Additionally, many users find it difficult to understand EV-specific information due to the difference between these and conventional cars. Therefore, simplifying complex data such as SoH can significantly enhance the user experience and improve the longevity of BEV.

1.1 Problem Statement and Research Questions

According to a new legislation (ACC2/EU/GTR-22), EVs are required to display battery SoH on the vehicle monitors [1], [2]. The new legislation is not only new to the EV drivers but also novel to manufacturers in the automotive industry. However, compliance with the regulations does not take into account the user experience and the value that this new information can bring to them. Moreover, the lack of research in this area makes it challenging to know the user needs and requirements. Therefore, there is a need to investigate and establish best practices when battery SoH is provided to EV drivers. A concern for environmental sustainability and technological innovation sparked an interest in investigating and researching the problem area. The design community also highlighted the lack of previous research and potential research challenges, which further motivated research on the topic.

The main research questions that will be investigated are:

1. What information should be displayed to enhance user understanding of battery health in order to prevent excessive degradation and promote best prac-

tices?

2. What are design recommendations for displaying the battery SoH information to enhance the in-vehicle experience for BEV drivers?

The scope of the study is focused on BEV leasers for several reasons. First of all, the projects time constraints needed a group of participants who were easily accessible to run several evaluation tests. With Volvo Cars serving as the case study, there was direct access to a considerable number of users who currently lease company-produced BEV. Moreover, BEV leasing is becoming more popular for sustainability and environmental reasons, and mobility as a service (Maas) is expected to grow in the future. By investigating the impact of SoH information on BEV leasers, the study aims to enhance the battery life expectancy of future vehicles and reduce environmental impact. Providing clear SoH information with best practices or recommendations for battery care to prevent excessive degradation, can directly influence user behaviour and battery longevity. Awareness of battery lifetime through SoH information is relevant not only to BEV owners but also to every individual who drives the vehicle, including the leasers.

1.1.1 Purpose

The aim of the thesis is to develop design recommendations for the display of battery SoH from a user-centred design perspective. One of the goals is to investigate what information about the battery SoH is suitable to enhance user experience and provide a helpful and useful set of information that will enrich users' knowledge about the battery SoH. Another goal is to investigate the information visualisation of the battery SoH parameters in the in-car display of the BEV. With a focus on usefulness, utility and usability, a prototype will be developed and tested to evaluate proposed guidelines and requirements.

1.1.2 Expected Contributions

The expected outcomes of this research are diverse. The research and proposition of requirements and guidelines for battery SoH information visualisation will contribute to the field of in-vehicle human-machine interface design. Since not much research has been done on battery SoH functionality from a user-centred perspective, our contribution can be valuable for further research. Our research will also help to deepen the understanding of users of BEVs and better understand the in-car BEV driving experience for users.

With a user-friendly display of SoH information, we hypothesise that BEV drivers will be able to perceive, interpret, and use the SoH information easily and efficiently. Adding more information along with SoH values could probably help the driver understand the overall battery condition, and which factors can influence SoH values.

Introducing SoH information aims to encourage sustainable driving practices among BEV drivers, including smarter charging habits and more environmentally friendly driving behaviours, leading to a positive environmental impact. We expect that this information will benefit not only BEV car drivers but also potential buyers in building trust and estimating resale values. These expected outcomes represent positive changes in user behaviour, industry practices, and environmental sustainability, which could uplift an overall experience and create a great milestone in the automotive industry.

2

Background

This chapter provides the context required to understand the research problem presented and analysed in this study. The company Volvo Cars is introduced, together with the topics related to BEVs and battery SoH. Related findings in the literature review shed more light on the topic, revealing some of the findings in this field while also identifying some gaps in the current knowledge.

2.1 Stakeholders

This research is expected to benefit various stakeholders. Some of these primary stakeholders, such as Volvo Cars, the automotive manufacturer where the research is taking place, and the drivers, will be kept close throughout the project since their involvement and feedback are crucial to helping execute the project successfully.

- **Drivers:** The drivers are the primary users who will benefit from the findings of this research. By involving them in user research and evaluation, we will be able to understand their needs and gain valuable insights.
- **Automotive manufacturer and industry:** Volvo Cars, in particular, will benefit from the outcomes of this master thesis for future implementations of the new SoH display. Volvo Cars will play a vital role in providing all essential support and contributing resources to facilitate this research work.
- **Automobile dealers and service centres:** Both first- and second-hand automobile dealers could benefit from a better understanding of SoH for their services as well as a more accurate calculation of the re-sales price of EVs.
- **Insurance companies:** As the SoH information could be used to assess vehicle conditions and usage behaviours of the users, this could be beneficial for the insurance companies to assess their customers.
- **EV charging providers:** More understanding of the battery SoH of EVs might impact the usage of charging stations. The providers can leverage this SoH to optimise charging strategies.
- **Environment:** Informing the drivers on how to take care of battery SoH could enhance the lifespan of batteries, which will positively impact the environment.

- **Bystanders:** The implementation of the findings of this research could influence the perception of electric cars and impact their demand for electric cars in the future.

2.2 Volvo Cars

Volvo Cars is a well-known multinational car manufacturer with headquarters based in Göteborg, Sweden. The company's three core values are personalisation, quality, and care for the environment [3]. These three core values not only define the company's philosophy but also guide its operations and product development strategies. In its move towards sustainability, Volvo Cars has achieved a 19% reduction in CO2 emissions per vehicle since 2018 [4], highlighting its dedication to reducing its environmental impact.

The company is investing in EV technology and infrastructure with the introduction of electric models like XC40 Recharge, and C40 Recharge, as well as the latest EX30, EX90, and EM90. By 2025, Volvo Cars intends half its sales to be EVs and the other hybrids as a form of building up towards their total lineup by an exclusively fully electric car target set for 2030 [5]. Besides, Polestar, a company known for producing EVs, is an affiliate of Volvo Cars. This partnership encompasses a broad range of areas, including research and development (R&D), manufacturing, after-sales services, and commercial operations [6]. This collaboration benefits both brands by ensuring they stay at the forefront of EV technology.

Volvo Cars has shifted to electric mobility in the past years due to its need for sustainable practices resulting in financial success following a 70% growth in EV sales rates, contributing 16% of global sale volume [7]. Such growth increases requirements for EVs, placing Volvo Cars as one of the eminent contributors to the automotive industry's evolution towards sustainable production. Investigating the user's centric perspective about the battery health of EVs can produce fertile results that can be of high interest to the company. Enhancing the user's understanding of the EV's battery and creating more value for the user can be a gain to the company nowadays and in the future.

2.2.1 Pre-Study on Battery SoH

According to new legislation (ACC2/EU/GTR-22), battery electric vehicles are required to display battery SoH on the vehicle monitors to the customers [1], [2]. Regarding this, more than a year ago, Volvo Cars Sweden conducted an interview study to investigate where would be the best location to present SoH information and what relevant information the user would see to acknowledge this information. The study was conducted using survey and interview methods (both on-site and online) with the user group as BEV and PHEV leasers who are Volvo Cars employees in Sweden.

The findings revealed that most of the respondents are aware of the battery SoH, but are not actively concerned or trying to maintain the battery SoH. They acknowledged that there is an advice of charging 80-90% instead of 100% but they were not sure of why it makes a difference. Despite less concern about battery health, many respondents would like to have more information regarding possible actions to protect the battery, including how and why those actions affect their cars battery life. In terms of the location of the SoH, most respondents said that they would look for SoH information on the infotainment screen in the first place while many of the participants mentioned the location and usage of SoH on their mobile phone as an example. The battery SoH information was typically expected to display in the same location with the other car status, i.e., tyre pressure, however, most participants would like the information to not be displayed all the time but rather notify them when there is an issue with the battery SoH.

2.3 Vehicle Subscription

MaaS, or mobility as a service, is changing how we view owning a car, particularly in light of the growing popularity of EVs. Between 2023 and 2031, the global car subscription services market is projected to grow at a rate of almost 35.3% [8], [9]. A study by Liljamo et al. [10] found that the introduction of automated vehicles (AVs) and MaaS, along with improved public transportation quality, could lead to a decline in car ownership in Finland. The study found that 39% of participants would not need to own a car if adequate connections to public transportation were provided, 58% if mobility services were offered, and 65% if all cars in traffic were automated.

A popular MaaS model is a car subscription, which offers an alternative to purchasing or leasing a vehicle. Volvo's Care by Volvo [11], for instance, offers a comprehensive package that includes maintenance, insurance, and rental, allowing customers to drive an EV without long-term financial obligations. The program offers a flexible option with a three-month notice period, compared to 36-month leasing contracts. The company refers to its system as a subscription rather than leasing, drawing comparisons to TV, music, or news subscriptions. Investigating Volvo Cars employees who lease a BEV will offer more insights into how consumers perceive the importance of managing EV battery degeneration while subscribing to the car.

2.4 Battery Electric Vehicles

BEVs are quickly becoming more common in cities throughout Europe and the United States, as a result of the policies aimed at decreasing traffic pollution and greenhouse gas emissions [12]. Automakers are encouraged to shift away from vehicles with internal combustion engines (ICE) [13], [14] due to the technical and environmental advantages that EVs present. BEVs are particularly appealing because they produce no exhaust emissions, which cuts greenhouse gas emissions, especially when they run on renewable energy [15], and reduces reliance on fossil fuels. Many experts believe that BEVs will soon take over from traditional ICE vehicles [16].

However, BEVs face technical challenges which stand in the way of their widespread use, such as battery degradation and the need for more charging stations [14]. More research and development on the battery health and charging infrastructure is required to address these issues. For this reason, tackling the battery degradation problem from a user-centred perspective can add value to the research and delve further into possible solutions.

2.5 Battery State of Health

The health of EV batteries significantly affects safe driving and minimising risks of premature failures. The health of the battery in regard to its SoH, therefore, is indispensable for the trustworthiness and functionality of EVs. According to Xiong et al. [17], correctly estimating SoH is critical.

SoH measures how well a battery is performing compared to when it was new. Initially, a battery's SoH is 100%, but it decreases over time due to inevitable chemical and physical changes, a process known as ageing. This decline impacts the battery's ability to hold and release energy. Once the SoH drops below a certain level, the battery, although still operational, is considered to be at the end of its life and needs replacing. At this point, the SoH is effectively zero [18]. It is important to mention that the exact point at which a battery's SoH is considered zero varies among manufacturers, based on their individual criteria.

Determining the SoH accurately is difficult because of the complex chemical reactions happening inside the battery and the various external factors that can affect these reactions. Liu et al. [19] highlight that these complexities make it hard to measure SoH precisely. To address this, there is a lot of research aimed at creating advanced methods for estimating SoH. These methods often use mathematical algorithms and incorporate techniques like big data analysis and machine learning to improve prediction accuracy. However, despite these efforts, there are still major issues with the current research, as Yang et al. [20] have noted. After reviewing 190 studies, they pointed out problems such as unclear categorisations, incomplete reviews, and insufficient evaluations of the methods for estimating the SoH. This criticism highlights the emerging nature of this field and the continuous need for more research and development. As battery technology evolves and improves, the methods for assessing and maintaining battery health will also advance.

According to Zhao & Burke [21], battery SoH is an ongoing concern because it affects vehicle range, battery cycle life, vehicle trade-in value and total ownership cost, which is the sum of expenses that are associated with the purchase, maintenance and operation of the car. As a result, information such as the battery's SoH will not only benefit the driver of an EV, but will also increase trust in the battery's performance, reliability and safety [21].

2.5.1 Factors and Prevention of Battery Degradation

The lithium-ion battery, a crucial component of EVs, is a significant portion of the EV's total cost. Despite its benefits like high energy density and fast charging, battery degradation is inevitable due to time and usage [22]. Batteries also degrade non-linearly, since once the battery health drops below 80%, the battery's capacity fades rapidly [23]. Users of EVs can directly affect the degradation of the battery since some of the factors and circumstances that influence the battery's SoH can be prevented or reduced.

As summarised by Eider & Berl [24], battery degradation in EVs can be influenced by cyclic and calendar ageing. Cyclic ageing occurs due to charge throughput during driving and charging cycles, while calendar ageing occurs over time and when the battery is powered off. To reduce cyclic ageing, it is recommended to avoid fast charging, use low temperatures when fast charging, and delay charging. The State of Charge (SoC) should not exceed 80% during charging, and frequent discharge to a high SoC should be avoided. Usage during EV driving also affects battery health, with discharge rates affecting the level of cyclic ageing. Ambient temperature and SoC levels are critical factors in calendar ageing. EV batteries should be kept in a temperature range of 15 ℃ to 50 ℃, with a 10 ℃ increase doubling the degradation rate. The SoC level plays a significant role in ageing EV. It's essential to avoid high SoC during parking to prolong battery life while maintaining a low SoC, around 50% is ideal.

To ensure long service life and good performance, each car manufacturer specifies the recommended actions that the driver should take for their specific vehicle battery. These static recommendations can be found in the car's manual. Volvo Cars [25], for example, presents these recommendations in the following way:

- **Charging:** When charging a battery, choosing active charging (AC) is recommended in preference to direct (DC) fast charging whenever possible, as it is less damaging. Avoid charging the car to 100% unless necessary, as it may damage the battery. If the battery is below 20%, charging is always recommended to prevent full discharge, as it can lead to severe damage.

- **Parking:** To minimise the risks, when parking longer than one month it is recommended to have a charging range of 40-60%. For longer parking periods, constant charging is advised.

  Avoid parking in extreme temperatures for more than 24 hours, especially around 55 ℃. Moreover, avoid leaving the car unconnected at temperatures above 30 ℃, since the car will actively cool the battery and consume power which will decrease the SoC.

  Low temperatures can temporarily reduce battery performance, so charging and preconditioning (which is heating the battery before driving in advance) can prevent reduced performance. If parking for over 24 hours when it's below -30 ℃, connect the car for charging.

As can be seen above, there are several factors and circumstances that affect the batter's SoH, many of which can be prevented or reduced by the user. In order to answer our research questions, these elements will be investigated from a user-centric standpoint to determine what information should be shown to the user about battery health that can enhance their understanding of the matter.

2.6 Display Challenges with Related Information of SoH

Although there have been no user-centred studies on battery SoH, several studies have identified a number of difficulties that impact drivers' experience with BEVs interfaces and the content that is displayed to them. For instance, Strömber et al. [26] found that study participants had difficulties understanding EV-specific information content in the driver interfaces. It was determined that the participants felt insecure when dealing with innovative interfaces because they expected the vehicle to function like a conventional car with a traditional interface. It becomes obvious that more attention should be paid to how and what information should be presented to make the driver understand the content required to operate the EV efficiently because of the novelty and lack of experience with the new interfaces and the way that electric vehicles operate. This is also supported by Neumann & Krems [27] who studied the human-machine interface of BEVs from the user's perspective. They discovered that drivers struggle to understand the electrical units and energy usage of BEVs. As a result, information on BEV displays that affect range and energy consumption needs to be improved. Furthermore, they demonstrated the significance of incorporating user preferences and needs into the design of BEVs interfaces through their longitudinal study.

Despite the fact that no studies have explored the information display of battery SoH from a user-centric perspective, Wang [28] investigated the effects that battery SoH may have on drivers' range anxiety, which is the driver's fear that the battery will not have enough charge to reach the destination. Battery SoH is closely related to range, as it affects the BEV's range estimation. Consequently, excluding battery SoH could lead to inconsistent estimation, which would reduce the reliability of the range information that is currently available. Wang et al. [28] argue that this lack of consistency will worsen uncertainty and range anxiety. The authors' findings lead to the conclusion that range anxiety in drivers can be reduced if a range-related in-car information system provides correlated data, such as battery health and adjusted remaining range. Furthermore, the authors claim that, while battery health is closely related to the remaining range, it is not considered in current research. As a result, further investigation of the battery SoH in-vehicle information display will not only provide additional research on the topic but will also aid in better understanding and exploration of related topics such as range-related information or battery SoC.

2.7 Recommendations

Based on the compiled taxonomy of user requirements for the BEV display, as well as the content of the BEV's range information and its factors, Neumann & Krems [27] propose that BEV-specific features should be developed and displayed while keeping general design principles in mind. Furthermore, the authors emphasise that the following principles can contribute to addressing the issue:

- **Predictive aiding:** giving drivers access to data that can assist in predicting future conditions. This will facilitate planning and decision-making by providing comprehensive feedback on the factors influencing range and energy consumption.

- **Redundancy gain:** presenting the information in multiple ways to improve understanding and help retain information. As a result, the graphical and numerical representation might reinforce this understanding.
- **Proximity:** closely locating the information related to the same task and goal in order to facilitate its processing and integration.
- **Minimisation of information access cost:** accessing critical information with minimal effort. BEV displays must present crucial information in a way that is easy to access and understand.

Even though the authors concentrate on range and energy consumption primarily, the battery's SoH is closely related to this topic. As they point out, additional information can help the driver understand and trust the information more [27]. Therefore, the battery health information display may benefit from these particular design principles.

When it comes to battery SoH-specific recommendations, to limit degradation and maintain battery health, there are several actions that the driver could do. However, some of these recommendations are difficult to follow and not available in certain driving and charging contexts. To address this problem, Eider & Berl [24] proposed dynamic recommendations, which are based on battery-friendly ranges of static recommendations, by giving recommendations right on time based on the current driving, parking, and charging context. For instance, a recommendation for fast charging is presented when the ambient temperature of 10 °C over a month. By sending recommendations dynamically, prioritisation plays a vital role in ensuring that the driver receives the most important recommendation which could significantly impact battery health. The authors enable dynamic recommendations by analysing parameters, categorising the recommendations into groups, and implementing an algorithm to interpret the parameters and criteria, as well as testing it with the real data gathered from EVs. Based on the test result, dynamic recommendations were generated at a certain point in time when the criteria were met.

This context-aware and prescriptive guidance can therefore be divided into three different groups: driving, charging and parking and aims to help users actively influence and slow down the degradation rate of EV batteries. However, rather than concentrating on the user-centric perspective and the user's assessment of these dynamic recommendations, the authors concentrated on the computation and processing of these recommendations. In their most recent study [29], the authors dive into the computational model of dynamic recommendations' implementation and assessment. The authors note in the evaluation that 3.49% of the time, no recommendation was given. The authors also point out that some recommendations happen concurrently and overlap. Similar to most studies on the battery SoH, this SoH research primarily considers the computational viewpoint. On the other hand, it is evident that when it comes to receiving recommendations, there is a lack of user-centred perspective.

In this research, the user's experience will be the main focus to provide users with the information they need about battery health, the factors that can affect it, and the recommendations that should be followed to ensure that the battery is properly taken care of.

2.8 Regulations

This section describes the new regulations concerning the battery SoH in EVs. These regulations are regulated in section 1962.5 as part of the Advanced Clean Cars II (ACC II) of the United States [1]. Meanwhile, in the European Union, these are included as part of the United Nations Global Technical Regulation No. 22 [2].

These regulations provide a standardisation for the car manufacturers to implement the battery SoH metrics starting in 2026. These regulations are one of the reasons that the subject of battery SoH is a concern and this research has the potential to provide new insights into this area. Although we are aware of regulatory compliance, this research will focus on how to display the battery SoH from the user's perspective, and how they might benefit from this information.

2.8.1 Advanced Clean Cars II Regulations

To achieve long-term greenhouse gas emission reduction goals of the United States and meet California's health-based air quality standards, all vehicles should generate zero emissions as closely as possible. In 1990, the California Air Resources Board (CARB) accepted the requirements related to Zero-Emission Vehicle (ZEV) as part of the Low-Emission Vehicle regulation. These ZEV regulations have been modified over the past 30 years to reflect the state and adapt to fast-changing technology. In 2022, the ZEV regulations were adopted along with the Advanced Clean Car II (ACC II), a regulation aiming to decrease emissions by increasing the sales of EVs and reaching 100% zero emission by 2035. The ACC II was introduced to meet the federal ambient air quality ozone standards and comply with California's objectives for carbon neutrality [30]. The regulations stipulate higher standards for low- and zero-emission vehicles in the new model years (2026-2035), including Data Standardisation Requirements for 2026 and Subsequent Model Year Light-Duty Zero Emission Vehicles and Plug-in Hybrid EVs in section 1962.5 [1].

Apart from the functions required to be implemented, the standardisation specifies the data to be displayed to the user serving as a communication protocol between the user and vehicle, e.g., battery SoH and charging rate. The SoH data shall be displayed as the requirements, specifications, and conditions as follows:

Requirements:

- SoH, distance travelled since SoH last updated or reset, and quantity of battery energy remaining in reserve must be accessible for all off-board charge-capable vehicles.

Accuracy:

- SoH is required to normalise and display within a range from 0 to 100%.
- The normalised percentage should align with the Usable Battery Energy (UBE) for the certification range value, as measured following the ZEV Test Procedure.
- The reported parameter of SoH shall be no more than 5% higher than the SoH from measured UBE.
- For vehicles designed with reserved batteries for later access when ageing, manufacturers should normalise reported SoH so that 100% reflects the designed maximum allowance, including reserved one.
- Manufacturers are allowed to limit the re-calculation of an updated SoH value to certain usage conditions of the vehicle.

Display of Data

- SoH shall be able to display in vehicles to the users without the use of any tools.
- SoH shall be able to access with no more than five sub-menu selections from the home or default screen.
- SoH shall be displayed in alphanumeric format.
- SoH shall be displayed in the same resolution as standardised data.
- SoH shall be converted to standard engineering units as applicable.

2.8.2 Global Technical Regulation

With the goal of reducing emissions of greenhouse gases and air pollution, the proportion of electrified vehicles is expected to increase in the future. However, the in-use performance of the battery has not yet been regulated and the excessive degradation of the battery was recognised which may affect environmental performance, range, efficiency, and emissions. For these reasons, the Global Technical Regulation (GTR) was introduced by the United Nations (UN) with the objective of addressing the negative impacts of battery degradation on EVs by introducing a method where battery health can be monitored over time. Within the GTR, the terms State of Certified Energy (SOCE) and State of Certified Range (SOCR) were defined to represent a percentage of the certified battery energy or electric range remaining at a given point in time. In similar terms, SOCE was also recognised as UBE. Both terms should be estimated and displayed as the following requirements [2].

Requirements:

- The SOCR and SOCE monitors shall be installed over the vehicle's lifetime to monitor the estimated value of the on-board SOCR and SOCE.
- The on-board SOCR and SOCE shall be re-calculated and updated with optimal frequency to maintain the accuracy of the values.

- The on-board SOCR and SOCE shall be reported as the nearest whole number from 0 to 100.
- The recent on-board SOCR and SOCE shall be accessible through the OBD port and optionally over-the-air (OTA).
- The recent on-board SOCR and SOCE shall be available to the owners via at least one appropriate method, e.g., dashboard indicator, infotainment system, and remote access (mobile-phone applications).

3
Theory

This section serves as a foundation of the research, helping to comprehensively explore significant frameworks and theoretical concepts relevant to the study, including Wicked Problems, User Experience Design, Interaction Design Approaches, Human-Vehicle Interaction, and Information Visualisation. The outcomes will aid in planning and designing the approaches to tackle the problems further.

3.1 Wicked Problems

In a social context, the problems that are particularly difficult to solve due to their complexity are called wicked problems [31]. These problems are unique because they change and evolve as people try to solve them, meaning there's no clear initial definition of the problem. As solutions are proposed and tested, our understanding of these problems shifts. This makes solving wicked problems a non-linear process, where problem-solving and understanding the problem happen simultaneously. Rittel & Webber [31] also noted that solutions to wicked problems aren't simply right or wrong. Instead, they are judged as better or worse, or good enough or not good enough.

In the context of this research, our objective is to deliver a collection of recommendations regarding a novel design concept of battery SoH in the automotive industry which has not been thoroughly explored. Due to its complexity, this challenge is considered a wicked problem with no clear solution. Various factors can influence the problem, such as user behaviour, demographics, location, environmental responsibility and evolving technology of the battery and computer models. The problem might have multiple viable solutions, and identifying a feasible and optimal solution is the goal of the research. Moreover, the iterative process that characterises wicked problems is particularly relevant to this problem, where every stage of the process might lead to new insights about the problem. The solution will be evaluated based on the clarity and usability that it will provide to the user.

3.2 User Experience Design

According to the International Organization for Standardization (ISO), the definition of UX was standardised in ISO 9241-210:2010 as "A person's perceptions and responses that result from the use and/or anticipated use of a product, system or service". This term goes beyond the user's interaction and experience with a product, system, or service. Apart from emotion, belief, preference, and behaviour, it includes various aspects, e.g., perceptions, physical and psychological responses, and accomplishments throughout the entire journey before, during, and after using [32].

UX design is an umbrella term for several design and usability disciplines that designers use to create useful, usable, and desirable products, systems, or services [33]. With this term, Cooper et al. [34] highlight its interconnection and emphasise three overlapping concerns: form, behaviour, and content as in Figure 3.1. They also suggest that for any design project, designers should pay attention to orchestrating design disciplines to deliver an optimal level of user experience. However, Sharp et al. [35, p. 13] also describe that designers could not design the user experience, but only design *for* a user experience. In other words, a designer cannot directly design sensory experiences but one can design features that have the power to trigger those desired sensory responses, with the intent to manage and *influence* experience of users. Visualising battery SoH information involves integrating informative information with friendly user interfaces. This activity is a part of designing a user experience to provide a better understanding of the information with the goal of enhancing awareness and confidence in the vehicle's capabilities.

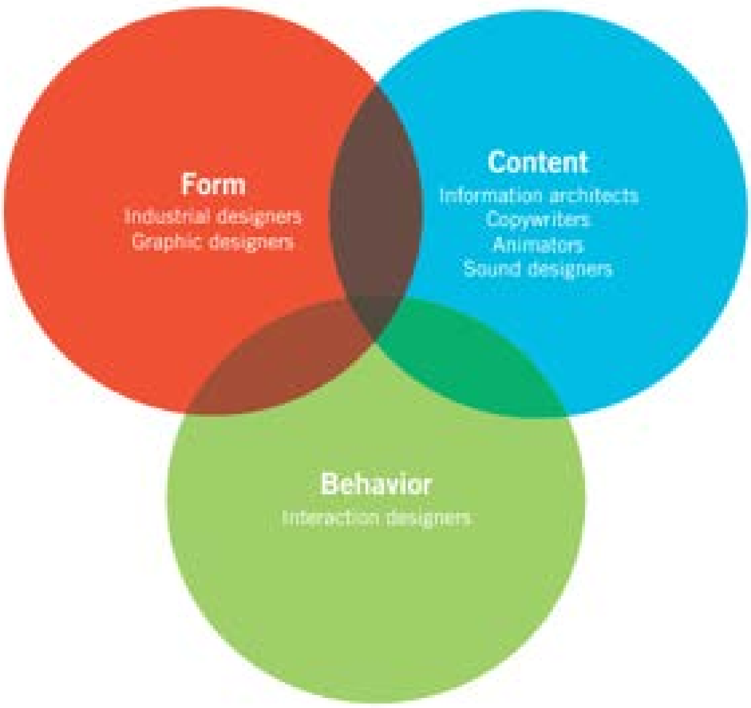


Figure 3.1: UX design has three overlapping concerns: behaviour, form, and content [34, p. xxiii]

3.3 Interaction Design Approaches

Interaction design (IxD) is a term that describes a field of designing an interaction between an individual and a product, system, or service. With this term, Sharp et al. [35, p. 9] define it as follows:

> "Designing interactive products to support the way people communicate and interact in their everyday and working lives."

Typically, the term IxD is used to describe and refer to the field which includes a range of theories, approaches, frameworks, methods, and guidelines that interaction designers can employ to initiate and deliver a high-quality level of user experience [35, p. 13].

Before delving down into the framework or design process, it is essential to understand the design approach which serves as a philosophy or mindset guiding designers through the entire design process. According to Chammas et al., designers are also encouraged to apply more than one approach based on the nature and direction of the project [36]. Given the purposes, directions, and contexts of this research, a combination of IxD frameworks is considered essential. Two main frameworks that will be employed with human-centred design are user-centred design and research through design, which will be elaborated more in the next sub-sections.

3.3.1 User-Centred Design

User-Centred Design (UCD) is a multidisciplinary design approach in which users are involved in several stages of the design process; typically during requirement gathering and usability testing, to understand their needs and iteratively improve design through evaluation [37]. In similar terms, product development is driven by real users and their goals, not just only the technology [35, p. 47]. With a focus on the users and emphasis on how to create a product with high levels of usability, UCD is considered an effective approach to overcome technical constraints from a system-centred design [37]. The term was first introduced in the United States in the 1980s by Donald Norman [38] and was constantly developed to become popular usability guidelines nowadays. This term can be elaborated with five following principles [35, p. 48]:

- The development is centred around users' tasks and goals
- The system is designed based on the study of users' behaviour and context
- Users' characteristics are considered factors in the design
- Users are involved consistently throughout the design process
- Every decision is made within the context of users, activities, and surroundings

This research aims to study EV drivers as active participants and involve them in several stages of the design process. This includes observation and interview to empathise with their needs, and usability testing to assess their interaction with the prototype, validating the design with their requirements and preferences. The UCD is applied throughout the project, continuing improvement based on the user input.

3.3.2 Research through Design

Research through Design (RtD) is an approach for conducting academic research by using design methods, practices, and processes to generate new knowledge as deliverables. This approach utilises design's strength as a reflective practice to reinterpret and re-frame complex situations as well as generate artefacts for evaluation to derive potential solutions to problematic situations. This can be done through the process of generating and criticising prototypes continually until potential solutions are achieved. Zimmerman and Forlizzi [39] suggested following these five steps to conduct RtD:

1. **Select:** Select a research problem and design opportunity by focusing on the complexity of the problems.
2. **Design:** Explore problem spaces and start designing prototypes or ideas.
3. **Evaluate:** Evaluate selected artefact based on chosen RtD practice.
4. **Reflect and disseminate:** Reflect and document the outcomes or key takeaways as well as spread them through publications or demonstrations.
5. **Repeat:** Repeat the process to deepen understanding and achieve better outcomes.

By applying RtD, researchers can iteratively investigate the speculative future, figuring out the right things or directions of how artefacts could and should be transformed. Zimmerman et al. [40] proposed a new model that is based on RtD approach from Frayling [41] but they specifically emphasise how interaction designers can engage with wicked problems. They believed that the integration of true and how knowledge in conjunction with the design process of ideating, iterating, and critiquing potential solutions, can help researchers in concreting the wicked problems and articulating the right things or preferred state of artefacts. In the context of this research, delivering a novel design concept of battery SoH in the automotive industry, which has not been thoroughly explored, is challenging and considered wicked, therefore it is suitable for using the RtD approach, enabling researchers to tackle the challenges in automotive visualisation.

3.4 Human-Vehicle Interaction

With the emergence of the Internet of Things (IoT), Lee and Ju [42] anticipate that information and communication technology will play a pivotal role in the relationship between humans and vehicles. One of the obvious examples of vehicles being transformed with more automation is intelligent parking assistance in high-end vehicles, as seen in Volvo (2017), BMW Group (2017), and Tesla Model S (2017) [42]. To achieve the greatest performance, efficiency, and user satisfaction, intelligent interior systems have been explored and installed to enhance the overall user experience, acceptance, and trust [43]. The term Human-Vehicle Interaction (HVI), which means various types of interactions that individuals may have with the vehicle [44], has become attractive and gained more popularity. From the research conducted by Sun et al. [45], the evaluation of HVI can be classified into three main stages:

- **First stage:** The first stage focuses on the primary driving tasks, providing informative gauges and current states of the vehicle to the drivers.
- **Second stage:** In the second stage, the focus is on minimising the driver's distraction and cognitive loads during the control of the vehicle and visualising information more effectively. In this stage, a range of techniques and technologies is employed, such as integrated digital assistant, voice interaction, augmented reality, etc. [46].
- **Third stage:** The goal for the last stage is to expand the landscape of functions or services, supporting the user with more technologies and applications.

Sun et al. [45] also state that the expectation of the user towards HVI goes far beyond safety and comfortable experience, reaching the state where the entire cockpit is equipped with the interfaces, and the driver is able to interact with them in a smart way. To unlock the full potential of drivers and help them reach the greatest extent of the vehicle's efficiency, the development of HVI should consider applying a human-centred design approach [47]–[49]. Involving human perspective in every step of IxD [50] can enhance the usability and usefulness of systems.

3.4.1 Mental Workload

Driving is more complicated than turning the steering wheel or pushing the pedals. Marquart [51] defines it as a very visual and mental activity, thus emphasising the complexities of driving. Driving implies dealing with sensory stimuli from vision to hearing. Drivers are continuously fed with information that needs instant attention and response. De Waard [52] observes that although the driver's cognitive system is very effective, it has limitations. Such limitations become particularly evident when a driver must process vast amounts of information, resulting in scenarios where the required mental effort is too high for them to handle. This may lead the driver into even more dangerous situations. Despite the difficulty of directly assessing how much mental effort is used, it correlates strongly to operator performance, task demands, and available capacity [53].

The successful management of mental workload implies determining the point where there is too much or insufficient demand on one's mind, known as Mental Overload (MOL) and Mental Underload (MUL), respectively. MOL is a situation whereby the cognitive demands placed on a driver are beyond what they can handle, leading to overwhelming situations. However, MUL occurs when the cognitive demands are inadequate, which leads to reduced alertness that may threaten safety. Da Silva [54] stresses the significance of identifying and eliminating such extremes to keep drivers concentrated. One of the significant effects resulting from this imbalance is increased accident risk. Piechulla [55] observes that a wide range of actions inside the car, including navigation systems use, hands-free phone calls, or speech-to-text features for emailing, can cause distractions and information overload. In addition, studies by Lansdown et al. [56] reveal that adding multiple in-vehicle systems can significantly increase a driver's mental workload, highlighting the need to manage these technologies to promote safe driving properly. This research aims to investigate what and how the information about the battery SoH should be displayed inside the vehicle. Therefore, the workload that this information can create should be taken into account and MOL should be avoided.

3.5 Information Visualisation

Card et al. [57] define the definition of InfoVis as "The use of computer-supported, interactive, and visual representations of data to amplify cognition". The information visualisation goes far beyond visualising attractive images for the data [58]. This process involves representing the information in a visual format with the purpose of enhancing cognitive performance through external representation, minimising the use of an individual's internal cognition and memory to the perceptual system [59]. Throughout the entire process, there are several points of human interaction which can be described with the InfoVis reference model as in Figure 3.2. The process is divided into four stages: *raw data*, *data tables*, *visual structures*, and *views*. In each transformation between stages, human interaction plays a crucial role as a parameter that directly influences the process, allowing users to shape outcomes while seeing the feedback from their actions instantly [60].

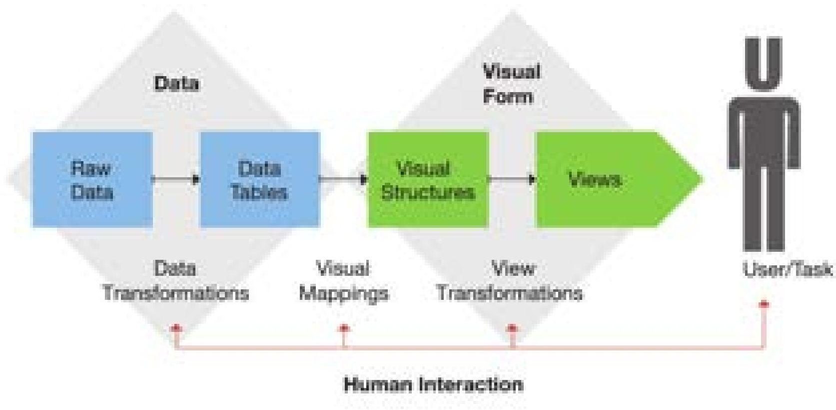


Figure 3.2: The InfoVis reference model

In the context of the interactive system, users typically interact with various activities apart from the visualisation of the artefact. The context of use therefore is considered important when designing any InfoVis due to its direct influence on the design of representation, presentation, and interaction. For this reason, Spence suggests taking the context where the visualisation occurs into account to ensure that it is suitable and able to serve the user's needs in various contexts as possible [58].

Due to the complexity of displaying the SoH and other technical information, visualisation can play a pivotal role in our research, making the information attractive, simply understandable, and accessible to the vast majority of audiences.

4

Methods

This chapter will introduce the process of interaction design employed in the thesis and present the chosen methods for each phase. Additionally, it will include a justification for the selection of these methods from a life cycle perspective.

4.1 Double Diamond

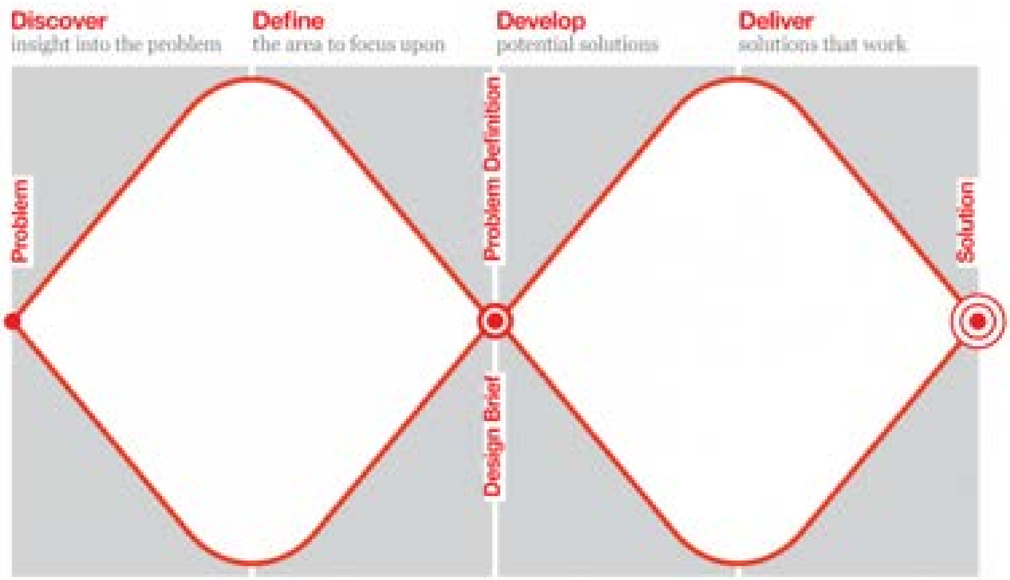


Figure 4.1: Double Diamond design process [61]

Even though there are several design processes in the field of interaction design, the processes have commonalities which typically cover multiple stages taken in design and innovation projects along with the methods and tools used. One of the well-known interaction design processes is the Design Council's [62] design methodology, Double Diamond, which consists of four phases represented by two diamonds as in Figure 4.1. The first half of a diamond represents the process of investigating an issue in a comprehensive and intensive way (divergence), while the second half of a diamond describes the process of deciding and taking action (convergence). The four phases of the Double Diamond are described as follows [35], [61], [62]:

- **Discover:** The first phase will focus on researching the issues and gathering insights from the people who are affected by the problems.
- **Define:** This phase is for understanding the insights and shaping the problems in different areas to focus upon. The deliverable of this phase is a design brief or problem definition.
- **Develop:** After the challenges have been identified, the next phase is to brainstorm possible solutions and collaborate with a range of people to design and develop potential solutions including testing and iterations.
- **Deliver:** The last phase involves testing potential solutions, choosing one for further enhancement, and delivering the most prospective solution.

4.2 Methods for Discover

In this section, a range of methods considered suitable for the Discover phase is presented, including literature review, questionnaire, contextual inquiry, and expert interview, aiming to gather insights or challenges from users.

4.2.1 Literature Review

The literature review is a method of researching, gathering, and synthesising information on a specific topic from published academic literature and public sources. This method is considered an integral part of not only academic publications but also any project in the interaction design field. In order to conduct an effective literature review, the relevance of information and credibility of sources should be taken into account, ensuring that the information is associated and reliable. The review should not be summarised directly from sources, but rather synthesise and categorise into the same category if related [63, p. 148]. This method is suitable to use during the Discover phase since it provides a related and in-depth background of a SoH topic serving as a foundation for our research.

4.2.2 Expert Interview

Expert Interview is a qualitative research method that utilises interview methods to gather qualitative data from experts who are specialised in a particular field or domain [64]. Conducting an expert interview can help researchers receive rich and detailed data and insights which will reduce the time consumed in the data-gathering process. Additionally, there is evidence that the method helps researchers to get quick and positive results. For this reason, conducting an expert review at the beginning of the design project, i.e., the Discover phase, could be beneficial for the project and stakeholders. This method can be used in addition to the literature review to gain more in-depth information apart from public sources and published academic papers; it is suitable in this context where access to experts within the company is insightful and readily available.

4.2.3 Questionnaire

A questionnaire is a research tool used for gathering data from individuals with the purpose of collecting and analysing the information, typically in written form. The collected information can include demographics, characteristics, opinions, feelings, and behaviours. A questionnaire could be in both physical and digital formats, however, an online questionnaire could be more efficient and effective in terms of generating and distributing to the potential respondents [63, p. 178]. additionally, special attention should be given to the wording of questions ensuring that the questions are simple, understandable, unbiased, and ethical, avoiding triggering a specific group of respondents and making them feel intrusive and harmed [65]. For the Discover phase of our research, the objective is to understand issues and gather insights from individuals affected by the problems. Consequently, this method is considered suitable due to its simple construction and administration.

4.2.4 Focus Group

A focus group could be described as a design technique that utilises an in-depth interview to collect qualitative data from a specific group of participants on a given topic. The output from the focus group could be a range of ideas, opinions, or feelings regarding the problems. This technique was utilised to gather specific insights from a small group of users which typically five to eight participants but it could range from four to twelve participants. Krueger and Casey stated that a focus group should be large enough to gather diverse perspectives or views, while it should remain small so that every participant has the opportunity to share their opinions. Even though a small focus group may limit the number of ideas from the participants, a mini-focus group or a focus group of four to five people is optimal since this size allows participants to share their ideas while ensuring a sufficient amount of diversity [66, p. 6]. According to Guest et al., [67], 80% of the findings were figured out or revealed with two to three focus groups. This recommended that a small number of focus groups can result in or lead to substantial insights. During the Discover phase, designers aim to gather and understand user insights or needs related to the problems. Involving a focus group in this phase could be beneficial and valuable for the next phase of the design process since it allows designers to discover pain points, needs, and diverse ideas from the target users or stakeholders.

4.3 Methods for Define

Considering the primary objectives of the Define phase, an analysis technique called affinity diagramming is employed to help us analyse, understand, and identify relationships between data from the Discover phase. In the next step, personas are executed along with scenarios to identify the target users and the situations of use. This step helps us in framing a group of users and situations to focus on. The process continues with the benchmarking which helps us define the actions needed to achieve the best practices and ends with a requirement list as a deliverable for further development.

4.3.1 Affinity Diagramming

Affinity diagramming is an analysis technique used to organise large amounts of qualitative data gathered from researching, interviewing, or brainstorming, with the purpose of synthesising insights and identifying the relationship between information [68]. The process utilises an affinity diagram as a visual tool to present data categorised into clusters based on affinity and deliver as part of result documentation [63, p. 12]. There are 4 steps required to create the diagram [68]:

1. **Label making:** generating ideas or capturing data on a separate piece of note.
2. **Label Grouping:** analysing and rearranging the notes into a cluster and then giving a name to each group.
3. **Chart making:** annotating the cluster with signs, i.e., arrows, to represent a relation between groups.
4. **Explanation:** verbally presented the chart result to the group and documented it in a written format.

Rather than putting the notes into predefined groups, individual notes should be grouped into clusters before labelling, allowing organic themes to be generated [68]. Since affinity diagramming helps capture insights and identify problems in various organisational contexts, with common applications for contextual inquiry and usability testing; it is well-suited for the Define phase [63, p. 12].

4.3.2 Personas

A persona is an ideal representation of real potential users of a product, presented in the form of user profiles. The purpose is to understand and communicate the characteristics, skills, patterned behaviours, pain points, and goals of target users [69], [70]. In order to synthesise commonalities in data and identify behaviour patterns, employing qualitative analysis methods, i.e., affinity diagramming, is considered more efficient. The diagram working in conjunction with the personas in the Define phase could provide explicit insights, relations, and target audiences of the product. This representation not only facilitates discussion among design teams but also serves as a persuasive reference to clients when discussing research results or summaries [63, p. 170].

4.3.3 Scenarios

A scenario is a narrative that depicts situations from the user's perspective to simulate the way a user uses or interacts with a product or service. The objective of writing a scenario is to concretise the idea and help designers and stakeholders understand situations and the way the product is likely to be used by a user. Each persona should have at least one scenario, and the scenario should be written in a way that focuses more on how technology enables actions or impacts user experience rather than technical details. Both persona and scenario create value and supplement each other to communicate user personas and bring them to life with the scenarios. Both methods are well-suited in the Define phase of Double Diamond, helping researchers to define the target user and the ideal situation for a product or service [63, p. 190].

4.3.4 Requirement List

A requirement is a statement that specifies what the product is supposed to achieve and how it functions [35, p. 387]. The list of the requirements is deliverables of the Requirement Analysis, a process of studying, defining, and documenting the requirements of the new system to solve the problems [71]. A requirement typically includes acceptance criteria as a measurement to verify the solutions if it is fulfilled after development [35, p. 388]. Having clear statements and acceptance criteria at the early stage helps reduce uncertainty and ambiguity as well as the costs and time of the project. Additionally, it is also considered a crucial factor in developing successful information systems [71]. One of the effective ways to document the requirements is in the form of User Stories, a written description of requirements from the user's perspective. Even though these user stories could be in physical forms, the digital format is considered more effective. The reason behind this is that digital user stories could store additional information in various forms, e.g., detailed diagrams, attachments, and hyperlinks [35, p. 388].

4.4 Methods for Develop

The third phase of the Double Diamond is initiated to bring ideas to life by transforming them into a tangible format. This process involves creating prototypes with different resolutions for evaluation purposes. The relevant methods suitable for this phase are brainstorming, low-fidelity prototyping, and high-fidelity prototyping.

4.4.1 Benchmarking

According to Anand and Kodali [72], benchmarking is a method of searching and identifying the best practices in the industry with the purpose of reaching an exceptional performance by implementing similar practices. However, the definitions vary depending on the activities [73, p. 18], but it could be identified with the keywords: measurement, comparison, and identification of the best practices. A definition of benchmarking below was defined by [74, p. 411] which could reflect the majority of benchmarking activities:

> "A continuous analysis of strategies, functions, processes, products or services, performances, etc. compared within or between best-in-class organisations by obtaining information through appropriate data collection method, with the intention of assessing an organisation's current standards and thereby carry out self-improvement by implementing changes to scale or exceed those standards."

A broad definition of benchmarking could lead to different activities and steps, yet the distinction between benchmarking is considered significant and helpful in forming goals and operational action plans. With a classification of benchmarking called the 'Nature of the referent other' [74, p. 411], there is a type called 'industry benchmarking' which is used to compare with the companies within the same industry including non-competitors. Since the topic of battery health is relatively novel to the automotive industry, 'Generic benchmarking' could therefore help discover and identify excellent work practices across industry boundaries [74, p. 411], i.e., the technology industry. Benchmarking could be conducted at the early phase of the design process to study the best practices and identify actions and factors that could be beneficial for development [75].

4.4.2 Brainstorming

Brainstorming is a technique used for generating ideas or finding solutions to problems. This method can be executed via both individuals and groups to generate and share large amounts of ideas in a non-judgmental environment [76, p. 2]. In the field of interaction design, brainstorming can be used for different purposes including generating ideas and new ways of working for existing artefacts, structuring UI architectures, and exploring new design spaces. While brainstorming was recognised as simple and useful, some issues limit brainstorming productivity, e.g., shyness, ego, informal relationships, and cultural norms. With planning ahead on structures, rules, and agendas, a great and productive brainstorming session is possible. Even though the method is commonly used in the early to middle stages of product development, it is possible any time that discussion or sorting is required [76, p. 18]. In the context of this research, brainstorming at the early stage of the Development phase can help generate new ideas and explore new design spaces which can be adapted in the prototyping.

4.4.2.1 Crazy 8's

Crazy 8's is an exercise typically used during brainstorming to quickly generate eight unique ideas within 8 minutes. The goal of this exercise is to force generate the first idea with fast sketching for the concept and to generate a wide variety of solutions as possible. This method can be executed by several team members at a time, starting with each folding a piece of paper into eight sections for eight ideas to be generated and then followed by setting a timer to eight minutes. Each member sketches an idea inside a block and ensures that all eight blocks are filled with ideas at the end of the session. The sketch could be in any format, either a rough drawing or a text-based description. The key to this activity is to communicate the ideas rather than focusing on the aesthetics of the sketches [77]. In the context of this thesis, this method is considered ideal to be conducted at the early stage of the development phase, as it can help the first idea to be generated regardless of how practical it is. With a sketch of each idea, it can serve as the first draft of the design concept which can be developed further in the later step.

4.4.3 Prototyping

Prototyping is a simulation of artefacts at different levels of fidelities [63, p. 176]. The purposes of creating a prototype can be divided into four main categories: (1) evaluation and testing; (2) understanding of user experience, needs, and values; (3) idea generation; and (4) communication among designers [78]. According to the IDEO consulting firm [79], the prototyping process was divided into three stages guiding the development of the solutions throughout the project timeline as in Figure 4.2. Several prototypes are initialised to explore a range of ideas, while some of them are developed further with the intent to enhance more features and refine the design. In the last stage of the project, only the chosen prototype that looks promising and has the most potential will be used for validation [79, p. 4]. A prototype evolved and validated in this phase helps us to filter interested design qualities and manifest how the prototype is constructed and what it is intended to represent. Since prototypes serve as visual representations of the design concepts, the visual aspect helps participants understand proposed ideas and facilitates communication between participants and researchers.

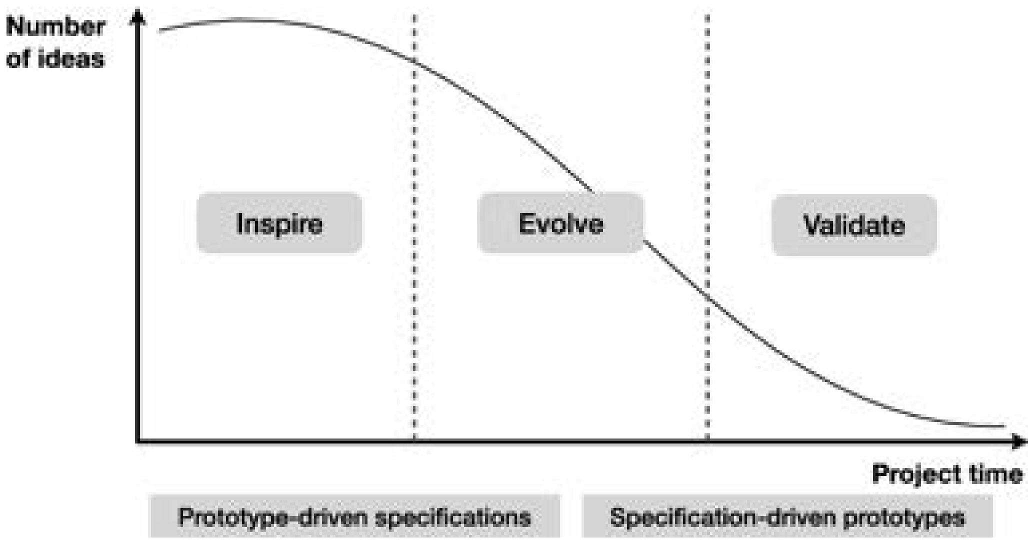


Figure 4.2: The design process from IDEO utilising prototypes to evolve and validate product specifications [79]

4.4.3.1 Low-Fidelity Prototype

Low-fidelity prototype is a simple version of a design or product that is commonly initiated at the beginning of design disciplines, delivering as concept sketches, story-boards, or sketch models [63, p. 176]. The characteristics of low-fidelity prototyping are its simplicity, rapid creation, cost efficiency, and adaptability, making it a perfect option for exploring alternative ideas at the early stage of development [35, p. 426].

A common method for low-fidelity prototyping is sketching, a rough drawing of objects regardless of certain types, sizes, shapes, and positions. This uncertainty plays a vital role in a creative process helping the designer to express and explore more ideas as well as communicate them among team members in a tangible format. When sketching artefacts in interaction design, it is important to pay attention to the overall structure and workflow of interaction rather than details and visual aspects [80]. Despite its simplicity and efficiency, sketching is considered difficult for many individuals since the perception of the quality of their sketches can impact their confidence in sketching, enabling less engagement during the process [35, p. 427]. To overcome this challenge, the usage of verbal communication in conjunction with sketching helps transfer and exchange knowledge among team members. Both sketching and verbal communication serve as essential in the early stage of design [81, p. 400]. Executing a sketch at the beginning stage of development leads to a better understanding and elaboration of the concept solutions.

4.4.3.2 Semi-Functional and High-Fidelity Prototypes

A semi-functional prototype is an improved version of a low-fidelity prototype with a focus on function and interaction but it cannot fully be operated. It is in the middle between low-fidelity and high-fidelity prototypes allowing users to interact with certain aspects of the design, providing valuable insights during the early stages of development [82]. In contrast, a more refined and detailed simulation of the design is called a high-fidelity prototype, representing the appearance and some basic functionalities of the final product [63, p. 176]. This prototype plays a vital role in the evaluation phase, especially for usability testing, since visual and functional experience can be similar or close to the final product, allowing the user to perceive, experience, and provide feedback for evaluation purposes. Additionally, researchers can learn many factors regarding the prototypes, including user interaction, technological constraints, and factors that affect in a real context [35, p. 429].

4.5 Methods for Deliver

In the final phase of the double-diamond framework, usability testing will be conducted to assess the solutions and choose the most promising ones for delivery. This process can employ several techniques together, such as contextual inquiry and think-aloud methods. In the context of our research, the combination of both methods can lead to invaluable feedback from the participants, helping us to identify the difficulties of their decisions and understand how they interpret and understand SoH from the interface.

4.5.1 Usability Testing

Usability testing is an approach that involves several activities and a collection of evaluation techniques to evaluate the usability and user experience when interacting with the interfaces. During the testing, a variety of methods, e.g., think-aloud and contextual inquiry, are used to evaluate interfaces. Additionally, designers could also record the testing in video or audio format for studying purposes. Usability testing covers multiple aspects including how easily users can learn, how well users can complete specific tasks, what issues occur, and how satisfying the interaction is.

These aspects help the team to identify, prioritise, fix, and retest the issues before launch, as well as inspire designers of new features for future products [35, p. 496][63, p. 242][34, p. 57].

An artefact used in usability testing should be relatively complete, i.e., a clickable prototype, to validate product design. Additionally, when designing a usability test, it is important to have specific tasks that reflect the goals of the target audience and give scenarios that help contextualise the tasks. Since a prototype is required for evaluation, usability testing would rather be appropriate for the later phase in the design cycle, i.e., the Discover phase or part of refinement [63, p. 242][34, p. 57].

4.5.2 Think-Aloud Protocol

Concurrent think-aloud protocol is a usability testing method where participants are asked to say out loud what they are feeling, thinking, and doing when they are completing a set of tasks, unfolding what brings a positive experience, what is confusing, and what frustrates the user [63, p. 224]. For some tasks that require a high level of concentration from participants, it might be necessary to remind them to verbalise their thoughts during the session. By doing think-aloud, evaluators are able to understand user's thoughts, understandings, and misinterpretations regarding the design, allowing them to learn the reason why misinterpretations happen and how to resolve the issues [83].

4.5.3 Interview

The interview is one of the survey research methods to collect qualitative data from the interviewee, such as opinions, experience, attitudes, and perceptions. Ideally, the interview should be conducted in person to instantly observe the participant's behaviour, body language, and interactions. There are two types of interviews: structured and unstructured interview. A structured interview was perceived as a formal interview where a set of questions is strictly followed. The advantages of this type are that it is controllable in terms of questions, time, and ease of analysis for the researchers. On the other hand, an unstructured interview has more flexibility as the session will be held in a conversational format, providing more comfortable surroundings to the participants. With more flexibility, it is essential for the researcher to manage and allocate the time appropriately to ensure that all necessary information is successfully gathered within a predefined time slot [63, p. 102]. This method is typically used in many phases of the design, however, in the context of this research, the method aims to be conducted mainly as part of the evaluation or usability testing to gather feedback and real experience that users have with the design concept. Regarding this, an unstructured interview is considered suitable for this exploratory purpose.

5
Planning

This chapter describes the project's initial planning, which took place over 19 weeks of the duration of this master's thesis. The supervision by Chalmers's supervisor and external supervisor at Volvo Cars is held at least once a week to ensure that the development and progress of the project are as intended.

The project's development and execution are divided into four main stages, which follow the double diamond process described in the previous chapter, comprised of the following phases: discover, define, develop and deliver. Additionally, two more stages were added to meet specific academic requirements, focusing on report writing and the final submission of the master's thesis. The time plan begins with the planning report phase, which lays the groundwork for the project. It concludes with the report phase, which contains all the crucial deadlines for the master thesis report and thesis defence. Furthermore, throughout the project, three official presentations within the Volvo Cars' R&D department were planned, which aim to keep the company updated about the thesis progress and provide valuable team feedback.

5.1 Gantt Chart

A Gantt chart of the time plan was created to guarantee smooth progress and a follow-up throughout the project. The Gantt chart can be seen in Figure 5.1. The timeline also includes some critical deadlines and milestones, such as submitting the draft to the opponents, defending the thesis and submitting the final report. Weekly milestones are also planned throughout the project to ensure synchronicity between the thesis partners, communication and the need to make adjustments.

Throughout the project, some of the planning steps had to be adjusted as the project progressed. The final version of the project can be seen in the Gantt chart in Figure 5.2. Some methods, such as contextual inquiry, were decided to be excluded during the Discover phase. However, some new methods had to be included in order to improve the research and progress of the project. For example, a focus group was included in the Define phases, and the Develop phase was expanded to include one more iteration of the design concept. In order to meet the deadlines that had been set at the start of the project, the steps were modified in accordance with the plan.

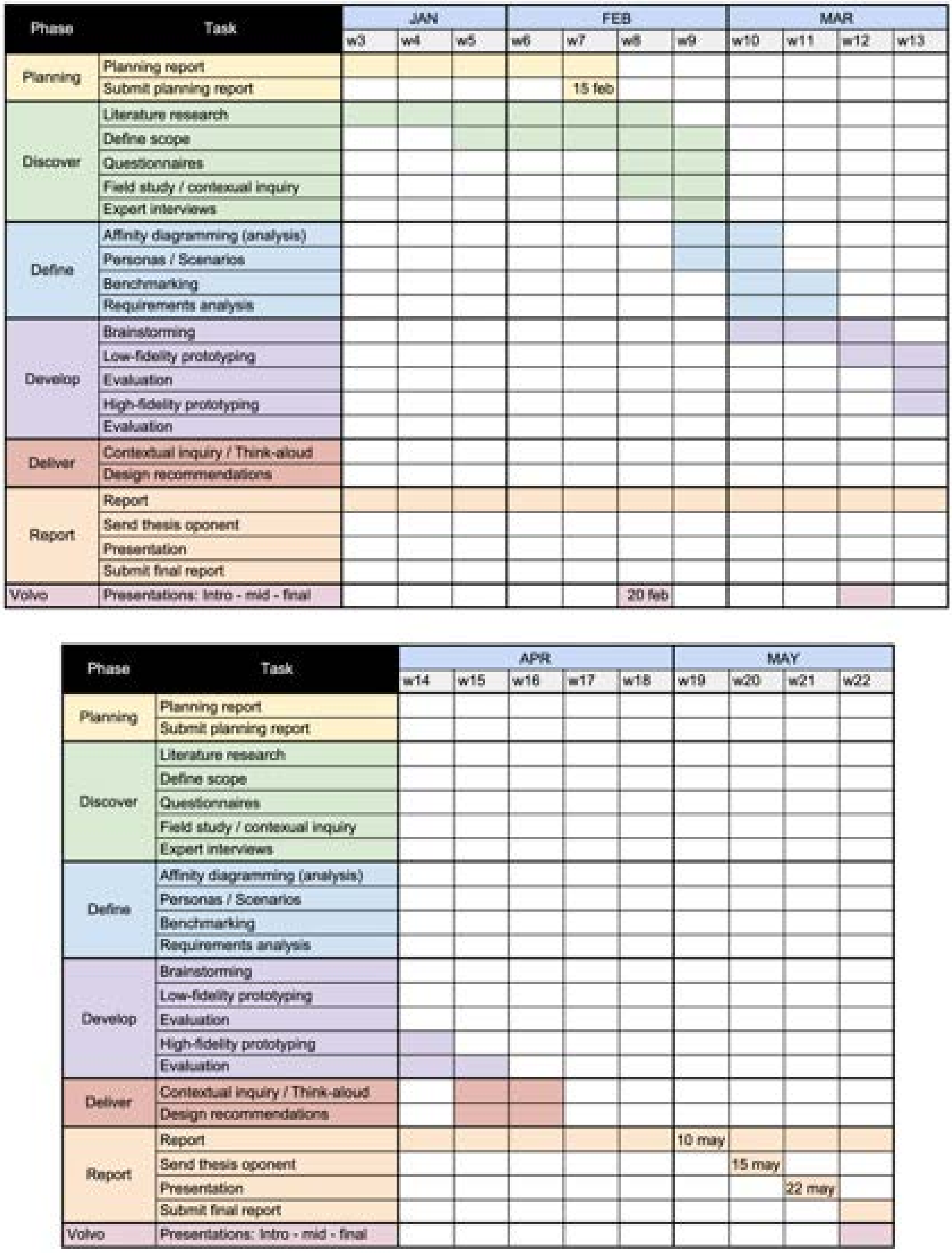


Figure 5.1: Gantt chart of the project, where every colour block represents different stages of the master's thesis development and execution.

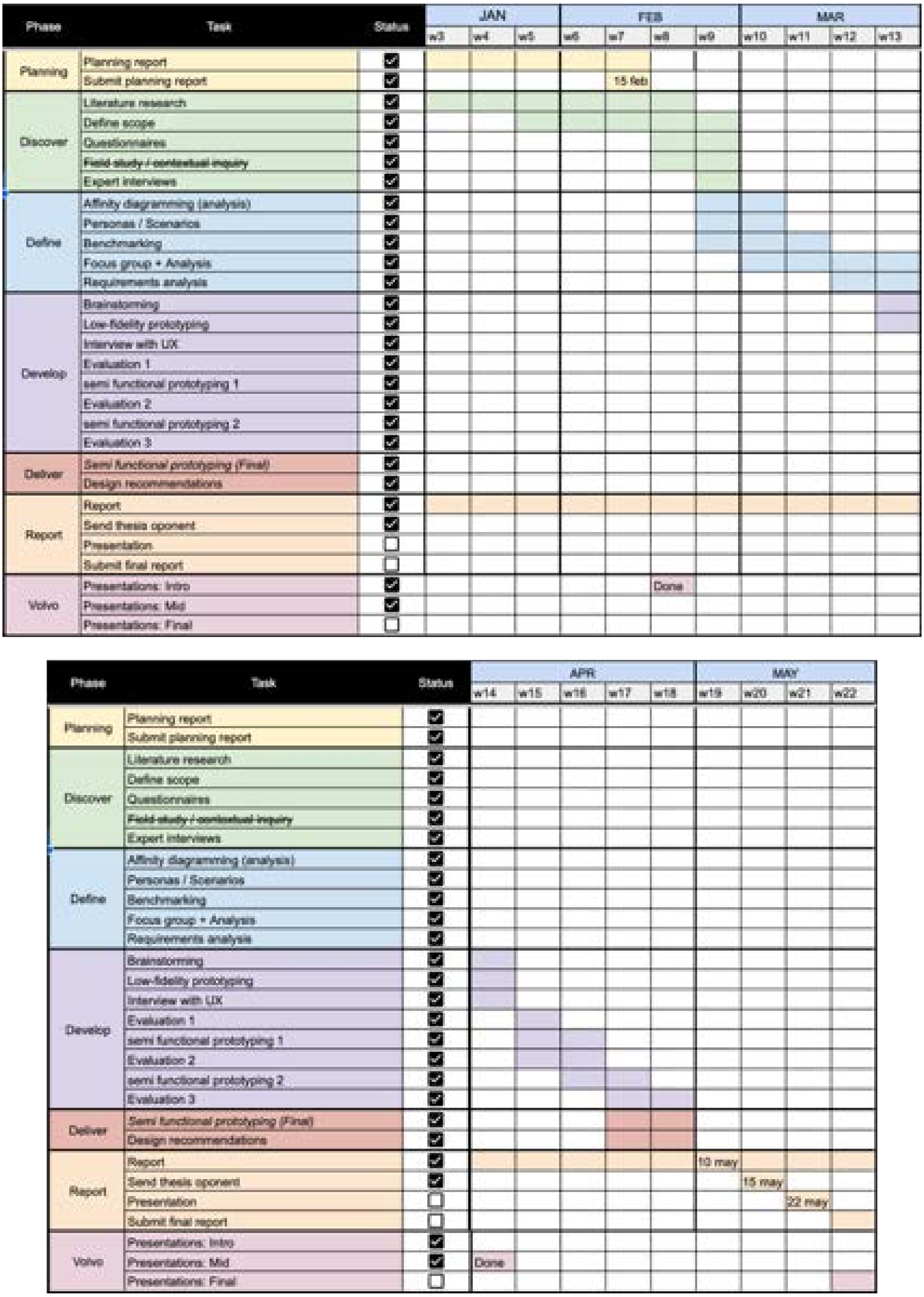


Figure 5.2: Modified Gantt chart at the end of the project, where every colour block represents different stages of the master's thesis development and execution.

6

Execution and Process

This chapter describes how methods were applied and how they were executed in each phase of the interaction design process. The chapter consists of four sections which correspond to four phases of the Double Diamond, a chosen interaction design framework for this thesis. Refer to Chapter 4 for more explanation of the framework and methods applied.

The entire research process is organised into two primary stages. In the first stage, which can be seen in Figure 6.1, the focus was on the Discover and Define phases. These phases involved extensive research, including conducting a literature review, interviewing experts, and running a questionnaire and focus groups. This helped to develop a comprehensive list of requirements. Concurrently, efforts focused on defining and refining the projects scope and pinpointing the specific user group the research would target.

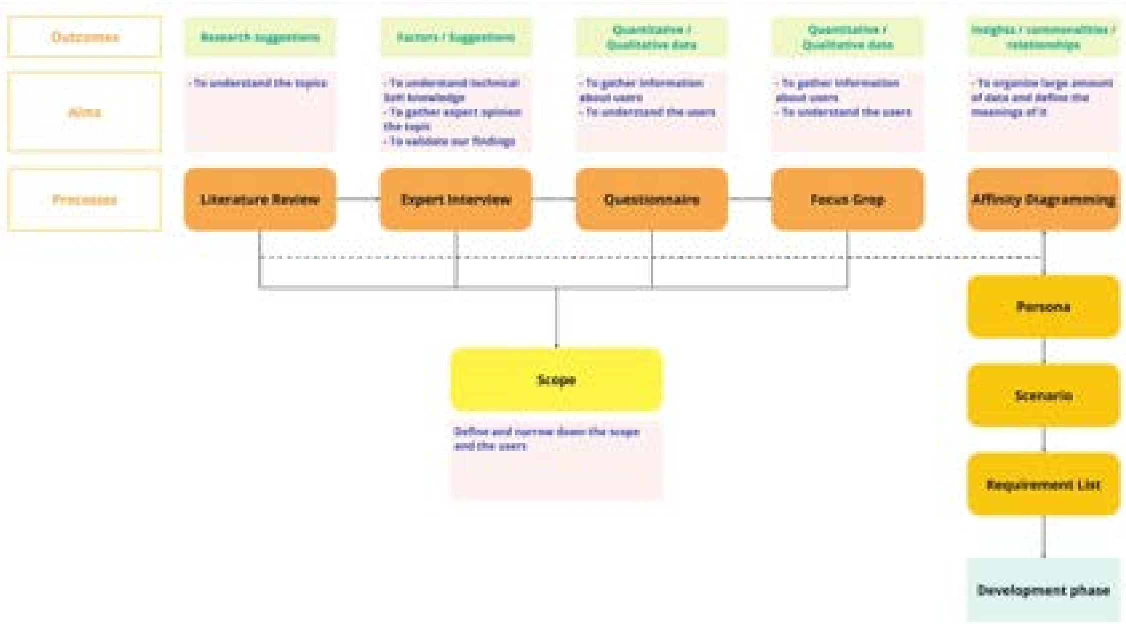


Figure 6.1: Stage 1 of the Double Diamond framework: Discover and Define phases

Following this initial stage, the attention was shifted to the second component of the research, which involves the developing and delivering phases of the double diamond model. The visual representation of the second stage of the process can be seen in Figure 6.2. Based on the previous requirement list and benchmarking results, an iterative process of the design concept began, which included prototyping, evaluation, and analysis for each iteration. After three iterations, the final result of this process was the formulation of design recommendations. Below, is a detailed description of each section separately.

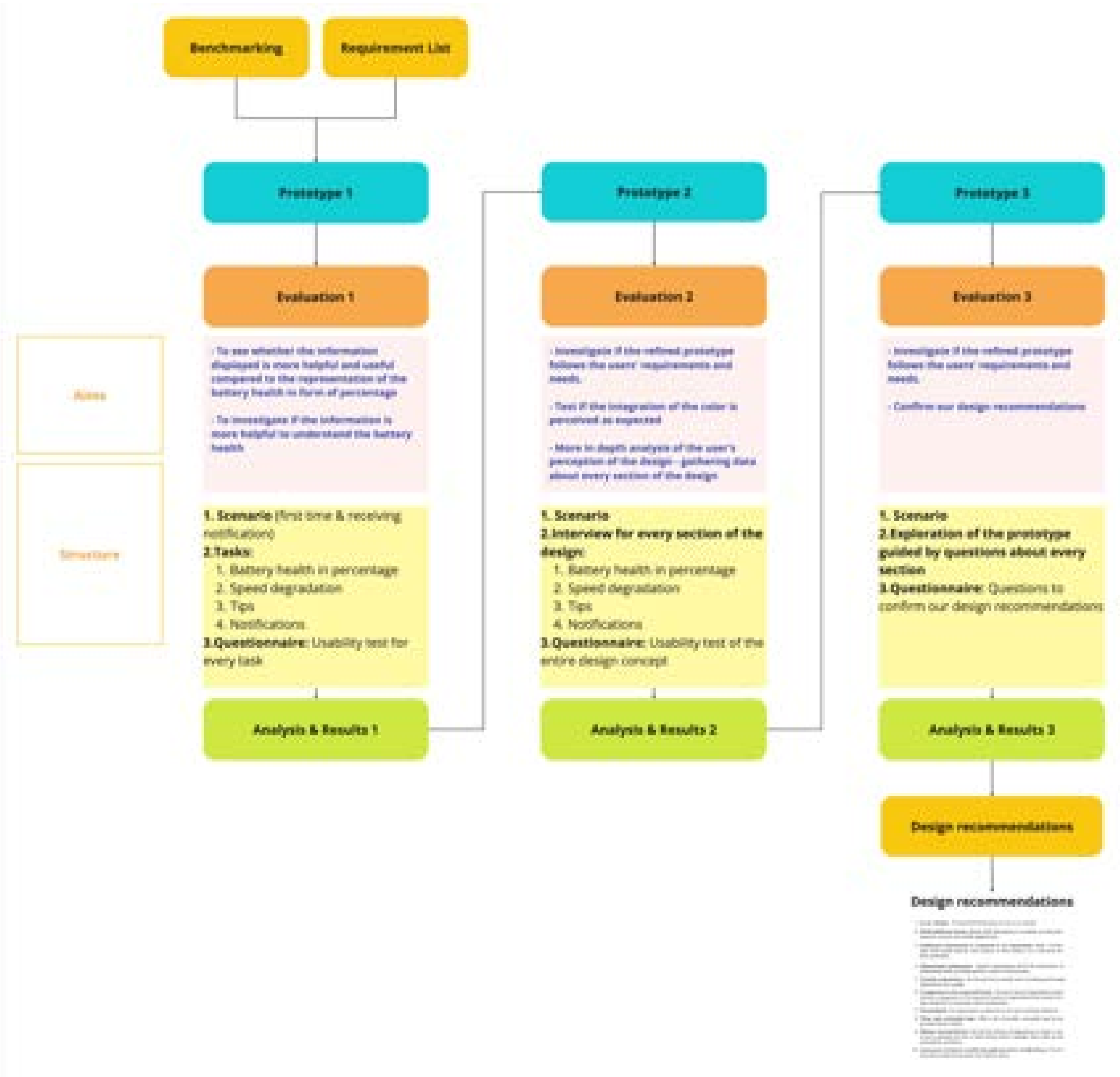


Figure 6.2: Stage 2 of the Double Diamond framework: Develop and Deliver phases

6.1 Discover

The Discover phase will focus on researching and gathering data and insights to understand problem spaces, users pain points, and needs. All the methods mentioned in this section were conducted to have an in-depth background on the topic and gather data from the users for further research and development.

6.1.1 Research from Previous Studies

A literature review was a method used for researching and gaining knowledge from previous academic studies to have a basic foundation and knowledge regarding battery SoH on BEVs including the current trends and challenges to discuss further with experts in the next step. The results from the literature review and research were summarised and presented in the Background and Theory Chapters of this thesis.

6.1.2 Data Gathering

Various methods were used to collect data to gain a better understanding of the subject. An expert interview was chosen to increase current knowledge on the topic of battery health together with solving questions that emerged from the literature review. The questionnaire had the purpose of proving an understanding of user behaviour, specifically the leaser's knowledge and understanding of battery health. Finally, the focus group allowed us to collect more detailed qualitative data.

6.1.2.1 Expert Interview

Due to the novelty of the topic and the lack of consistent conclusions from the literature review regarding the factors and the effects that these factors have on battery health, a more in-depth understanding of the topic was required. Expert interviews were chosen as a method since they would help clarify doubts, answer follow-up questions and provide a more expert perspective on the factors that directly impact the battery health, as well as other crucial points to consider when investigating the battery SoH display in BEVs.

The expert interview was conducted with two Volvo Car employees who are considered subject matter experts in their respective departments. Expert 1 from the Battery Cell Analytics team and Expert 2 from Energy Management participated in a one-hour semi-structured interview each, which was conducted on-site at Volvo Cars. After agreeing to be audio recorded, the participants were asked questions to help guide the interview, although additional questions were asked if it was relevant. In addition to the audio recording, written notes were also taken. The interview questions covered the following subjects: factors that affect battery health, how those factors affect battery degradation, how to estimate and evaluate battery health generally and best practices for battery maintenance and its alignment with the manufacturer's manual. The experts responses were later analysed and key conclusions were extracted. All the findings are described in Section 7.1.1 of the Result Chapter.

6.1.2.2 Questionnaire

The purpose of the questionnaire was to collect general data from drivers who lease a BEV and investigate how users approach battery care. At the end of the questionnaire, the users were also asked if they wanted to participate in future research on the topic, to ensure the possibility of having users for future interviews and evaluations.

The questionnaire was created using Microsoft Forms and published on Vival Engages (formerly Yammer), which is the company's social networking service [84]. Simultaneously, the survey was displayed on all entrance screens in Volvo Torslanda (Gothenburg) and Stockholm offices. A physical brochure was also distributed in various common areas throughout Torslanda, such as building entrances and department common areas. See all distributions in Figure 6.3.

The target users were employees at Volvo Cars in Sweden, who leased one of the company's BEVs, which include the following models: XC40 Recharge, C40 Rechargeable, EX30 and Polestar 2. The questionnaire was divided into three major sections. First, general information about the driven car was requested, which also helped to ensure that all the participants met the conditions of the target user. Secondly, questions about the user's understanding of battery health were asked. Finally, the participant's demographics were collected. The list of questions in the questionnaire is shown in Appendix A. The findings from the questionnaire are described in Section 7.1.2 of the Result Chapter.

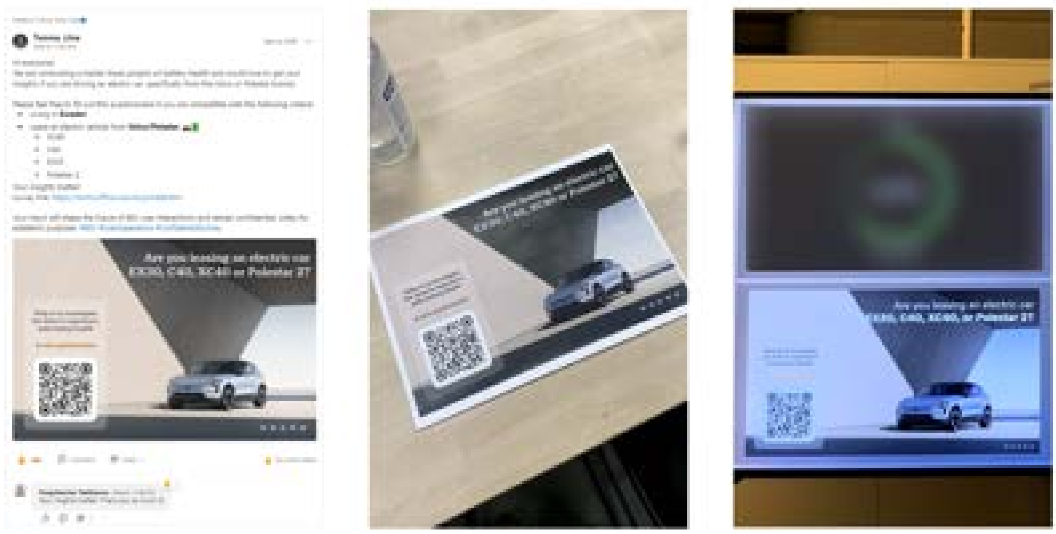


Figure 6.3: Distributed location of Questionnaire

6.1.2.3 Conducting Focus Groups

Based on the questionnaires results, the gathered information was insufficient to define a requirement list for the new design concept of battery SoH in vehicles. Regarding this, the focus groups were chosen to gather more qualitative data on how the users would like to perceive the battery health in BEVs. The primary goals were to investigate how the users would like to be encouraged to take care of the battery, to find out what information related to battery health the users would like to see in a vehicle, and to know when and how the users would like to perceive battery health information. To achieve the goals, two mini-focus groups were conducted with four participants for each group [66], [67].

The process started by defining the participant's criteria for focus groups as follows:

- Work at Volvo Cars
- Lease a BEV from Volvo or Polestar (XC40 Recharge, C40 Recharge, EX30, Polestar 2)
- Be able to attend a 45-minute focus group in person at Volvo Torslanda

For the recruitment process, the researchers discussed with Volvo Cars internal collaborative development fleet, a group of Volvo Cars employees who lease Volvo or Polestar BEVs from the company, regarding the requirements and asked for their collaboration to recruit and pre-screen the participants. After receiving a list of eligible participants, another screening was conducted additionally ensuring the diverse backgrounds and demographics of the participants. See Table 6.1 for a list of participants.

Table 6.1: List of participants in focus groups

Person	**Age**	**Gender**	**Own vehicle**	**Focus Group**
P1	≥ 60	Female	C40 Recharge	1
P2	50-59	Male	XC40 Recharge	1
P3	50-59	Male	Polestar 2	1
P4	50-59	Female	EX30	1
P5	40-49	Female	XC40 Recharge	2
P6	40-49	Male	Polestar 2	2
P7	50-59	Male	Polestar 2	2
P8	50-59	Male	C40 Recharge	2

After the users confirmed their participation, the documents, e.g., the consent form, questionnaire, and recommendations for battery maintenance, were prepared for the session, and the room was set up with printouts, stationery, and electronic devices for audio recording and timing as in Figure 6.4.

The duration of a focus group was 45 minutes in total. The participants were presented with forms asking for their consent to conduct the focus group and proceed with their data during analysis, as well as a questionnaire asking for their demographic data and behaviour. The focus group continued with an ice-breaking session letting the participants introduce themselves and then followed with a discussion regarding battery health. After that, participants were presented with three scenarios, each scenario was composed of a scenario description and followed by a set of questions to bring a discussion to the topic (Figure 6.5). All the findings from the focus groups can be found in Section 7.1.3 of the Result Chapter. Refer to Appendix B for the scenarios and questions of the focus groups.

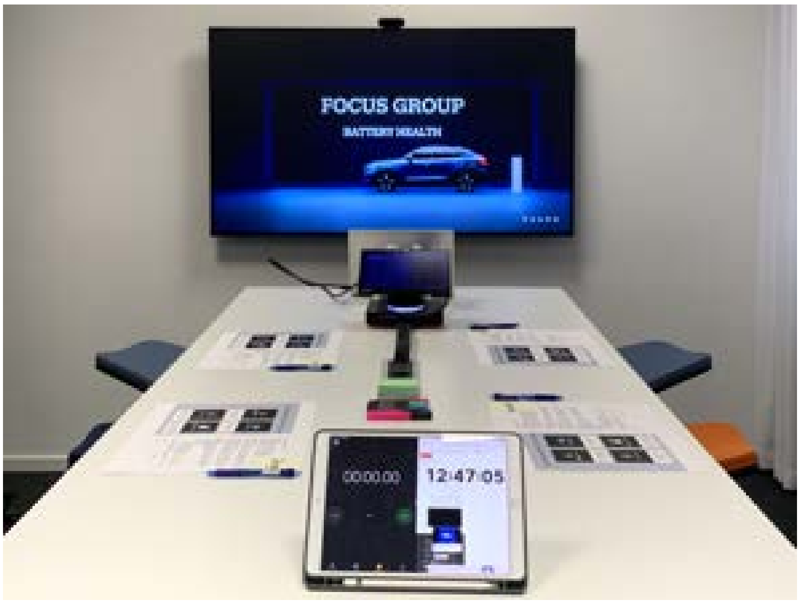


Figure 6.4: Setup for a focus group

Figure 6.5: The first focus group

6.2 Define

The objective of the Define phase is to clarify insights gathered from the discovery phase, understand the user's pain points and needs, and define requirements to focus upon for the next step of the design journey. The phase involves two main processes: analysing the data collected earlier and identifying requirements for the development phase.

6.2.1 Data Analysis

As both quantitative and qualitative data were gathered during the Discovery phase, the analysis for both types of data was conducted to extract key takeaways from the data. For qualitative data, multiple affinity diagrams were created to analyse information from expert interviews, a questionnaire, and focus groups. This process was conducted virtually using the Miro Board, an online collaboration tool [85]. On the other hand, the quantitative data was derived mainly from the questionnaire and was analysed using Microsoft Excel [84] to identify trends and insights from a statistical perspective.

6.2.1.1 Affinity Diagram from Expert Interview

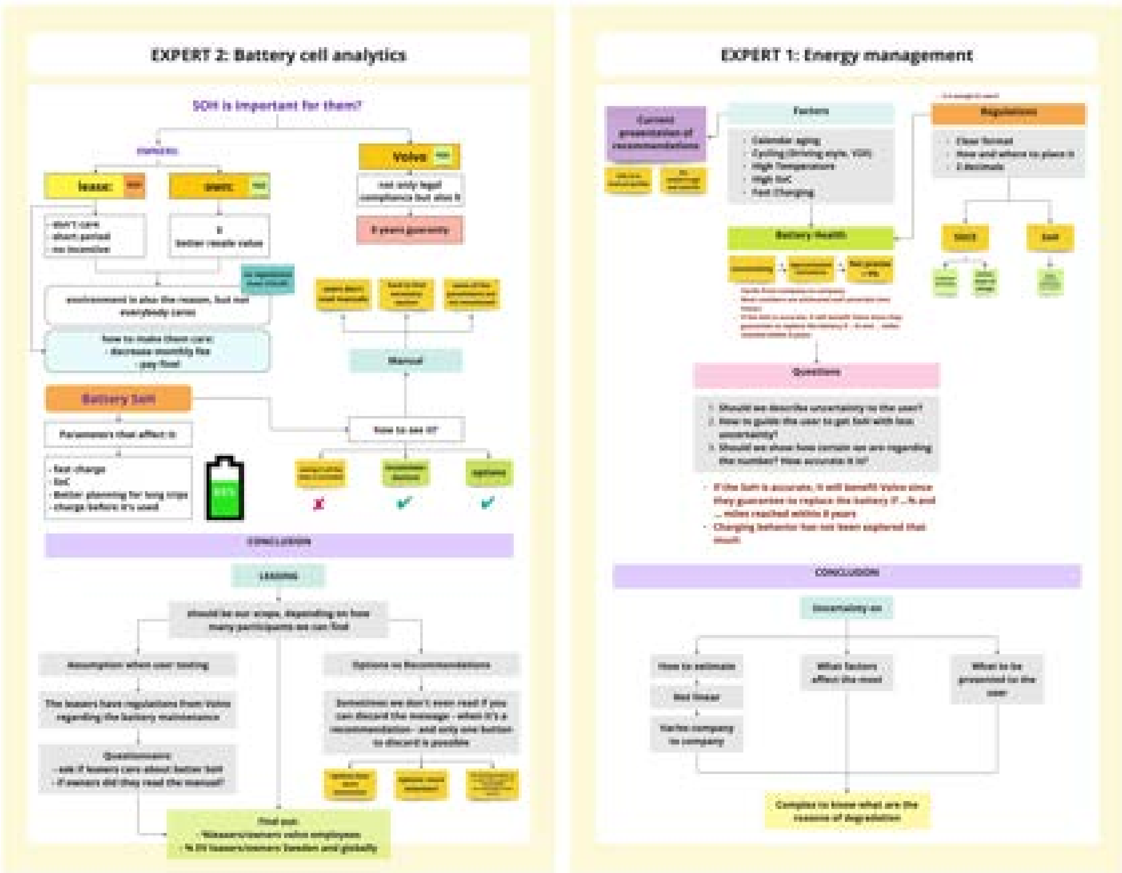


Figure 6.6: Affinity diagram from expert interview

To analyse the information provided by the experts, an affinity diagram was created. The process and execution of the expert interviews are described in Section 6.1.2.1. Audio recordings were transcribed and key points were extracted onto a Miro board

[85], allowing to cluster and organise different ideas and topics that emerged during the interviews. Figure 6.6 shows the final stage of the affinity diagram analysis where all the main conclusions were gathered. The analysis results of the expert interviews are shown in Section 7.1.1 of the Result Chapter.

6.2.1.2 Analysis of Questionnaire

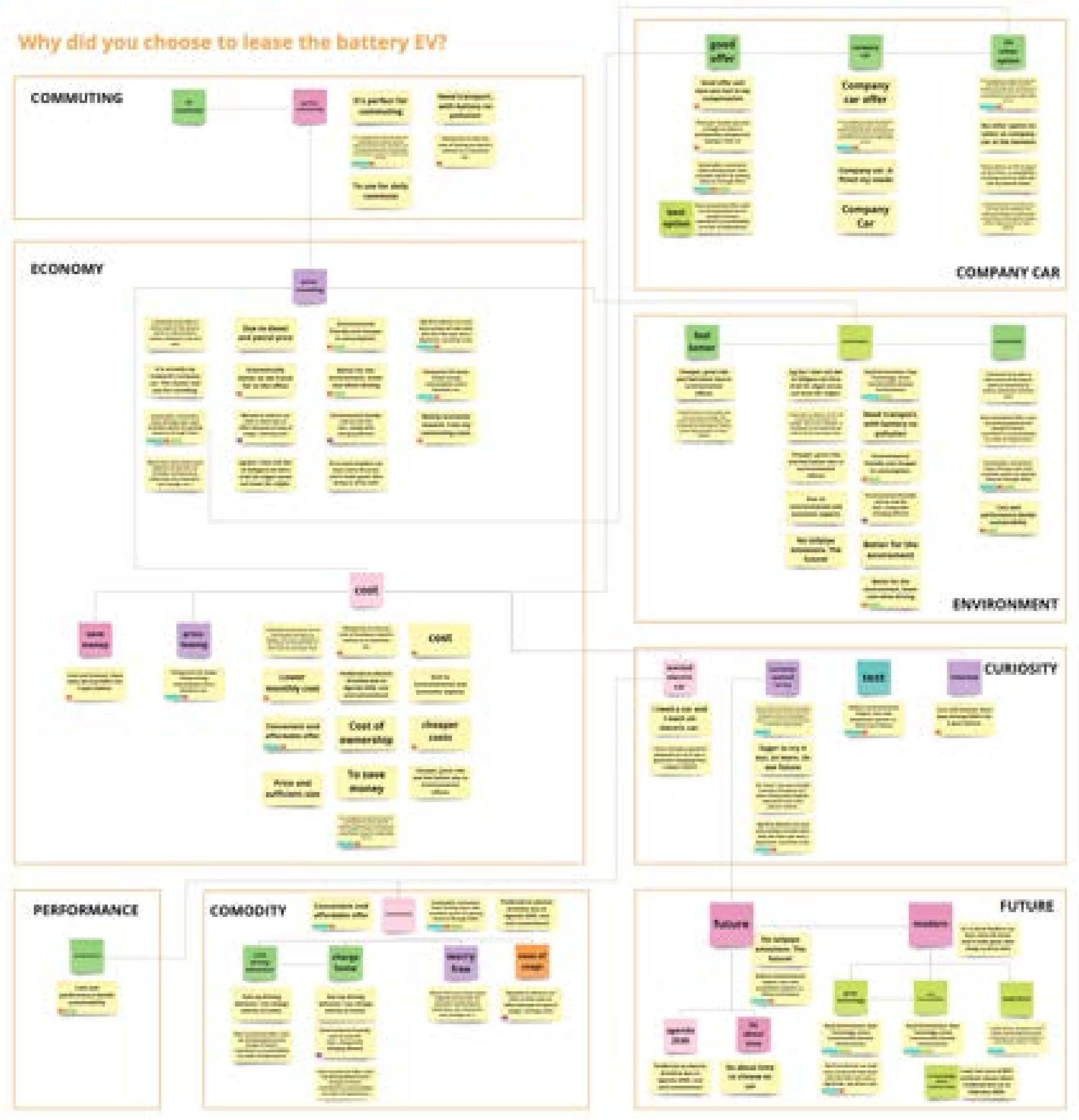


Figure 6.7: An example of an affinity diagram of a qualitative question from the questionnaire

The results of the questionnaire were examined question by question. The process and execution of the questionnaire are described in Section 6.1.2.2. Questions with quantitative data were analysed and presented in a graph using Microsoft Excel [84], while qualitative questions were analysed on a Miro board [85], by performing an affinity diagram. An example of an affinity diagram performed on qualitative data from the questionnaire can be seen in Figure 6.7, where different topics were noted down for each question and those topics were later organised and grouped together. Moreover, additional analysis was performed to conduct a cross-analysis between answers to understand better the participants who care the most about their battery health. Once the analysis was completed, a list of general takeaways from the questionnaire was summarised, which can be found in Section 7.1.2 of the Results Chapter.

6.2.1.3 Affinity Diagram from Focus Groups

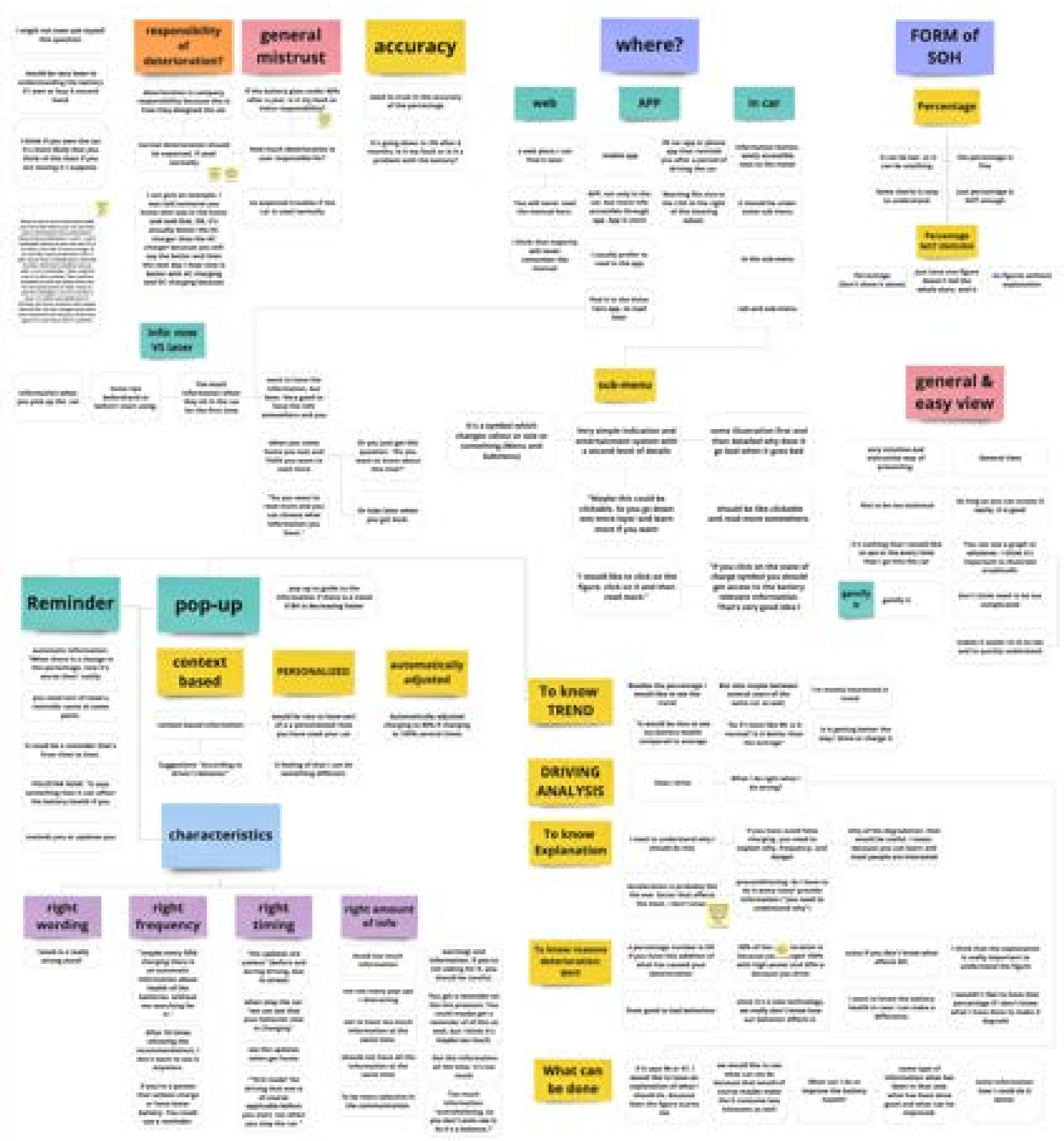


Figure 6.8: Affinity diagram from focus groups

An affinity diagram was created after conducting two sessions of the focus groups to analyse quantitative data from all discussions simultaneously. This approach could help minimise bias from the first to the second group as common themes or patterns were identified across both groups concurrently. Refer to Section 6.1.2.3 to read about the process and execution of the focus groups. To derive an affinity diagram, the audio recordings from the focus groups were transcribed using the transcription feature on Microsoft Word Online as part of Outlook 365 [84]. The transcript was reviewed and corrected manually to ensure accuracy and to obtain the correct data for the analysis. From the transcript, key points were extracted and listed using a card on the Miro Board [85]. Similar or closed information was clustered together and then assigned with a code. The next step was finding the relationship between each group and connecting each group as an affinity diagram in Figure 6.8. The findings create a better understanding of what SoH information that BEV drivers would like to see including how and when they would like to perceive it in their vehicles. The data analysis is summarised into three main groups which are: SoH, recommendations, and concerns and can be found in Table 6.2, Table 6.3, and Table 6.4. The final takeaways from the analysis of both focus groups are shown in Section 7.1.3 of the Result Chapter.

Table 6.2: Summary from focus groups: SoH

SoH	
Where SoH information should be displayed?	Users would like to see SoH information on: 1. **In-vehicle screen:** preferably inside sub-menu on the infotainment screen 2. **Mobile application:** to access at their convenience 3. **Website:** as an additional option
How SoH information should be displayed?	Users preferred to have a general view and a more detailed explanation in **sub-menu**
Is more SoH information required?	Users confirmed that they would like to see more information rather than a percentage of SoH
What information should be displayed along with SoH?	Users would like to have more information: 1. **Trend:** comparing users battery health with others 2. **Degradation analysis:** analysis with reasons for current deterioration 3. **Reasons:** why they need to do particular actions

SoH	
	4. **Actions:** actions that might slow down the deterioration
Frequency of SoH	Users would like to be notified when there is a change in their battery health

Table 6.3: Summary from focus groups: Recommendations

Recommendations	
How to present recommendations?	Recommendations for battery health maintenance should be presented through a balanced combination of: 1. **Periodic reminders:** for essential actions 2. **Strategic pop-ups:** to notify when high degradation on SoH is detected.
Characteristics of the displayed recommendations	**Right wordings:** The recommendations should use gentle wordings. **Right frequency:** The recommendations should not be too frequent. **Right timing / right context:** The recommendations should be provided in the right context and timing. **Right amount of info:** The recommendations should be prioritised and avoid too much information at the same time (more selective communication). **Personalised:** The recommendations should be personalised based on the driver's behaviour. **Automatically adjusted:** The recommendations should be automatically adjusted to simplify the driver's experience, so they have to keep less track of all the factors. **Gamification:** The recommendations should be presented in an appealing, friendly, and playful way.

Table 6.4: Summary from focus groups: Concerns

Concerns	
Responsibility of deterioration: outline expected degradation	Users have general mistrust regarding their culpability of battery deterioration: since the deterioration is expected when the car is used, and there is no accuracy in the percentage either which adds up to the mistrust.
Context of the recommendations	The users considered context as one of the most significant factors since they would like to receive recommendations only when they needed them. Regarding this, the mobile application may be a suitable location for some of the recommendations since some advice should be presented in the context where the user is not in the car.

6.2.2 Requirement Identification

The insights from the data analysis were used to form design documents and requirements. The demographic data collected from the questionnaire was used as input for initiating personas and formulating scenarios. Additionally, the results received from the questionnaire together with the participants' feedback gained from the focus groups, were used to establish the requirement list. Since it describes the information and functions required for the design solution of SoH, this list acts as the foundation for the design concept and ensures that it is effectively aligned with the objectives and needs of the users.

6.2.2.1 Initiating Personas

After synthesising commonalities in demographic data and identifying behaviour patterns and needs from the questionnaire, two personas were formulated based on demographic information, background details, pain points, and goals collected from the data-gathering process, mainly from the questionnaire. The primary objective of constructing these personas is to identify target users and provide explicit insights, relations, and target audiences of the product. Conducting this method helps to understand the characteristics, skills, typical habits, main frustrations, and overall goals of the target users. The initial step in creating these personas was to organise the contents of the personas, encompassing demographic information, background, identified pain points, and desired goals. The information analysed from the questionnaire (Figure 6.7) was then summarised, and the narrative was developed and tailored to suit the ideal personas. Based on the data gathered, two types of users were identified: individuals who prioritise the care and maintenance of their BEVs for sustainable and environmental purposes and individuals who aim to maintain their BEVs with minimal effort to reduce maintenance costs. See results of personas in Section 7.1.4 of the Result Chapter.

6.2.2.2 Formulating Scenarios

Following the personas, scenarios were then formulated to concretise the situations and the way the product is likely to be used by a user. As recommended by Bruce and Bella [63, p. 190], each persona should have at least one scenario. Consequently, two scenarios were generated to address the different needs of both personas: a scenario for individuals who prioritise the care and maintenance of their BEVs and another for those who aim to maintain their BEVs with minimal effort. The scenarios were written in the text describing contexts while incorporating the desired goals or needs of the personas. See results of scenarios in Section 7.1.5 of the Result Chapter.

6.2.2.3 Establishing Requirement List

The development of the requirement list is the final step in the define phase, which allowed us to summarise the findings in a more compact way. The requirement list was documented in the form of User Stories [35], which provided the users' needs through action and how it will benefit them. The requirements list recompiles the takeaways from the literature review, expert interviews, questionnaires and focus groups, and can be found in Section 7.1.6 of the Results Chapter.

6.3 Develop

The development phase started with benchmarking and brainstorming before delving into the development process. The iterative process involves designing, testing and refining the design concept and it was conducted in three iterations. Each iteration of the design concept was tested on five participants, therefore the concept was tested on 15 participants overall. The details regarding the process and execution are described below.

6.3.1 Benchmarking

Displaying battery SoH on a monitor in-vehicle is not only new to Volvo Cars but also novel to other companies in the automotive industry meaning that there are fewer best practices for displaying SoH to look into. Regarding this fact, the competitor benchmarking with only BEV manufacturers within the premium sector is considered insufficient and limits learning from companies in other sectors within the same industry. Therefore, industrial benchmarking was conducted instead of competitor benchmarking to find the best practices from the companies within the same industry including non-competitors [74, p. 411]. By conducting this type of benchmarking, general practices of presenting the battery SoH could be found and used as a reference or inspiration in the process of prototyping.

In order to benchmark how battery SoH is presented on a vehicles screen, it is crucial to have physical access to the other companies BEVs. Since these user interfaces of the vehicle screens are not widely published on the Internet, collaboration with Volvo

Cars enables access to various BEVs from many manufacturers in a timely manner. Despite less availability of in-vehicle user interfaces related to SoH on the Internet, some were presented online, e.g., Nissan Leaf, Jaguar I-PACE, and BMW i3 while the others were discovered through physical exploration at Volvo Cars Torslanda office. This process was conducted by exploring the presentation of SoH and SoH-related information as well as observing features related to battery maintenance in BEVs. Even though 11 BEVs were investigated, the presentation of battery SoH was merely discovered as shown in Table 7.2 since battery health is relatively new to the automotive industry.

According to the conducted research on how the battery health of EVs is assessed in general, the battery SoH assessment is typically done either through a workshop at a service point or manually using a diagnostic tool from third-party services. Regarding these findings, generic benchmarking [74, p. 411] was employed to investigate how third-party applications that provide SoH assessment services to EV drivers and other companies beyond automotive industry boundaries, i.e., the technology industry, present such information. Since the applications and technology companies have a strong digital presence on the Internet, this process was conducted by researching the official websites of the applications, Apple Store, Google Play Store, and customer reviews. The generic benchmarking involves investigating terminology and visualisation forms of SoH, as well as related information displayed along with the SoH from third-party applications and companies in the technology industry. The results of all the benchmarking were shown in Section 7.2.1 of the Result Chapter.

6.3.2 Brainstorming

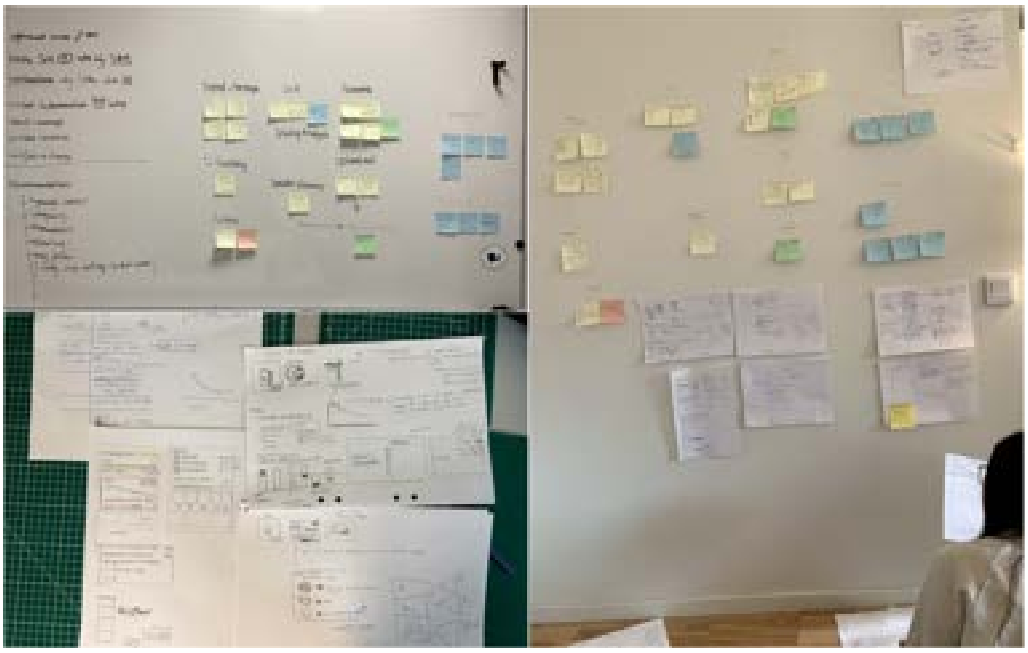


Figure 6.9: Recompilation of the brainstorming sessions which were held to generate ideas and discuss possible design solutions.

The purpose of brainstorming was to generate various ideas that could be used to accommodate and meet all the users' requirements. To accomplish this, all the users' requirements were listed first and then used the Crazy 8's technique, a brainstorming method that generates eight different ideas in eight minutes per person, with the goal of encouraging creativity and quick thinking. The ideas were drawn or written on Post-its and then presented to one another, which generated further discussion and new ideas. Following that, the most promising ideas were placed on the whiteboard and grouped into various topics and areas to consider when designing the SoH feature.

The brainstorming session was iterated several times, and where possible designs were refined and further discussed. Benchmarking results were also brought into account, and various competitor sections and visualisations were discussed and debated. Figure 6.9 provides a visual representation of the process of different brainstorming sessions. The outcome of the brainstorming sessions evolved into the first low-fidelity prototype which is discussed in the following sub-section.

6.3.3 Iteration 1

As mentioned at the beginning of this chapter, the interactive process of the design concept was conducted in three rounds with five participants each. This decision has been made according to the findings of Dow et al. that iterating multiple times provides more benefit and efficiency than a single iteration, especially under time constraints [86]. Additionally, the structure of this iterative process was decided as per recommendations from Nielsen Norman Group that the usability testing should be conducted in three iterations with five users each. This approach was chosen since conducting usability testing with a small group of participants multiple times can provide a high percentage of usability problems and allow the design to be improved efficiently based on user feedback [87].

The first interaction of the design process involves three main techniques, which are sketching, low-fidelity prototyping, and the first usability testing with the prototype. The primary objective of this iteration is to translate the ideas into visual representations and establish a foundation for the design concepts based on the requirement list and information gathered from the previous phase. These prototypes play a vital role in the development serving as tangible representations of the ideas while helping to identify strengths, weaknesses, as well as areas of improvement which can then be adjusted in the next iteration. In this context, the prototypes will be used as a tool to test if the provided information is sufficient for the explanation of the SoH. For the evaluation, the first usability test included five participants, a number that aligns with Nielsen, Lewis, and Virzi's claim that 80% of usability problems can be identified with a sample of five users, known as the magic number [88]. However, there is some disagreement in the research community regarding this matter so there is no clear consensus about the ideal number of participants for a usability study due to the complexity of the problem [89]. Nonetheless, Alroobaea & Mayhew (2014) [89], found that even with five participants, problems related to content and structure, together with cosmetic problems can still be identified. Given the constraints of time and scope, the decision was made to opt for five participants, a number which will allow us to have more iterations instead.

6.3.3.1 Development of Low-Fidelity Prototype

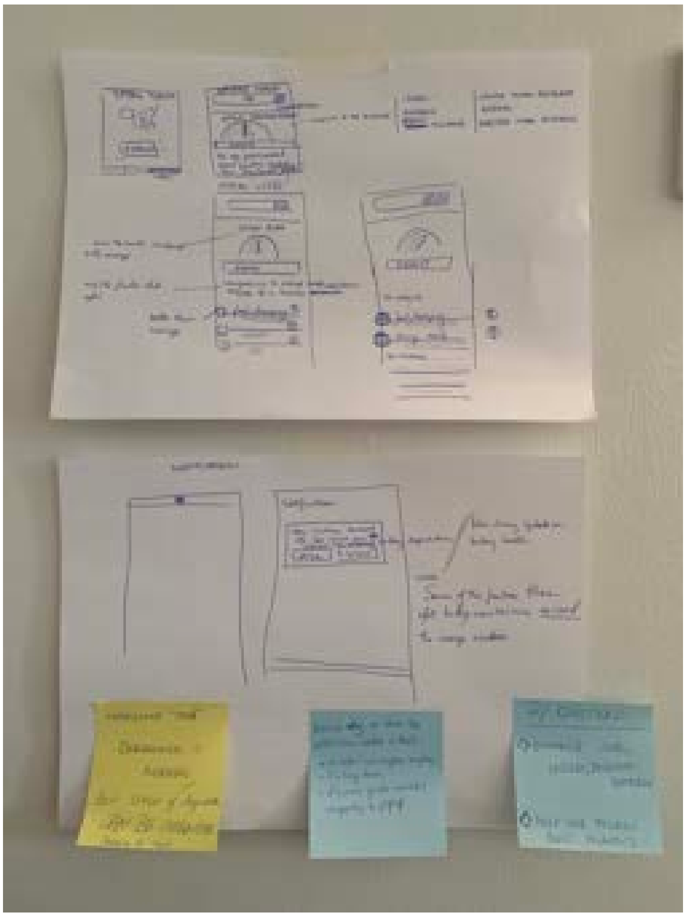


Figure 6.10: Sketches of the design concept

Following the brainstorming session where a large amount of design alternatives were generated and selected (more information about the process can be found in Section 6.3.2), a concept sketch was then initiated in the simplest way using pen and paper to visualise the overall structure and workflow of the design concept. The goal of the first iteration was to translate previously formulated user requirements into a cohesive design concept so that it could be evaluated in the usability study to determine how users perceive it.

Having several screens with annotations and descriptions, the sketches aimed to simulate the presentation of battery SoH information on the infotainment screen. Additionally, design rationales were written on Post-it notes to provide justifications for the chosen design concepts, ensuring that they align with objectives and user needs. See the sketches in Figure 6.10. Subsequently, these prototypes were translated into low-fidelity prototypes, which served as a solid manifestation of the design concept. The prototype was iterated several times to obtain a clear design that could be evaluated by the participants. The prototype with a low level of fidelity was created on Figma [90] using a black-and-white colour scheme so the users or stakeholders can pay more attention to the clarity and presentation of the information rather than minor details and aesthetics of the design concept. During the prototyping process, several design alternatives were simulated to explore many visualisation possibilities for each type of information, i.e., recommendations.

Since the concept was intended to be displayed on the infotainment screen, the existing screen's screen size was utilised for this prototyping, ensuring that the design was aligned with the intended design context. The prototypes were divided into three main parts: battery health overview, recommendations, and notifications. The details are described below.

Battery health overview

Figure 6.11: Low-fidelity prototypes: battery health overview screen

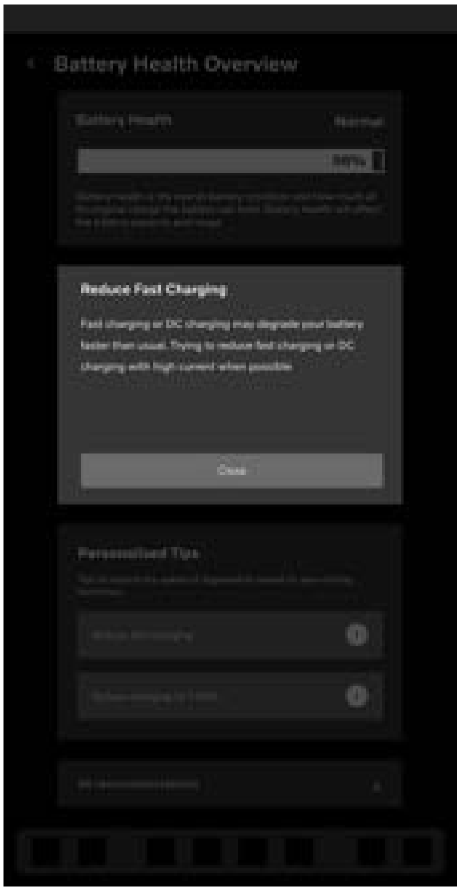


Figure 6.12: Low-fidelity prototypes: more information from personalised tips

This screen as in Figure 6.11 was designed to represent an overview of the vehicle's battery health with the purpose of providing users with an easily accessible and understandable view of their battery's conditions in their vehicle [R1] [R2]. The screen was divided into three main sections displaying the battery health, speed of degradation, and personalised tips. This screen also included one additional button for navigating to all recommendations which were organised on another screen as a sub-menu [R2].

For the battery health section, a percentage figure was displayed along with the battery health status helping users to have a clear overview and better understanding regarding the current state of their battery health. In addition to providing information, a progress bar was employed as an additional visual aid to enhance users' understanding of battery health [B4]. This visualisation method offers users a more intuitive understanding of their battery health, supporting the provided information. Additionally, the description of why the users should maintain battery health was also provided in a text-based format as part of the section [R3]. Since the degradation limit varies across different battery cells, it was decided to keep the progress bar without minimum and maximum percentage figures and provide the explanation in the sub-menu instead.

Following the battery health section, the speed of degradation section was presented using gauge chart visualisation to indicate the user's degradation compared to the other drivers in similar conditions [R5]. This feature aims to highlight that degradation is inevitable but there is a general baseline for battery health throughout usage and timespan, to avoid blaming or making the user responsible for the entire degradation process since it is a natural process, and finally to represent the average trend of battery degradation in an easy to follow manner. The degradation status was also included on the top right corner, alongside the date of measurement to indicate when the measurement has been executed. To be consistent, a list of tips was presented in the subsequent section which is personalised based on their driving behaviour [R9]. This list aims to inform the users about the actions they could take to better care for the battery health and slow down their speed of degradation [R6], which could imply the causes of the deterioration of their battery health [R4]. For each action, an information icon was also provided at the end for more detailed information. A pop-up window will be displayed when clicking the icon to present additional information as in Figure 6.12. This design choice was selected to minimise the text from the overview screen, keeping it as simple as possible.

Recommendations
Upon clicking on the 'All recommendations' button, the users will be navigated to the other screen displaying all the recommended actions for battery health maintenance [R7]. Similar to the personalised tips section on the battery health overview screen, this list of recommendations also provides an information icon where the users can interact to see more information. See Figure 6.13 for the recommendation screen.

Notifications
As the users would like to receive reminders from time to time when the recommendations were not properly followed [R10], this six-month notification serves as a reminder reporting the analysis of battery health for every six-month usage. A gentle reminder should not be abruptly displayed in the form of a pop-up on the

Figure 6.13: Low-fidelity prototype: all recommendations

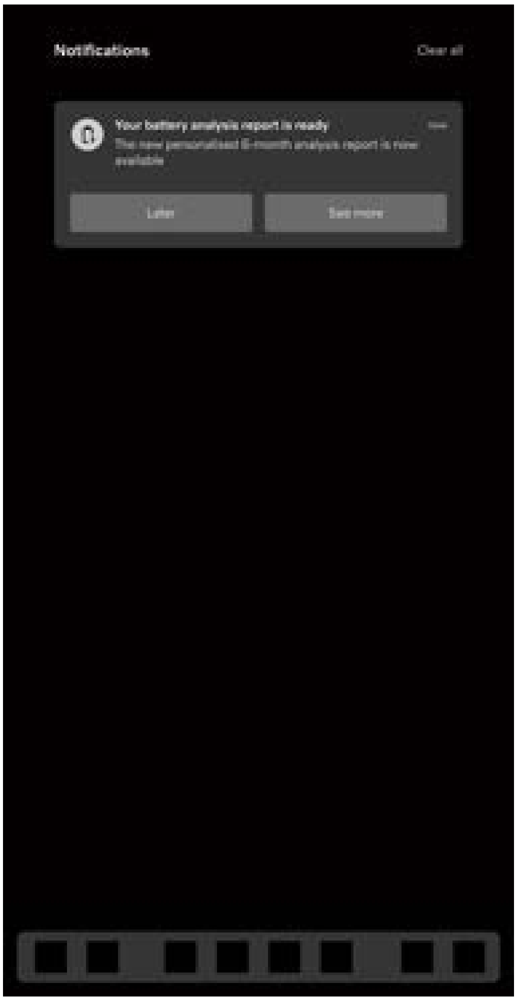


Figure 6.14: Low-fidelity prototype: six-month silent notification

infotainment screen. Therefore, silent notifications or notifications that do not display alerts and disturb the users were chosen, allowing the users to check them at their convenience. See Figure 6.14 for the notification screen.

6.3.3.2 Evaluation of Low-Fidelity Prototype

Prior to the first usability testing, three pilot studies were conducted to test if the session was prepared on time with a proper structure and approach. After the feedback was received, it was discussed and brainstormed for further improvement. Following that, some changes were made to the prototype before conducting the actual usability test, such as changing the theme from light to dark mode for a better visual focus and revising the wording of recommended actions.

The first usability testing was conducted with five target users, according to recommendations from Nielsen, Lewis, and Virzi [88], to gather feedback regarding low-fidelity prototypes for further improvement. The usability test engaged both previous and new participants to ensure that both perspectives were taken into account for further improvement. Additionally, the aim of this usability testing is to validate the design concept and assumption with the previous users who provided input during data gathering, ensuring that the design meets their needs and goals as the target audience. After receiving a list of eligible participants from the team, another screening was conducted manually to ensure diversity in backgrounds and demographics among the participants. As a result, five participants, three from the focus groups and two newly recruited, took part in a 20-25 minutes usability test. The participants were two women and three men, with an average age of 51 and 2.5 years of experience leasing a BEV. See Table 6.5 for a list of the participants of the first usability test.

Table 6.5: List of participants of the first usability testing

Person	**Age**	**Gender**	**Own vehicle**	**Participated in a focus group**	**Years of experience with BEV**
P1	60	Female	C40 Recharge	Yes	1
P2	56	Male	Polestar 2	Yes	1.5
P3	52	Male	Polestar 2	Yes	3
P4	38	Female	C40 Recharge	No	3
P5	49	Male	C40 Recharge	No	4

Figure 6.15: Preparation for the first usability testing session in iteration 1

After the users confirmed their participation, the prototypes and documents, e.g., the consent form, demographic questionnaire, scenario, and evaluation questionnaire, were prepared for the session. The room was set up with printouts, stationery, and an electronic device for audio recording as in Figure 6.15. See more details about the procedure and questions of the evaluation in Appendix C.

The duration of a test was approximately 20-25 minutes in total. The participants were first presented with forms asking for their consent to conduct the usability test and proceed with their data during analysis, as well as a questionnaire asking for their demographic information. The participants were then presented with a scenario and set of tasks that they needed to perform. There are four tasks in total and on each task, the participants were presented with a different set of information as shown below. For each task, different sets of information and visualisation were presented to investigate if additional information is required to understand the SoH information.

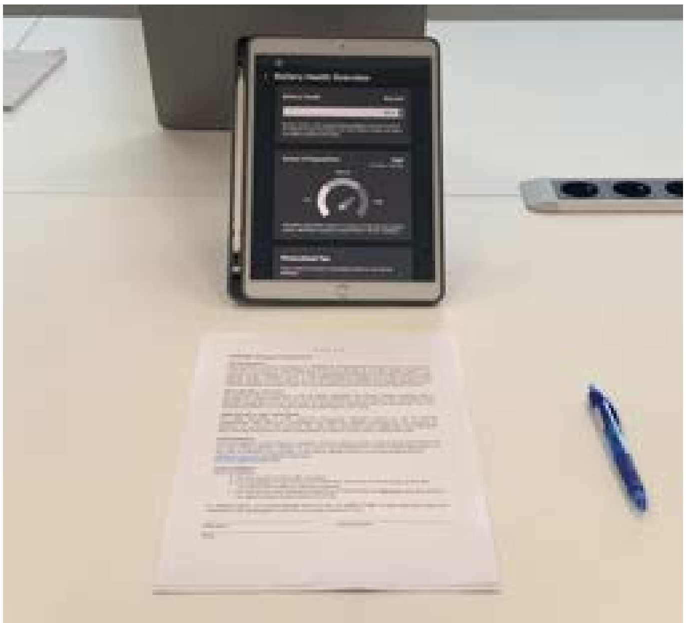


Figure 6.16: Preparation for the remaining usability testing sessions in iteration 1

The information presented for each task:

- **Task 1:** battery health
- **Task 2:** battery health and speed of degradation
- **Task 3:** battery health, speed of degradation, and personalised tips
- **Task 4:** six-month notification

Each task consisted of three steps: performing the task, filling out the questionnaire, and answering questions in the interview. While performing the task, the participants were encouraged to speak out loud about what they saw or verbalise their thoughts using a think-aloud process. The participants were presented with a modified System Usability Scale (SUS) questionnaire that was based on the Single Ease Question (SEQ) questionnaire [91], which is typically used as a post-task questionnaire. The goal was to quickly and easily assess how information was perceived for each task in order to analyse which tasks were clear and which were not. Participants were asked to rate the information presented on a Likert scale of 1 to 5 for simplicity, relevance, personalisation, clarity, organisation, understandability, usefulness, and helpfulness.

The first usability test was conducted with paper-based prototypes, which were printed out for evaluation. However, the first participant suggested changing the approach of presenting the prototypes from paper to tablet for a better experience in interacting with interactive prototypes. Therefore, the rest of the participants conducted usability testing on the tablet as shown in Figure 6.16.

6.3.3.3 Result Analysis of the First Iteration

For the qualitative data, an affinity diagram was created. To create an affinity diagram, audio recordings from the usability tests were listened to multiple times, and key quotes were extracted and listed using a card on the Miro Board [85]. The quotes were also compared to the notes taken during the evaluation to ensure that any additional details discovered during the evaluation were considered. The key quotes were initially grouped under each task, which defined different sections of the design concept, such as battery health, speed of degradation, personalised tips and notifications. The quotes were later clustered, rearranged and finally discussed between the researchers to come up with the takeaways from the first iteration. Both researchers worked together to ensure that no details were overlooked. For the quantitative data, all of the results from the Likert scale questions were compiled into a table to provide a better overview of the results and to detect potential trends. The aim of the analysis was to use the results as the main input for the next iteration of the design process. Key takeaways for the first iteration are presented in Section 7.2.2.

6.3.4 Unstructured Interviews with Stakeholders

Throughout the project, there were opportunities to meet with numerous internal stakeholders within Volvo Cars. A series of weekly meetings were held with Micaela Nilsson, the thesis advisor within the company, who provided invaluable support and guidance with research and design throughout the thesis process. Additionally, several sessions were conducted with people from various departments, including teams working on energy management, battery control and cell analytics, charging diagnostics and in-car UX, ensuring that the thesis was in sync and aligned with Volvo Cars' objectives and principles. The general goal of the meetings was to present the ongoing work, discuss the findings, resolve any uncertainties regarding the topic of battery SoH, gain additional information and insights, and receive contact points for more insights and collaborations. While these meetings provided us with a great overview, better understanding, and fruitful knowledge of the topic of SoH, similar to expert interviews, some meetings focused mainly on technical aspects, which were relatively challenging to consider or include in the design process.

From all sessions, two meetings during the development were considered critical for the project. The first session was a meeting with representatives from the Battery, Charging and Energy management teams. During the session, the research findings and outcomes from the brainstorming were presented in the sessions to receive feedback from the team based on the research gathered and to ensure that the project's direction and progress met the expectations of internal stakeholders. The second meeting was scheduled with two UX designers who have been working on implementing the SoH regulations in the in-vehicle display. The primary objective of this meeting was to receive their insights and to ensure that nothing important was missing from the design concept. To avoid contaminating our design thinking, a meeting with the UX team was intentionally postponed until the first design concept was developed.

Due to the complexities of the topic of BEV's battery health, discussing with diverse teams across departments assured us of progressing with our design concept and evaluating our prototype. During the brainstorming and development of the low-fidelity prototype, our research findings and proposed ideas received positive and helpful feedback from Volvo Cars' internal stakeholders during the team meeting. This ensured that the direction of the thesis was aligned with Volvo Cars' objectives and stakeholder expectations. Additionally, constructive feedback regarding the SoH information was provided by UX designers who are in charge of SoH implementation. They suggested paying attention to the information presentation, for example, whether it is useful to the users and aligned with regulation and the company's expectations.

The design guidelines of the company were also considered during the development phase of the design concept. The design guidelines, including typography, colours, and components, were followed while designing the prototypes. Despite having these guidelines, there was still freedom to innovate and create new design concepts. New information and visualisations were also included, i.e., the speed of degradation with a gauge chart. Additionally, the unstructured interviews with UX designers allowed cross-checking to ensure that the main design implementations, such as the silent notifications, were feasible according to the company's design standards.

6.3.5 Iteration 2

Following the iterative process, the second iteration was performed to improve the design with a higher level of fidelity and test the user needs even further. Once the semi-functional prototype is developed, it is tested again on the users.

6.3.5.1 Development of Semi-Functional Prototype

The development of the semi-functional prototype began with a discussion of all the takeaways from the first usability test (presented in Section 7.2.2), followed by brainstorming of potential improvements. Based on the users' feedback, it was necessary to improve the display of the battery status on the progress bar and its explanation, together with the degradation speed history. By refining the low-fidelity prototype based on the input collected from the usability test, a semi-functional prototype was further developed in Figma [90]. The modifications to the design concept in Figma [90] are listed and motivated below. Additionally, colours were added to the prototype during this stage of the design concept to make it appear more refined and increase design fidelity. All of the interactions were added to improve the fidelity of the prototype and allow the user to navigate through it digitally.

Display of battery status

The display of battery status on the progress bar of battery SoH has been modified to make it clearer to users since it generated confusion in some participants [EV1-2]. It was decided to divide the SoH progress bar into three statuses, which are included under the bar: ‘fair’, ‘good’, and ‘excellent’. The explanation of each status is also added in the section’s additional information, which is hidden under the ‘information’ button next to Battery Health (see Figure 6.17).

Degradation speed history

The degradation speed history view has been implemented, to meet users’ needs [EV1-4]. The history is shown as additional information since not all drivers considered it crucial. The historical view also contains future predictions as mentioned during the previous usability studies. (see Figure 6.18).

Figure 6.17: Semi-functional prototype: the display of battery status together with expanded information that clarifies the meaning of each status

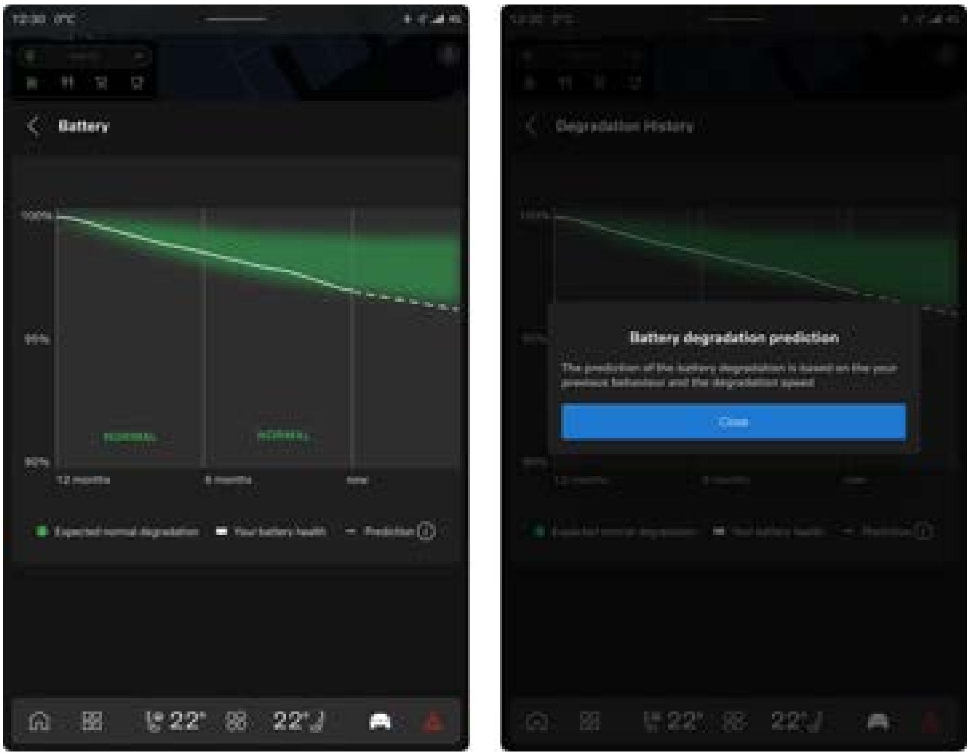


Figure 6.18: Semi-functional prototype: degradation speed history together with expanded information that clarifies the prediction

6.3.5.2 Evaluation of Semi-Functional Prototype

The semi-functional prototype was evaluated via a usability test with five participants. The main goal of the usability test was to determine whether the design continues to align with the user's needs, once the changes after the first usability test were applied. The specific goal was to ensure that the information presented was clear and sufficient for users to understand the state of health of their car's battery. Additionally, if the visualisation and design improve the user's understanding of the battery SoH. The feedback provided from this iteration allowed further improvement to the prototype, as well as more support to establish the design guidelines.

Before the usability test, a pilot study with three participants was conducted to fine-tune the wording of the tasks, confirm that the estimated time of the study was correct and if the overall study plan was followed as planned. See Table 6.6 for a list of participants in pilot study 2. One of the participants (P1) is an employee at Volvo Cars, while the other two participants (P2 and P3) are not employed by Volvo Cars. Minor adjustments were made after the first participant of the pilot study, followed by two more participants in order to make sure that the changes were clear to others.

Table 6.6: List of participants in pilot study 2

Person	**Age**	**Gender**
P1	29	Male
P2	31	Female
P3	37	Male

Similarly to the first usability study, five people (two from the focus group and three newly recruited) took part in the usability study and all the participants were Volvo Cars employees who are currently leasing a BEV. The participants included three women and two men, with an average age of 44 and 2.4 years of experience leasing a BEV. See Table 6.7 for the list of participants of the second evaluation. Two of the five participants took part in the focus group. As with the first usability study, the aim was to include participants from the focus group to ensure that their needs were correctly understood and there was a follow-up on their feedback. The user tests were conducted individually, on-site and lasted between 20 and 30 minutes.

At the start of the usability test, the participants were informed about the purpose of the study and the test, as well as the consent form that allowed the session to be audio recorded. Following that, the scenario was presented, and participants were encouraged to explore the design concepts while thinking out loud. After exploring, the participants were asked follow-up questions about each section of the prototype, including battery health status, degradation speed, degradation history, and recommendations. Finally, they were asked to complete a questionnaire rating the design concept. Because the goal was to evaluate the overall design concept, a more simplified version of a previous questionnaire was created. The questionnaire asked respondents to rate whether the information provided was sufficient, clear, and attractive. Furthermore, a question about the attractiveness of the design concept was raised, as more visual content and design aesthetics, such as colours, were introduced into this interaction of the prototype. The complete user study design, including questions and a questionnaire, can be found in Appendix D.

Table 6.7: List of participants of the second usability testing

Person	**Age**	**Gender**	**Own vehicle**	**Participated in a focus group**	**Years of experience with BEV**
P1	50	Female	XC40 Recharge	Yes	0.5
P2	35	Male	XC40 Recharge	Yes	0.5
P3	44	Female	C40 Recharge	No	5

Person	Age	Gender	Own vehicle	Participated in a focus group	Years of experience with BEV
P4	52	Female	EX30	No	3
P5	39	Male	EX30	No	3

6.3.5.3 Result Analysis of the Second Iteration

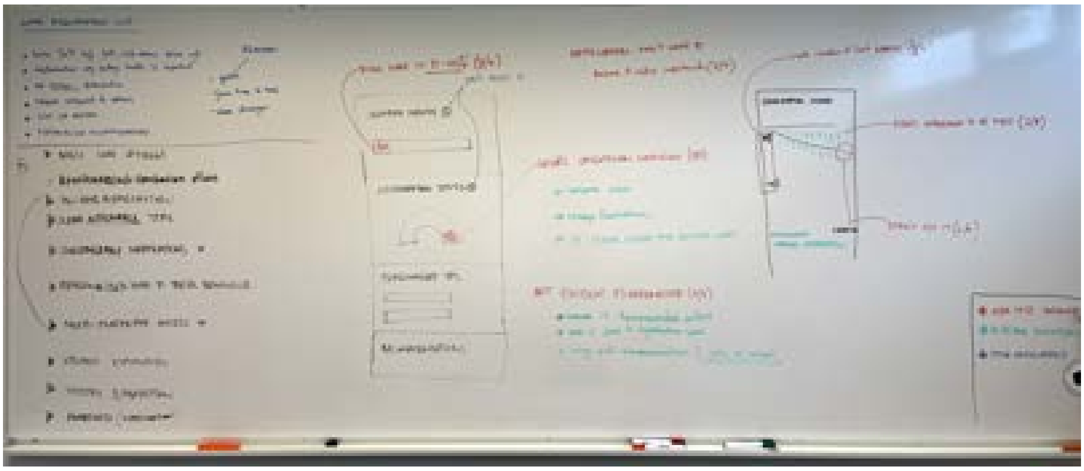


Figure 6.19: Analysis and brainstorming session of possible prototype improvements, together with the generation of future design recommendations

Similar to the previous iterations, the qualitative feedback was categorised by question, and the quantitative feedback was summarised to determine the overall efficiency of the design concept. The notes and recordings were used to compile on the Miro Board [85] all the important insights to prepare for affinity diagramming, focusing on the key sections of the design concept: battery health status, degradation speed, degradation history, and recommendations. The analysis aimed to not only use the key takeaways as the main input for the next iteration of the design process, as presented in Section 7.2.3. However, the participants insights were also used to motivate and brainstorm future design recommendations. The brainstorming session of the design recommendations can be seen in Figure 6.19, where all the important critiques and possible improvements are noted on the board for a better overview.

6.3.6 Iteration 3

The third iteration was conducted to test the user's understanding of the SoH design concept and ensure that the concept aligned with the users' needs after the previous iteration. Moreover, it was also important to see if the design recommendations that emerged after the previous evaluation were effective. The goal was to collect additional information to support the design recommendations based on the design concept. The evaluation feedback would provide us with additional data to clarify and finalise the design recommendations, which is the project's ultimate goal.

6.3.6.1 Development of Refined Semi-Functional Prototype

Similar to the previous iteration, the development of the second semi-functional prototype began with a discussion of all the takeaways from the second usability test, followed by brainstorming of potential improvements, based on user feedback.

While most sections remain the same as in the previous prototype, specific changes have been made to improve the information's clarity and understanding. The degradation section was perceived as the most conflicting section by participants in the previous usability test, so clear improvements were required. Furthermore, the participants provided valuable feedback on the history of degradation as well as personalised tips that needed to be reiterated and improved. Degradation and degradation history were two main sections that were modified in this iteration, which are explained in more detail below.

Degradation

Because the degradation section was confusing for some of the participants in the previous evaluation, all the modifications are listed below. The new Figma prototype can also be seen in Figure 6.20.

- **Degradation gauge chart:** The gauge chart has been adjusted by reversing it and changing its colours and labels since the display of the degradation was confusing for some users [EV2-5]. The orange 'High' degradation indicator, which was previously displayed on the right, was moved to the left of the gauge chart instead to align with the orange 'Fair' status, which belongs to the battery state bar located directly above the degradation section.
- **Title:** The title of this section has been changed from 'Degradation speed' to 'Degradation'. Because the degradation gauge had to be modified, the speedometer metaphor to represent the degradation speed was not as relevant anymore as it had been in the previous prototype. The speed at which the battery degrades therefore shifted to a more general overview of the degradation status.
- **Adjustment of personalised tips:** It was observed from the feedback from the usability testing that the relationship between personalised tips and the factors that affect the degradation was unclear. Many participants perceived the personalised tips as general recommendations rather than factors based on the driver's current behaviour [EV2-9]. To address this, it was decided to add personalised tips within the degradation section, in order to create a more direct link between them. The section was also renamed as "Actions to lower your current degradation". These changes were expected to clarify the connection between degradation and personalised recommendations.

Figure 6.20: Refined semi-functional prototype: the main page of the Battery Health

Degradation history
Some significant changes were also applied to the degradation history section. The prototype can be seen in Figure 6.21.

- **Title:** The title of this section has been renamed to "Degradation trends: Historical and Expected". The reason for this change was that participants in the usability test reported difficulty in quickly identifying that the green range corresponded to the expected normal degradation of the battery [EV2-7]. This change was made to clarify that the graph shows not only the history of the battery's degradation but also compares it to the normal battery degradation range.

- **Visualisation:** It was also discovered that some participants in the usability test struggled to recognise the presence of future predictions on the graph [EV2-7]. To improve this, the driver's location on the graph was highlighted by adding a more prominent point of reference. Additionally, a yellow line representing the 'now' on the time span is included. These changes are expected to help drivers understand that whatever is displayed to the right of their current state on the graph is a prediction.

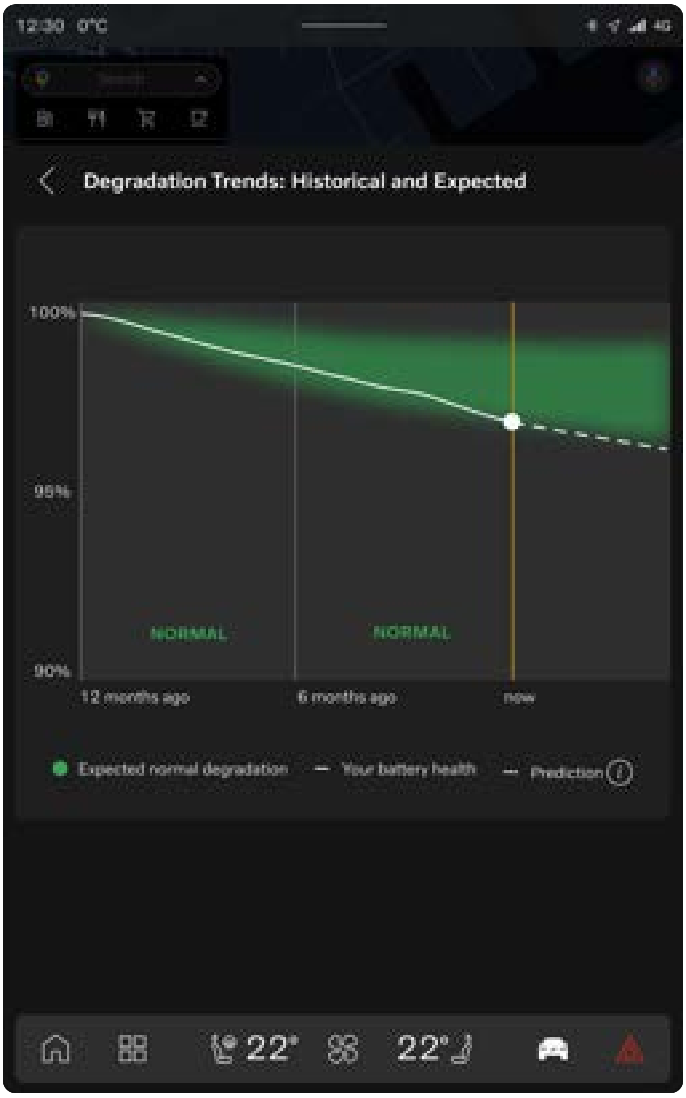


Figure 6.21: Refined semi-functional prototype: degradation history view

6.3.6.2 Evaluation of Refined Semi-Functional Prototype

Similar to the previous iteration, this prototype was evaluated using a usability test with five participants, which are listed in Table 6.8. The first goal of this evaluation was to see if the refined prototype met the users' requirements and needs after the changes from the previous evaluation were implemented. The second goal, which differed from the previous evaluation, was to confirm the design recommendations that became clearer following the second evaluation. To accomplish this, a questionnaire was developed to evaluate these design recommendations on participants.

Before the usability test, a pilot study with two Volvo Cars employees was conducted, similar to previous evaluations. Minor changes to the language and formulation of the questions were made before the studies. The structure of the evaluation was very similar to the previous one. Five participants, two from the focus group and three new recruits, took part in a 20-30 minutes usability test to evaluate the design. The participants included one woman and four men, with an average age of 44 and 2.4 years of experience leasing a BEV. At the beginning of the usability test, participants were informed about the study's purpose, and the consent form allowed the session to be audio recorded. The scenario was then presented, and participants were encouraged to explore the design concept while thinking out loud. General questions about each section were asked during the exploration of the concept, to help the participants navigate their exploration. Following the exploration, the participants were given a questionnaire in which they had to rate the design on a Likert scale and motivate their decisions. See Appendix E for the questionnaire and evaluation questions.

Table 6.8: List of participants of the third usability testing

Person	**Age**	**Gender**	**Own vehicle**	**Participated in a focus group**	**Years of experience with BEV**
P1	55	Male	XC40 Recharge	Yes	0.6
P2	37	Male	EX30	No	0.2
P3	38	Male	XC40 Recharge	No	0.5
P4	49	Male	Polestar 2	Yes	3.5
P5	43	Female	EX30	No	3

6.3.6.3 Result Analysis of the Third Iteration

Similar to the previous iterations, an affinity diagram was created for every question presented during the evaluation. Key quotes were extracted and listed on the Miro Board [85]. Each question contained key quotes as well as the average score of the Likert scale questionnaire, which was part of the quantitative data. The quotes were later clustered, rearranged and finally discussed between the researchers to come up with the takeaways from the third iteration. The goal of the analysis was to gain more insight into the design concept to refine the initial design recommendations, which began after the second iteration. Key takeaways for the third iteration are presented in Section 7.2.4.

6.4 Deliver

The objective of the delivery phase is to select a design solution, finalise the design concept, and prepare for implementation. In the context of this thesis, the process of delivery involves finalising and creating design recommendations for in-vehicle battery SoH display, which can be used as guidance for its implementation in the automotive industry further.

6.4.1 Establishing Design Recommendations

Following the second evaluation, design recommendations began to be compiled and brainstormed. However, it was not until the third evaluation that all of the information and insights were gathered to develop the final design recommendations for this research. These recommendations were supported with valuable insights or key takeaways from expert interviews, questionnaires, and focus groups, including feedback from all evaluation iterations. These recommendations serve as the research's final results, summarising all of the research conducted on the battery SoH for BEVs. The final list of design recommendations can be found in Section 7.2.5 in the Results Chapter.

7

Results

This chapter presents the research findings. Similar to the Process chapter, the results are organized chronologically and divided into two major stages.

In the first stage, which corresponds to the Discover and Define phases, all data collected and analysed was used to create a list of requirements. As a result, the findings and conclusions from expert interviews, questionnaires, focus groups, scenario and personas framing are presented, along with a reference to the final requirement list. During the project's first stage, more work was done on defining and refining the project's scope and determining the user group.

The second stage included the Develop and Deliver phases. As a result, this chapter presents all of the findings from brainstorming, benchmarking, and the iterative process of developing, analysing, and evaluating prototypes. The final goal of this stage is to develop design recommendations based on all of the findings obtained from design through a research approach.

7.1 Establishing the Requirement List

The results of data collection and analysis are presented below for each method used throughout the stages of Discover and Define of the design process. The final conclusions are presented as a requirement list at the end of this section.

7.1.1 Expert Interview

Although the primary goal of expert interviews was to first confirm the findings and resolve questions about battery health, it was also necessary to obtain a deeper understanding of the topic by finding other points that should be considered when working on the battery health feature. Section 6.1.2.1 describes the expert interviews' execution and process; Section 6.2.1.1 describes the interviews' analysis; and this sub-section presents the results. The expert interview confirmed existing knowledge, but it also became more technical. The focus shifted to the technical feasibility of the ideas rather than the design concept, interfering with the project's design process. The expert interviews became too technical for the research, which caused additional confusion in understanding the overview of the topic. However, some interesting takeaways from the expert interview are listed below:

E1: Uncertainty in estimating battery SoH
As discovered in the literature review, the computational models on battery SoH are progressing fast but are still lacking enough precision [19], [20]. The measurement errors and the complexity of the process challenge the accuracy of the model. This uncertainty can influence how users perceive the data provided by the vehicle.

E2: Variations in accuracy depending on charge and discharge patterns
The precision of SoH calculations can also vary based on the battery's charging and discharging stages. When the car has been fully charged and discharged, the battery SoH estimation may be more accurate. However, other factors can influence the accuracy of the estimation, making this a more complex issue.

E3: Differential degradation across battery cells
Battery packs are made of many cells, which may vary in the way they are affected by internal and external factors. For example, while the recommendations state that the battery should be charged up to 90%, some battery cells can be charged up to 100%, without any wear on the battery. As a result, the recommendations for battery maintenance can slightly vary depending on the battery cell which is installed in the car.

E4: Difficulty in pinpointing dominant factors of degradation
The factors that influence battery degradation are diverse, interconnected and difficult to isolate. Because of the topic's novelty and complexity, it is still uncertain which factors affect the degradation the most.

E5: External factors influencing battery degradation beyond the manual

There are additional factors, which are not listed in the manual, that in combination can have an impact on battery health. For example, aggressive driving and depth of discharge are not mentioned in the manual, but might still have an effect on battery wear. However, there is no clear consensus on this issue, so more data and further research are needed to investigate possible factors that affect battery degradation.

7.1.2 Questionnaire

The process and the execution of the questionnaire are described in Section 6.1.2.2, the analysis of the questionnaire is described in Section 6.2.1.2, and in this subsection, the results are presented. Although most of the participants of the questionnaire are originally from Sweden (81%) and work in the engineering and operation department (69%), the results are still diversified with participants from other departments including finance, HR (people experience), commercial operations, among others; and countries such as France, Sound Africa, Germany, etc. Moreover, the data is collected from both men (67%) and women (31%). All four models of cars are represented in the answers of the participants, with the least number of participants leasing EX30 (two participants). However, this most certainly is due to the recent release of this model into the market. The findings that involve battery health are listed below:

Q1: Only half of the participants have read the manual regarding battery

maintenance.
Although most of the participants (53 out of 55) drive their vehicle daily, only 49% have read the manual regarding battery health and battery care. This outcome was anticipated since the manual about managing battery health and performance was difficult to access, which required multiple steps and navigation on the website. As a result, the manual's recommendations should be presented in a more user-friendly manner to effectively inform users about proper ways to slow down battery degradation.

Q2: The participants care about battery health.
It is interesting to observe that most of the participants report to care considerably about the battery health (with 7.04 out of 10 on average). This supports the fact that, despite not owning the car they drive, the user group is still concerned with the maintenance of their electric vehicle's battery. It was also discovered that women are slightly more concerned about battery health, with an average of 7.24 out of 10, than men, with an average of 6.87.

Q3: Most participants take four actions to preserve the battery health, out of eight that were listed in the questionnaire.
Overall, the number of actions that are taken is 3.4 on average among all the participants. The most common actions that were performed are the following: (1) avoid charging the car up to 100%, (2) pre-condition the car, (3) keep the charge above 20%, and (4) avoid fast charging. It can be argued that the reason that avoiding charging the car up to 100% is performed by the majority of the participants (43 out of 55) is due to the fact that this recommendation is displayed on the infotainment screen of the vehicle. Pre-conditioning the car has other benefits to the user; such as convenience and comfort.

Contrarily, the four least frequent actions performed by the participants are: (1) using the ECO mode, (2) maintaining 40-60% charge when parking over a month, (3) charging continuously for longer parking, (4) charging continuously in temperatures above 30 ℃. Actions 2, 3 and 4 do not happen as frequently as the previous actions throughout the drivers journey, which can explain the low level of importance for the users. Eco mode is not listed in the Volvo Cars manual to preserve battery health, however, it has a direct effect on the driving range and the number of cycles of the battery, which is connected to the battery degradation. Additionally, only two participants claimed that they did not take any specific action for battery maintenance.

Q4: Most participants are not willing to change their behaviour. Those who care the most about their battery think that they perform enough actions.
When asked about whether the participants will take more actions in the future, there was a clear consensus in opinion with 41 participants out of 50, claiming that they will not change their actions. This is due to various factors, such as convenience, their belief that they do enough and not caring due to the fact that the car is leased and not owned. It was observed that those who care about the battery the most (levels 6 to 10) were more willing to change their actions. However, this group of

participants also most commonly rated their actions as enough and not willing to change. Therefore, although the participants claimed to care about the battery and performed four actions out of eight actions on average, many believed that it was enough to preserve the good health of the battery. It can be argued that there is a lack of reference to a clear baseline of the level of impact that the users actions can have on battery degradation.

Q5: Participants still would like to improve some of their actions.
Within the actions that the participants would like to improve or add, the actions that were listed by the participants are: (1) avoid charging to 100%, (2) charge continuously for longer periods of parking, (3) keep charge above 20%, (4) pre-condition the car, (5) avoid fast charging, (6) improve driving behaviour. To conclude, these actions can be adopted by more drivers if they are properly informed and notified.

Q6: Users prefer to receive information about battery health in different scenarios and contexts.
There is a general division about when the participants would like to get the information about the battery health, which is almost equally divided between receiving it while parking, driving and charging. Others suggested to receive it on the app or on request. This suggests that the information presented to the users should be displayed in different scenarios, adapting to the user's context and actions.

Q7: Users prefer to receive the information on the infotainment screen.
When asked about where the users would like to see this information, 40% of the respondents chose to see it as static feedback on the infotainment screen, as well as a notification pop-up on that screen (20%). Static feedback on the steering screen was chosen by 17% of the participants, as well as pop-up notifications on that screen (11%). It can conclude that there is a clear preference for the location to receive information about the battery health, which is the infotainment screen of the vehicle.

7.1.3 Focus Groups

Section 6.1.2.3 describes the focus groups' execution and process; Section 6.2.1.3 describes the analysis; and this subchapter presents the resulting takeaways of the focus groups. From the data analysis, six takeaways from the focus groups are extracted. These key takeaways were listed down with the label from F1-F6 including quotes from participants of the focus groups.

F1: The drivers prefer to see SoH on infotainment screen and mobile application
While discussing the location for SoH information, three interfaces were mentioned among participants as the most suitable locations for SoH information, which are the vehicles infotainment screen, mobile application, and website. All participants would like to have the information available on the infotainment screen so that they can access the information when they are in the car. Moreover, the participants stated that SoH information should be available on more than one channel. They mentioned that the information should be available not only on the vehicles infotainment screen but also on the mobile application, i.e., the Volvo application so that they can access

it at their convenience. A participant mentioned the website as a channel to display battery SoH, however, many participants argued that the majority of drivers never check their car information on the website as well as the car manual which is available online.

> *"I would like to have a very simple indication of an entertainment system with a second level of detail which could explain more."* - P2

> *"I think its good to use the app for this kind of information, not only in the car because that's maybe more convenient to do on your sofa or somewhere else than the car."* - P4

F2: More information is required to understand battery SoH
Most of the participants confirmed that only the figure or percentage of battery capacity is insufficient to understand battery SoH. They would prefer to have an explanation to help them understand their battery health status better. Many participants reported that the cause of battery deterioration would be useful for them to know, while other participants said that they would like to see the trend of their battery health compared to other drivers who drive the same cars in similar conditions. Apart from that, most of the participants would like to know the actions that they could probably take to preserve their battery health more. In terms of how frequently the SoH information should be reported, some participants mentioned that they would like to be notified automatically when there is a change in the percentage of battery health.

> *"One figure doesn't tell the whole story. I think that the explanation is really important to understand the figure. I would like to have an explanation of what I should do because then the figure scares me."* - P4

> *"I think a percentage number is OK if you have this addition of what has caused your deterioration, that 30% of the deterioration is because you charged to 100% with high power and 30% is because of your driving."* - P2

> *"So that's also why I wouldn't like to have that percentage actually to see it. If you don't know what you have done to make it degrade."* - P7

> *"Besides the percentage I would like to see the trend."* - P3

> *"I would like to be notified when there is a change in percentage."* - P4

F3: SoH information should have visualisation and be presented in two layers: overview and detailed view (sub-menu)
For the form of SoH, all participants state that they did not have any concern with the figure or percentage. However, some participants suggested including visualisation since it would be more helpful and easy to understand the SoH information. Most of them prefer to have two layers of information: overview on one screen and details on another screen.

> *"The percentage is fine."* - P6

> *"It can be a bar chart."* - P1

> *"Some charts would be easy to understand."* - P3

> *"Maybe this could be clickable. So you go down one more layer and learn more if you want."* - P3

> *"It should be like clickable and read more somewhere."* - P4

> *"Some illustration first and then detailed why does it go bad when it goes bad."* - P2

F4: battery health status and recommendation could be in the forms of periodic reminders or pop-ups
Battery health status and recommendations for battery health maintenance could be presented through a balanced combination of periodic reminders for essential actions and strategic pop-ups to notify when high degradation on SoH is detected.

> *"But I guess it could be nice with an event or pop-up in the car if it's possible if I have a trend that my battery's state of health is decreasing much faster than average people in Gothenburg. And it could be nice with a pop-up and a guide to this information."* - P1

> *"You get a reminder on the tyre pressure. You could maybe get a reminder of this as well, but I think it's maybe too much. It could be a reminder that's from time to time. "* - P8

> *"You need to understand why you should do this. It would be good if you get this information when you get the car delivered. You also need some sort of reminder at some points."* - P5

F5: Recommendations should be gentle, personalised, context-aligned, and balanced
Regarding this, participants prefer battery SoH maintenance recommendations to be delivered in a gentle approach, with appropriate frequency, contextual timing aligned with relevant factors or behaviours, a balanced amount of information to prevent cognitive overload, personalised suggestions tailored to their behaviour, and gamification to increase user engagement in battery maintenance.

> *"Avoid for example is a very strong word."* - P4

> *"It could be something, maybe every fifth charge there is automatic information about the health of the batteries, without me searching for it."* - P3

> *"I think you should not have too many pop-ups because it's distracting me."* - P4

> *"To be more selective in the communication."* - P8

> *"You should avoid too much information in the car that there's so much information on the screen. I think to have warnings and information. If you're not asking for it, you should be careful."* - P4

F6: Deterioration responsibility and context of recommendations are the main concerns of the users
Participants mentioned mistrust regarding their role in battery deterioration, as the battery is expected to be degraded over time of vehicle usage. Additionally, a lack of accuracy in SoH calculation could lead to uncertainty which adds to their mistrust of the vehicle as well as the company. Apart from the deterioration responsibility, participants raised another concern regarding the context of the recommendations. They prioritise contextually relevant recommendations first, preferring to receive advice only when needed. Regarding this, the mobile application becomes suitable for some recommendations, especially in the context where certain advice is necessary outside of the vehicle.

> *"How much of the deterioration I'm responsible for? I mean the majority of the deterioration, the company is responsible for it because they've designed the project product for normal use and if I use it normally, I wouldn't expect to get it to any trouble."* - P2

> *"Some recommendations like preconditioning should be in the app, not in the car, or when it sort of applies. If it comes to the consumer in some way when it's sort of actual."* - P5

7.1.4 Personas

Two personas were formulated and used as references for the target users of the new design concept. Refer to Section 6.2.2.1 to read more about the process of initiating personas. A persona includes an avatar photo, quote, name, demographic information, work profile, vehicle leasing information, background, pain points, and desired goals. In the design process, the Avatars Generator, a plugin available on Figma Community was utilised to create diverse and customisable avatars for the personas [92]. In the background section, information regarding personal habits and attitudes towards battery preservation for BEV were mentioned to make the personas more relevant, realistic, and useful for designing products that meet users' needs.

The Persona of Camilla was developed as in Figure 7.1 to represent a type of target user who prioritises the care and maintenance of their BEVs for sustainable and environmental purposes. Camilla is a senior mechanical engineer at Volvo Cars who has an interest in exploring new technologies, especially new car releases. In addition to her interest, the persona presents her habits, such as consistent car maintenance even when leasing, and her attitude towards sustainability and environmental conservation. Additionally, the persona highlights her practice for battery preservation, i.e., reading manuals on battery preservation to slow down the degradation and prolong the lifespan of her vehicle's battery. Her pain points regarding the practice were also mentioned in the persona as well as her desired goals towards battery maintenance.

Figure 7.1: Persona one, picture from [92]. Figma Community Free Resource License

Figure 7.2: Persona two, picture from [92]. Figma Community Free Resource License

Another persona of Anton was constructed as in Figure 7.2 to represent individuals who aim to maintain their BEVs with minimal effort to minimise maintenance costs. Anton is a senior financial manager at Volvo Cars who is very busy and rarely refers to the manual for preserving his BEV battery. His persona reflects his belief that his current actions are sufficient to maintain the battery. This is beneficial for both himself and the company in terms of reducing maintenance costs. Time constraints and difficulty in understanding the technical aspects of his vehicle hinder him from proper car care. His primary objective is to minimise maintenance as little as possible, thereby reducing maintenance costs and easily understanding his car's conditions at a glance.

7.1.5 Scenarios

The scenarios were written in a text-based format and formulated based on the analysis results from the questionnaire encompassing background, pain points, and desired goals from the personas. Refer to Section 6.2.2.2 to read more about the process of formulating scenarios. These narrative scenarios were created to capture situations, challenges, and expectations of the personas, including their interactions with the product in various contexts.

Scenario 1: Camilla
Camilla has read the manual several times but she doesn't always remember some of the recommendations. She wants to receive more personalised guidance when she is driving, parking and charging her car that would recommend to her the best practice to slow down the battery degradation. She wants to see how her actions are affecting battery SoH. She would like to do the best she can to preserve the battery to maintain a sustainable practice and extend the vehicle's lifespan as much as possible.

Scenario 2: Anton
Anton cares about the battery but he also thinks that there are so many other things that he needs to keep track of and he needs to prioritise. He wants something simple and easy to understand that can provide him with the necessary information to assess the condition of the battery. He wants a clear reference to the state his current battery is in and quick help in case he needs to apply some changes in the future. The general overview of the battery degradation that has been happening until now will help him to see if there is anything that should be changed in his behaviour. He wants to make as few changes in his life as possible while still preserving considerably good battery health.

7.1.6 Requirement List

The requirement identification included a summary of all user needs gathered during the discover and define phases. Refer to Section 6.2.2.3 to read more about the process of establishing a requirements list. As a result, the list of requirements was derived from the literature review, expert interviews, a questionnaire, and focus groups. The requirement list was documented in the form of User Stories [35], which provided the users' needs through actions and how it will benefit them. The requirements started with a phrase: as a user, I would like to:

Table 7.1: Requirement List

No.	Requirement	Source
R1	be able to see the battery SoH information on both the infotainment screen and mobile app, so I can access it whenever I want.	[Q7], [F1], [F6]
R2	see basic SoH information for a quick overview of battery state, but also have the option to read more information about it in a sub-menu in case I need it.	[F2], [F3]
R3	have explanation of why I need to maintain the battery SoH so I can understand the implications of it.	[F2]
R4	see the reasons for my car's SoH deterioration, to be able to change its future condition.	[Q5], [F2]
R5	see a trend of my battery usage compared to the other cars that drive in similar conditions, so I can see how well I maintain the battery compared to the average of the users.	[Q4], [F2]
R6	have a list of actions which I can take to improve battery health.	[Q3], [Q5], [F2]
R7	see the recommendations in the car, because I don't check the manual.	[Q1], [Q7]
R8	receive dynamic recommendations based on the context, so it is relevant to the situation.	[Q6], [24], [F2], [F5]
R9	receive recommendations that are personalised to my driving behaviour.	[F5], [F6]
R10	receive reminders in a gentle and easy way from time to time when my actions do not follow the recommendations.	[F2], [F4]

7.2 Establishing Design Recommendations

After creating the requirement list, the benchmarking and brainstorming process for the design concept began. The outcome of the brainstorming sessions evolved into the first low-fidelity prototype of four design concepts. This section describes the steps taken to iterate the design concept, including developing, evaluating, and analysing it. The end result of this process is the development of design recommendations for a battery SoH feature for a BEV.

7.2.1 Benchmarking

The process and the execution of the benchmarking are described in Section 6.3.1, while in this sub-section the results are presented. A summary of the Battery SoH presentation and battery maintenance features in BEVs of Volvo Cars, Polestar, their competitors and non-competitors are shown in Table 7.2, Table 7.3, and Table 7.4. Within the automotive industry, a total of eleven BEVs were benchmarked during the process, namely, Volvo C40, Polestar 2, Audi Q8 e-tron, Porsche Taycan Turbo, Smart #1, Hyundai IONIQ 6, Tesla Model Y, Genesis GV60, X PENG P7 High Performance, Nissan Leaf, and BMW i3.

Table 7.2: Benchmarking of battery SoH presentation and battery maintenance features in BEVs of competitors and non-competitors in the automotive industry

Brand	**Model**	**SoH**	**Battery Maintenance Features**
Volvo Cars	C40	Not available	• Charging limit setting • Current limit setting • Charging time setting • Charging recommendations
Polestar	Polestar 2	Not available	• Charging limit setting • Current limit setting • Charging recommendations
Audi	Q8 e-tron	Not available	• Charging limit setting
Smart	# 1	Not available	• Charging mode selection
X PENG	P7	Not available	• Charging limit setting • Usage recommendations
Tesla	Model Y	Available	• Charging recommendations
Nissan	Leaf	Available	Not available
BMW	i3	Available	Not available
Porsche	Taycan Turbo	Not available	Not available
Hyundai	IONIQ 6	Not available	Not available

Brand	Model	SoH	Battery Maintenance Features
Genesis	GV60	Not available	Not available

Summary of SoH presentations in automotive industry
The items listed below are the summary from industrial benchmarking on SoH from both competitors and non-competitors of Volvo Cars.

- Only three out of nine benchmarked BEVs had SoH information displayed in vehicles.

- Tesla Model Y was the only car brand that provided SoH information in percentage as in Figure 7.3, however, the information was available only in service mode which required several steps and technical knowledge and skills to perceive the information.

- Nissan Leaf utilised a vertical twelve-block progress bar to visually represent the remaining battery capacity on the steering screen. This bar was positioned right next to the SoC indicator for easy comparison while not giving an exact numerical figure for SoH.

- BMW i3 provided the information as maximum battery capacity (Batt. Kapa. max) on the steering screen.

- Volvo C40, Polestar 2, Audi Q8 e-tron and X PENG P7 High Performance had a feature to limit battery charging levels. However, X PENG P7 High Performance provided an automatic restoration feature as in Figure 7.4 to the drivers meaning that if the limit is not 90%, it will be restored to 90% whenever the vehicle is power-on (except when the charging gun is inserted).

- Both Volvo C40 and Polestar 2 had features to limit the current for charging on the infotainment screen, however, Volvo C40 allowed drivers to set charging time additionally.

- Volvo C40, Polestar 2, Tesla Model Y and X PENG P7 High Performance provided static recommendations on the infotainment screen; Volvo C40, Polestar 2, and Tesla provided charging tips while X PENG presented recommendations for daily use, low-temperature climate, and preheat battery.

- Smart #1 allowed drivers to select changing modes; daily trip and long trip mode.

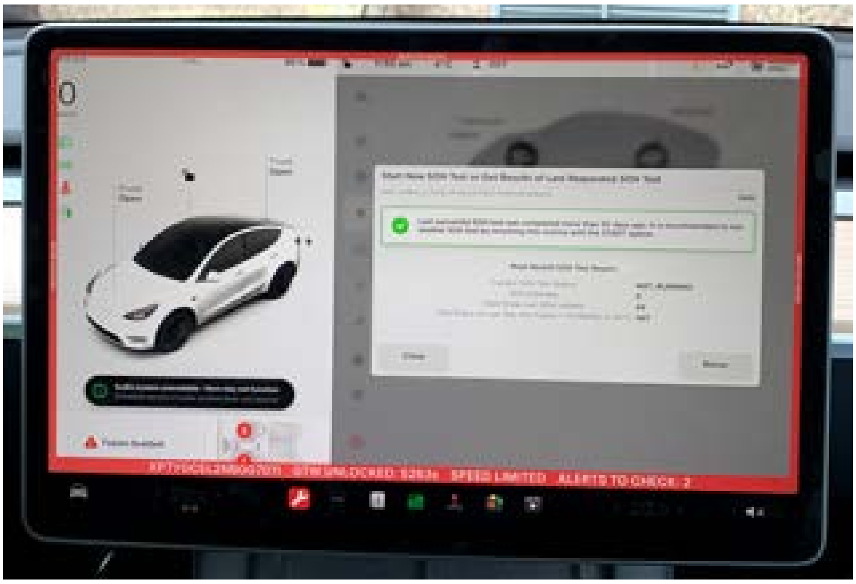


Figure 7.3: SoH test result from Tesla Model Y

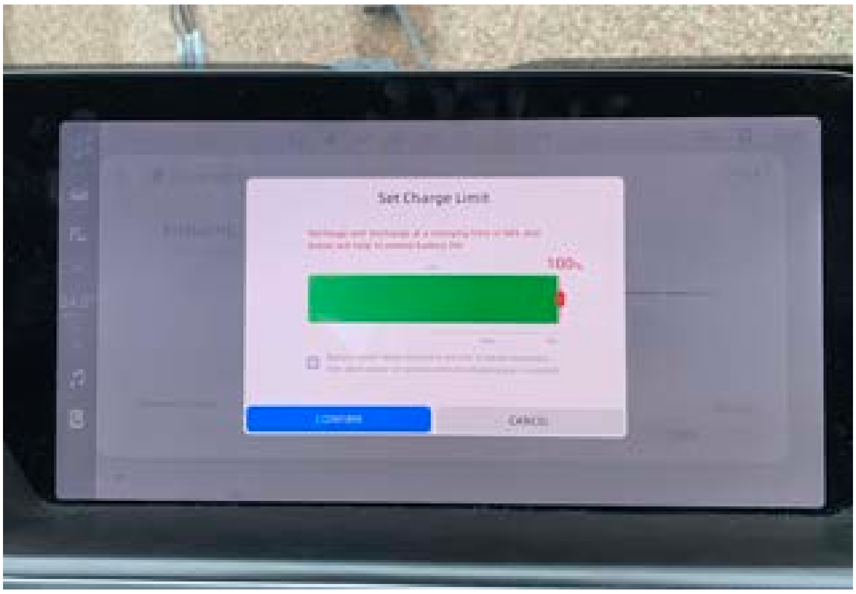


Figure 7.4: Set Charge Limit features from X PENG P7 High Performance

Apart from industrial benchmarking within the automotive industry, generic benchmarking was also conducted to investigate third-party applications that provide SoH assessment services to EV drivers. The result is shown in Table 7.3.

Table 7.3: Benchmarking of battery SoH presentation from third-party applications providing SoH assessment services

Application	**SoH Terminology**	**SoH Form of Visualisation**	**Related Information**
WattCat	Battery Health	Numeric (%) Progress bar	SoC Charging current
Car Scanner	SoH	Numeric (%)	Battery work time Odometer SoC
Dekra	State of Health (SoH)	Numeric (%) Progress bar	SoC Voltage
My Battery Health	Battery Status (SoH)	Numeric (%) Text-based (status)	Battery condition Health comparison
Recurrent	Battery Rating	Text-based (status) Progress bar	Status description
Power Check Control	Max Capacity	Numeric (%)	Odometer Average consumption

Summary of SoH presentations from third-party applications
The items listed below are the summary from generic benchmarking on third-party applications that provide battery SoH assessment services.

- The terminologies used for battery SoH are varied, however, the most common terminology is SoH.
- Five out of six benchmarked service providers displayed the SoH as a numeric value with the percentage unit.
- Half of the benchmarked service providers visualised the SoH in the format of a progress bar.
- Only two service providers provided a text-based status of the battery health.
- The most common information displayed along with SoH is SoC.
- Only one application provided battery condition compared to the general trend of EVs.

Battery has been used as a power resource for several types of electric devices and has been used greatly in the technology industry for many decades. Conducting a general benchmarking on how the SoH was displayed for many types of technology devices could be beneficial. The result is shown in Table 7.4.

Table 7.4: Benchmarking of battery SoH presentation in the technology industry

Product	**SoH Terminology**	**SoH Form of Visualisation**	**Related Information**
Apple iPhone 15	Battery Health	Numeric (%) Progress bar	Cycle count Charge current
Samsung S24 Ultra	Life	Text-based (status)	Overall status Capacity (mAh)
One Plus	Maximum capacity	Numeric (%)	Not available
Apple Watch	Maximum capacity	Numeric (%)	Not available
Microsoft laptop	Full charge capacity	Numeric (mAh)	Design capacity (mAh)
HP Support Assistant	Battery status	Text-based (status)	SoC Temperature Battery age
AccuBattery	Battery health	Numeric (%) Progress bar	SoC Estimated capacity Design capacity Charging statistics

Summary of SoH presentations from the technology industry

The items listed below are the summary from generic benchmarking in the technology industry on how to display the battery SoH.

- From the total of seven benchmarked products, four products displayed SoH information as a numeric value in percentage while three products presented the information as text-based status.
- AccuBattery visualised the battery health using a progress bar as a visualisation with the percentage.

- Five out of six products provided more information in addition to the battery health. The most common information displayed with the SoH is battery capacity.

Key takeaways from benchmarking
The items below from B1-B5 are the key conclusions from industrial benchmarking in the automotive sector and generic benchmarking in the third-party application and technology industry on how the SoH were displayed.

B1: Only one brand provided battery SoH information in percentage
Overall, only BEVs from Tesla provided SoH information in percentage as in Figure 7.3, while Nissan Leaf used progress bars and BMW i3 used maximum battery capacity figures as visualisations for SoH.

B2: Additional features were provided for battery maintenance
Many brands including Volvo Cars and Polestar provide additional features for battery maintenance, such as charging limit settings and charging mode selection, to help users maintain their BEV's battery conditions.

B3: Text-based recommendations were provided as guidance
Static recommendations were provided in text-based formats, guiding the users to take better care of their BEV's battery.

B4: Percentage, progress bar, and battery status were commonly used for presenting SoH
Several products and applications from generic benchmarking presented SoH as a numeric percentage and used progress bars as the primary visualisation method. Additionally, text-based battery status descriptions are generally provided to the users to have a clear understanding of battery health.

B5: Additional information was often provided to enhance users' understanding
Additional information such as battery capacity, age, and cycle is often provided to enhance users' understanding regarding battery management and usage.

7.2.2 Iteration 1: Takeaways

The first usability testing was conducted to collect both quantitative and qualitative data to assess how the users perceived the information and if more information was useful to the users. The process of the development, evaluation and analysis of the low-fidelity prototype is presented in Section 6.3.3. The results of the usability test of the first iteration are summarised in this chapter.

Regarding the quantitative data, the scores from the questionnaire's Likert scales are shown in Table 7.5. The results indicated that simplicity was consistently maintained throughout the tasks with high ratings of 4.7 out of 5 on average. All information shown on the battery health overview screen was highly relevant and could support each other with an average of 4.9 out of 5. The participants perceived it as more personalised when information was tailored to their driving behaviour (5 out of 5 for task 3). The scores for clarity and understandability were slightly dropped on the third task to 4 and 4.2 respectively. These were because the phase of recommendations inside the personalised tips was unclear and could be misleading. With more information provided on later tasks, the participants perceived it as useful and helpful for them to understand SoH (4.8 out of 5). Moreover, the results indicated that the six-month notification was well-designed and met user needs, expectations, and preferences, with high ratings of 5 for simplicity, personalisation, clarity, understandability, usefulness, and helpfulness.

Table 7.5: Scores from questionnaire's Likert scale

Assessment	**Battery health overview**			**Notification**
	Task 1	**Task 2**	**Task 3**	**Task 4**
Simple	4.8	4.8	4.6	5
Relevant	5	4.8	5	4.8
Personalised	3.4	4.6	5	5
Clear	4.8	4.8	4	5
Organised	4.2	4.8	4.6	4.6
Understandable	4.4	4.8	4.2	5
Useful	4.8	4.8	4.8	5
Helpful	4.6	4.6	4.8	5

From the interviews, most of the participants stated that only the percentage of battery health was not sufficient to understand the information and not encourage them to take action to preserve their battery. For battery health, a percentage figure with a progress bar was clear to understand the battery SoH. However, the status of the battery, for example, normal status, was misunderstood by some users. More explanation and clarification were required in this section. For additional information, the participants also stated that they are likely to take action to slow down battery degradation when they see the speed of degradation. They also suggested including historical data and visualisation for comparison, i.e., showing the data which can be compared with the previous six-month analysis. Apart from SoH information, the participants provided feedback regarding the recommendations in the personalised tips that the wording required to be revised for better understanding. A notification with a period of six months was considered optimal frequency for a reminder of SoH analysis.

The key findings and suggestions from the first usability testing were outlined for further improvement. These conclusions helped further explore and confirm the research questions and predictions regarding battery SoH design recommendations and are listed below.

EV1-1: The percentage of the battery health alone was not sufficient
The results from the usability test confirmed that the participants found that the percentage of battery health alone was not sufficient to understand and take action to preserve battery health. Including the speed of degradation together with the tips was useful and motivated drivers to take action with an average score of 4.8 out of 5. Participants also confirmed that only battery percentage does not help them understand the overall state of their cars battery and instead creates general stress due to not knowing the reason for the degradation.

> *"Now I have some more information that it's clearer to me why I have degraded battery to 98% because I am at high speed of degradation level here."* - P5

EV1-2: The use of a progress bar was clear and could enhance understanding of battery SoH
The use of percentage with a progress bar was clear and easy to understand the battery SoH with the high average score of 4.7, although the display of the battery status, i.e., normal, needs a more explicit explanation to avoid confusion.

> *"One could colour the progress bar maybe in green, then that would be simpler because then I would get to pieces of information the same. "* - P4

> *"What is normal? Yeah. Is that 100%, or is it normal degradation speed or what is normal?"* - P5

EV1-3: The users were empowered and felt proactive to take action when they saw the degradation speed and tips
It was confirmed that once the degradation speed and the tips were listed, the users were empowered and felt proactive to take action. Typically, the understanding of battery health was improved once the degradation speed and tips for improving the battery were added. However, some wording needs to be revised for better understanding since the average scores for clarity and understandability were slightly decreased from task number 2 to 3, reaching 4 and 4.2 respectively. In addition to personalised recommendations, general recommendations about battery maintenance were also appreciated by the drivers. However, the visibility of the button for general recommendations should be reconsidered in order to improve its visibility.

> *"I would like to understand why it's high. What have I done wrong or what should I do?"* - P2

> *"Here I see that degradation is quick compared to others, definitely, then I would probably start thinking of how to handle the car."* - P3

> *"Very likely to take action, because if I have a high speed of degradation here I have to do something. I would like to know how do I get down to lower speed of degradation. So I would probably act according to these personalised tips."* - P5

EV1-4: Historical data is considered advantageous and should be shown as additional information
Although the degradation speed presents a clear assessment of the battery for the past six months, the drivers also expressed a desire to see historical data in order to compare their battery degradation and predict its future state. Therefore it would be beneficial to present historic data for the driver to have a general overview but also to predict the future state of the battery. Several drivers (P2, P3 and P5) suggested a graphical representation of the vehicles lifetime. The historical data is adequate to be shown as additional information since not all the drivers considered it crucial to their understanding of the status of battery health.

> *"I know it will degrade, but how much and how the curve looks like, I really don't know. [...] More in the beginning and then it flattens out or less in the beginning and then it's steeper. [...] The historical data would be very interesting to know, definitely. [...] If you can predict it accurately then I would be interested to see. "* - P3

> *"I'm a data person, so maybe a graph would be nice. A graph that represents the battery health percentage, like the X-axis is time, and the Y-axis is percentage. That enables me to also extrapolate. Like two years down the line, what will my battery health be? If it's the same as it was."* - P4

EV1-5: SoH information should be available across devices or platforms, especially on a mobile application.
Several users expressed their interest in seeing the battery SoH information on their mobile application when they are outside of the car, even though the user test had a focus on the in-car display only. This confirms previous research regarding the need for cross-device availability for the drivers.

> *"Prefer to have it in the app rather than in the car. [...] The app is easy to have a look at when you're done with everything you have to do."* - P1

> *"Actually, my brother has a Tesla and he had downloaded an app where he could look at his battery health. but it was also good to understand it from there."* - P3

EV1-6: six-month is an appropriate frequency for battery health notification
Additionally, participants confirmed that a six-month notification of battery health is an appropriate frequency for receiving updates on the current battery state of health, and they would prefer to receive a reminder from time to time.

> *"I think the frequency is fine. I guess if it is every six months, it's not too often."* - P1

> *"Good that I'm reminded that I haven't seen or looked into this battery health for a long time and report for my battery."* - P2

> *"Every six months, it's probably a good idea."* - P3

7.2.3 Iteration 2: Takeaways

The second iteration of the prototype introduces more changes to the design concept based on the feedback provided by the participants from the previous usability study. The process of the development, evaluation and analysis of the semi-functional prototype is presented in Section 6.3.5. The results of the usability test of the second iteration are summarised in this chapter.

The results from the questionnaire, which summarise how the participants perceive the information displayed can be seen in Table 7.6. Overall, the satisfaction is considerably high, which is located between 4.2 and 4.6 out of 5. The highest score was for the questions about whether the information was enough and visually attractive, scoring 4.6. Participants also rated the information provided on battery health as useful and helpful, with a score of 4.4. The lowest score was for clarity and ease of understanding, which was rated as 4.2 on average. This is due to some misunderstandings during the evaluation of the prototype.

Table 7.6: Scores from questionnaire's Likert scale - Evaluation 2

Question	**Average Score**
The information provided was **enough** in understanding battery health.	4.6
The information provided was **clear** in understanding battery health.	4.2
The information provided was **useful** in understanding battery health.	4.4
The information provided was **helpful** in preserving battery health.	4.4
The overall battery condition was **easy** to understand.	4.2
The information and visualisation were **visually attractive**.	4.6

The takeaways from the evaluation of the semi-functional prototype are summarised below:

EV2-1: The battery status is clearly and easily understood based on the information provided.
The percentage, combined with the percentage bar, provides a clear overview of the current battery status. The visual representation is also helpful in understanding the scale. Users also appreciate the additional information regarding the status of the battery.

> *"Its quite simple, but it helps me to understand it clearly. The graphic was helpful in understanding the scale."* - P1

> *"Good to have both percent and where in the state I am. It's good to put it in three categories: good, bad or worse. Information part is appreciated if I need to know more."* - P3

EV2-2: Users preferred a colour-coded representation of the battery's health status
The colour-coded representation of the battery's health status, allowed them to better understand the visualisation. Orange was mentioned as a better choice for the 'fair' status because the red would be too worrying.

> *"The colour coding is pleasant... Orange is better than red."* - P2

EV2-3: The degradation speed provides valuable information to users
The degradation speed allows users to better understand the battery's current state. The percentage is supplemented with the degradation speed, which provides more detailed information about the battery's current state and elicits users to take action if necessary to keep the battery healthy.

> *"I see 98% so my car seems to be okay, but I have a high degradation speed, very interesting. The degradation speed worries me, I need to understand what should I do to improve it."* - P4

EV2-4: The visualisation of the degradation speed is beneficial
The visualisation of the degradation speed in the form of a gauge chart helps users notice and understand the battery's health better. It appears to be intuitive and easily distinguishable from the SoH progress bar.

> *"It's very intuitive and quite good that this one is a gauge - I think it's visually good for the eye that they are different."* - P2

EV2-5: The display of the degradation speed did not align with the expectations of several users.
There was some confusion about how the degradation speed is displayed, as the orientation and colours did not meet the user's expectations. Users expected the positive side to be on the right, similar to the previous progress bar. When later discussed, the participants understood that it was a speedometer and that the 'high' speed was supposed to be on the right side, but it was not aligned with the previous visualisation, which caused confusion.

> *"It was confusing because they are changed, I would expect it to be the other way around. But now I understand it and I see the colours as well, that they match."* - P1

> *"I would have it mirrored: the good part is often on the right, and it's not aligned with the previous part."* - P3

EV2-6: The history is helpful in expanding the users' interest and knowledge, but it is not always required
When the participants examined the degradation history, they found it interesting

and received a clear overview of the degradation speed; however, not everyone found it relevant due to the state of their current battery. It was stated that it would be more beneficial to look at only if there is a significant change in their degradation.

> *"It's clear that it says normal - I understand it like it's not a major issue and I follow the normal phase of degradation."* - P3

> *"If I am on the green side I am not that interested in knowing how it is measured, maybe if I was on the poor side I would be more interested in knowing these details."* - P1

> *"Maybe I wouldn't look at it a lot, but I think it's useful. Since it's so linear, if there is a huge change it would be interesting to understand what has happened."* - P4

EV2-7: It was not clear to all the users that the degradation history contained the expected normal degradation of the battery and the future prediction in the graph
Although some participants didn't have any difficulties understanding the graph and that the green boundary represents the expected normal degradation, together with the prediction, it was not unanimous. Two users didn't understand that the green colour was representing the expected normal degradation of the battery. Moreover, two users didn't notice that the history graph contained predictions.

> *"The green 'Normal' is the evaluation of the degradation speed - and I fall within the normal boundaries. The prediction is visually clear as well. My question would be why does it happen, but it would make sense if I fast charge every week. But there is no need to add anything else to understand it better."* - P2

> *"Degradation history is very interesting. I did not see what the green part is until I read what green is."* - P3

> *"I didn't see that there was a prediction, but it would be nice to see when the prediction ends."* - P5

EV2-8: Personalised tips and being able to see the reasons for the degradation was a fundamental requirement among all the participants
Participants emphasised the importance of personalised tips and understanding the causes of battery degradation. They found it beneficial to receive recommendations on how to improve their batteries. In some cases, as soon as the participants saw the battery status or degradation speed, they were already wondering how to change it or what went wrong. As a result, it is critical to provide personalised tips on the same page as degradation speed data, allowing users to see a call to action as soon as possible.

> *"Perfect, this is what I want, I need to know what I can do to improve it."* - P3

> *"Very straightforward - it would be interesting to get all this information in my own car when it is based on my driving behaviour."* - P2

> *"I can see that my degradation health is close to high, I want to know what I can do."* - P1

EV2-9: It was not clear to all the users that the personalised tips were customised for them specifically
Some users were unaware that the personalised tips were based on their driving behaviour and indicated which factors were above average. The reason for this was the wording of the title, as 'personalised' is not interpreted as being tailored to the users specifically. Another reason was that the personalised tips were displayed in a separate block, leading users to believe that they were unrelated.

> *"I can see that those two things are different: it is two different blocks so I didnt connect them together."* - P3

> *"It should be more clear that it was calculated based on your driving behaviour. It says it's personalised, but I still don't understand it. [...] When I read personalised tips, I don't think its for me."* - P4

EV2-10: General recommendations were found to be useful
The participants appreciated the general recommendations because they helped them understand what factors could affect the battery. One participant requested that the list be organised by the effect it has on the car, demonstrating that the personalised tips were not as clear as intended.

> *"I find it helpful to find all the access to the recommendations."* - P2

> *"I find it very useful to see all recommendations - to improve it more. It would be nice to get a score, based on my car history."* - P4

EV2-11: Some users expressed a desire to be able to access this feature from both the car and their phones
Although users found the information about battery health useful when displayed in the car, they expressed a desire to have it available on their phones as well. This would allow them to view the recommendations outside of the car when it is most convenient for them.

> *"Some recommendations like preconditioning should be in the app, not in the car, or when it sort of applies."* - P5

> *"It would be good to have it on the phone as well. I think having it on the car screen is very useful."* - P3

7.2.4 Iteration 3: Takeaways

The third iteration of the prototype introduces small refinements based on the feedback provided by the participants from the previous usability study. The process of the development, evaluation and analysis of the refined semi-functional prototype is presented in Section 6.3.6. The results of the usability test of the third iteration are summarised in this chapter.

The last usability testing was conducted to check if the refined prototype met the users' requirements and to confirm the design recommendations that became clearer after the second evaluation. Participants had some time to explore the third prototype and then were asked to fill in the questionnaire in which they had to rate the design on a Likert scale from 1-5 and motivate their decisions. See Table 7.7 from the questionnaire's Likert scale from the third evaluation.

Table 7.7: Scores from questionnaire's Likert scale - Evaluation 3

Q	**Statement**	**Average Score**
1	Based on the screen I have explored, I prefer battery health information to be displayed on the infotainment screen.	3.8
2	I think that the information I have seen about battery health should be available on multiple platforms, such as an infotainment screen and mobile application.	4.4
3	I think the additional information contained within the information button helps me understand the overall battery health status.	4.2
4	I find it important to include the reason why I should maintain the battery health, which is located within the information button.	4.0
5	Looking at the information provided, it is well-organised for both overview and expandable view.	4.4
6	I find it useful that the information includes a visual representation, such as a graph or a chart, to help me understand the content better.	4.6
7	I find it useful to compare my battery health to the overall expected degradation trend.	4.4
8	I find it useful that the recommended actions are tailored to my driving behaviour.	4.5
9	The recommended actions are clear and will help me maintain the health of my battery.	4.4
10	I find it useful to have historical data and predictions about my battery degradation.	4.6
11	I do not mind receiving periodic notifications about my battery health.	3.4

Q	Statement	Average Score
12	I find it useful to have general recommendations as a reference.	4.4

The takeaways from the evaluation of the refined semi-functional prototype are summarised below:

EV3-1: The users would like to see the SoH information on both the in-vehicle infotainment screen and mobile application
Based on the average score of 3.8 out of 5 [Q1] as shown in Table 7.7, the result indicated that there is a moderate level of preference for having the SoH information on the infotainment screen. With the average score of 4.4 [Q2] in Table 7.7, it could confirm that the SoH information should be available on multiple platforms both the in-vehicle infotainment screen and mobile application. Some participants mentioned that they would like to access the information when they are not inside the car.

> *"If available through to me via mobile, I would prefer that because then I can take my time to read it and etcetera. Still, I would have liked to find it in the car. [...] In my opinion, super valuable to have it on infotainment, but I would have preferred it to be sent to me via or across the app."* - P2

> *"I think it should be available on multiple platforms and mobile applications. [...] I would like to check the battery without needing to step into the car. I would like to explore that like from home or whatever so I don't end up in a situation with my kids in the car and something happens with the battery."* - P5

EV3-2: Informative explanation about the reason why the users should preserve their battery health was beneficial
With a score of 4.2 out of 5 [Q3] in Table 7.7, it shows that more information was required to understand battery SoH. Some users found it important and beneficial to have the reason why they should maintain battery health, although a user mentioned that they do not need it due to having a solid background and knowledge of the topic.

> *"Definitely, it helps me understand how it was, how the conclusion was reached. [...] I don't fully understand how the battery health affects the range so it's interesting to see."* - P2

> *"The problem is that I have a background in propulsion. I would never go into those anyhow, but I think it should be there from a product perspective. [...] I think it's really important to have that information about the reason why I should maintain the battery here. It is important as this is a new technology as of now."* - P3

EV3-3: The expected degradation trend with prediction were useful to

the users for comparison and assessment
The user found it useful to see the degradation trend since it can be used as a reference and proof that there is something wrong with the battery compared to the other car's battery health in general (rated as 4.4 out of 5 [Q7] in Table 7.7). The users also mentioned that providing the historical data with the prediction was extremely useful with a high rating of 4.6 out of 5 [Q10] (Table 7.7), especially for the second users who would like to buy a second-handed car as it could indicate when the degradation has worsened.

> *"Because I want to know if there is something wrong. To get some reassurance that is expected. It's very useful, it's super useful."* - P1

> *"Prediction there is great and you know just showing it on the graph and etc. makes a lot of sense, so I strongly agree."* - P2

> *"Especially if you buy a used car, this will be what people will go in and look at, that's for sure. So it's useful."* - P4

EV3-4: Additional information was organised nicely in both overview and expandable view
With a high rating at 4.2 [Q3] as shown in Table 7.7, it could be concluded that additional information could enhance users' understanding of overall battery health status. Many users also mentioned that the information amount was appropriate, easy, well-structured, organised, and understandable by several groups of users.

> *"I think I can find the information easily. It is not overwhelming and it is well kind of a divided."* - P2

> *"This is really good to me. It's simple. I understand it even though I'm not an IT or computer guy. Even my parents-in-law and my mother and father would probably understand this."* - P4

EV3-5: Using visualisation could enhance the user's understanding about SoH.
Apart from the content, using visualisation in addition to the text-based information provides a better context and understanding to the users. Visualisation of the design concept was also rated as high usefulness with an average score of 4.6 out of 5 [Q6] in Table 7.7, as it provides clearer insights regarding battery SoH.

> *"It gives a better context. I feel that I get a more complete understanding. So in that context, it helps me."* - P1

> *" It's always easier to see something with a graph or chart. Let's say even a drawing is mostly, it's easier to understand than just text, and it's visualised in a very good way."* - P4

EV3-6: Recommended actions were clear, relevant, and tailored to my driving behaviour.
Refer to Table 7.7, an average score was highly rated at 4.5 out of 5 [Q8], indicating that the users preferred to have a list of recommended actions that are tailored to their driving behaviour so that they can follow them easily. Apart from personalisa-

tion, the users would like the actions to be more explicit. They suggested revising some wording for the recommended actions for a better understanding.

> *"You always need to know what to improve and where can improve. Definitely, it should be connected like that."* - P4

> *"I think they were quite clear. [...] The wording there is that it should charge up to 90%, but it should be no higher than 90%."* - P1

EV3-7: General recommendations could be used as reference.
As shown in Table 7.7, most of the users stated that a list of general recommendations for battery health preservation was useful (4.4 out of 5) [Q12] and suggested that it should be easily accessible in a place. A user mentioned that many users did not read the manual on the website, which highlights that the recommendations should be available in a location where they can be easily accessed, and the user found it more useful to have it on the car than on the manual online.

> *"I think this type of information should be available for every customer to be honest to read through when the car is new. You should have all the information about battery health in one place. [...] Absolutely, no one reads the manuals. We already know that the only one who reads the manuals is sort of the one who develops those."* - P4

> *"I've heard stuff, but I don't know and don't work with electric vehicles. I assume the normal vehicle buyer doesn't either. So it's useful to know."* - P1

EV3-8: the users found it useful to receive periodic notifications about battery health, however, further study is required for the frequency of the notifications
While several participants expressed willingness to receive notifications about battery health periodically, some users preferred to receive the notification only when battery health was not as expected or after 3-4 years. Additionally, A user would like it to be configurable based on preference. Regarding these discrepancies in the frequency, the average score [Q11] was relatively low (3.4 out of 5) compared to the other average scores. Refer to Table 7.7 for reference. To derive a proper solution or optimal frequency of the notification, a study should be conducted to investigate further.

> *"I think that it will be important in the future or it already is important, but I don't think that all people understand that when buying a used car. I would like to have this information, yes."* - P4

> *"I think I would only want the notification when something is unexpected."* - P1

> *"If it's configurable, I like it. Otherwise, I don't want it. [...] I think it's more of interest after 3-4 years."* - P3

7.2.5 Design Recommendations

The design recommendations as shown in Table 7.8 are suggestions of how a BEV's battery health should be designed for the in-vehicle display. These recommendations emerged throughout the iterative design process by designing and continuously evaluating the design concept. This helped to better understand and formulate the guidelines that should be followed to create a more user-centred design for the battery SoH feature inside BEV. See Section 6.4.1 of the process and execution for establishing the design recommendations.

Table 7.8: Design Recommendations

No.	Design Recommendations	Description	Source
Display of SoH information			
DR1	SoH information on the infotainment screen	SoH information should be provided on the in-vehicle infotainment screen display, ensuring that the information is accessible at user's convenience and not distracting them during driving.	[Q7], [F1]
DR2	Available both on in-vehicle screen and mobile application	SoH information should be available both on the in-vehicle infotainment screen and mobile application, allowing the users to access the information at their convenience whether they are inside or outside the car.	[F1], [EV1-5], [EV2-11], [EV3-1]
DR3	Implement proactive battery health notifications	Proactive notifications regarding battery health status and analysis should be periodically provided to the users, reminding them of the current battery health status as well as promoting awareness on battery health	[F4], [EV1-6], [E3-8]
More information about SoH			
DR4	Include expected degradation trend for comparison	In addition to the current battery degradation, the expected degradation trend of the vehicles in similar conditions should be provided for better comparison and assessment as well as motivating the users to engage in battery maintenance practices.	[Q4], [F2], [EV1-1], [EV1-3], [EV2-3], [EV3-3]

No.	Design Recommendations	Description	Source
DR5	Provide additional explanation regarding SoH information	Apart from the percentage figure of battery health, explaining the importance of the battery health maintenance and cause of deterioration is considered beneficial to the users since it can enhance user understanding about battery health as well as encourage more battery maintenance.	[F2], [EV3-2]
DR6	Present clear and actionable tips	Presenting clear and actionable tips for battery health preservation directly on the infotainment screen can enhance accessibility and empower the users to take actions to preserve battery health proactively.	[Q1], [Q5], [F2], [EV1-1], [EV1-3], [EV2-8]
DR7	Offer historical data and prediction	Offering historical data and prediction of battery health to the users is considered useful, allowing the users to have a general overview of the battery health over time of usage and in the recent future. The information helps the users to anticipate their battery status better, assess the potential issues, and manage their battery health proactively.	[EV1-4], [EV2-6], [EV3-3]
Visualisation of the SoH information			
DR8	Present the SoH information with visual explanatory	Visualisation methods, such as illustrations, charts, and graphs, should be employed to visualise the SoH information. Using these techniques can enhance user perception and understanding of the information.	[F3], [B4], [EV1-2], [EV2-1], [EV2-2], [EV2-4], [EV3-5]

No.	Design Recommendations	Description	Source
DR9	Organise additional and detailed information in an expandable view	This detailed information can provide knowledge and enhance user understanding regarding battery SoH. Offering the main information upfront on the overview screen and detailed information on the expandable view (submenu) can contribute to a user-friendly and easily understandable screen, providing a positive user experience to users.	[F3], [B5], [EV3-4]
DR10	Tailor the SoH information to the user's driving behaviour	The information presented should be tailored or personalised to the user's behaviour, ensuring that only relevant and useful information is provided to the users.	[F5], [EV3-6]
Recommendations			
DR11	Provide general recommendations as reference	General recommendations regarding battery health should be provided inside the vehicle as a reference, enabling easy access to the recommendations and encouraging the users to follow the best practices for battery preservation.	[Q1], [B3], [EV2-10], [EV3-7]

7.2.5.1 Display of SoH Information

The following design recommendations are proposed as suggestions for the platforms or channels to display SoH information. These recommendations aim to enhance the user's understanding and experience when they perceive the SoH information. By presenting on both the infotainment screen and mobile application, the users can efficiently access the information at their convenience. Moreover, with proactive battery health notifications, the users will get reminders about battery health status. Through these recommendations, the users will be able to access the SoH information conveniently, which can truly enhance the overall user experience about the battery health of the BEV.

DR1: SoH information on the infotainment screen
In the context of being inside the vehicle, it is evident that the users prefer to receive the SoH information on the infotainment screen rather than the steering screen. This preference comes from the fact that the infotainment screen has a larger screen size, allowing the user to perceive the SoH information in a more comprehensive and user-friendly way. This information should be available on the infotainment screen since

it is not distracting them while driving ensuring their safety and more convenient user experience [Q7], [F1].

DR2: Available both on in-vehicle screen and mobile application
Regarding the availability of SoH, it becomes apparent that the users prefer to access the SoH information from multiple platforms including the in-vehicle infotainment screen and through a mobile application. The evidence comes from users' desires that they would like to access this information at their convenience and according to their preference, especially when they are outside the vehicle [F1], [EV1-5], [EV2-11], [EV3-1]. As a result, having the SoH information available through multiple platforms, both in the vehicle and mobile application, can benefit the users in terms of accessibility and flexibility.

DR3: Implement proactive battery health notifications
Proactive notifications about battery health are considered useful from the user's perspective since they notify the users about the current status of their battery health. Apart from notifying the current battery health status, they also serve as reminders reminding the users to maintain awareness of battery health. Despite a group of users indicating their preference that they would like to receive this type of notification periodically in a six-month timeframe [EV1-6], another group of users prefer to be notified only when the battery deterioration is worse than expected, i.e., high degradation [F4], [E3-8]. Regarding these discrepancies in the notification frequency, a study should be conducted further to investigate a proper solution or optimal frequency that can accommodate diverse needs and preferences.

7.2.5.2 More Information about SoH

A list of design recommendations offered insightful, supportive, and extensive information that the users found useful and helpful when presented along with the percentage of battery health. These recommendations provide not only informative details and explanations which help enhance the user's understanding of the battery SoH but also additional information to encourage battery health maintenance, such as degradation trends, clear actions, as well as history and prediction to preserve the battery.

DR4: Include expected degradation trend for comparison
Referring to the insights from the questionnaire, focus groups, and usability tests, it is evident that an expected degradation trend is essential and beneficial for comparison. The result from the questionnaire [Q4] revealed that the users feel discouraged about battery maintenance due to the lack of a baseline for assessing the impact of their actions. Additionally, the users expressed their needs regarding the trend of their battery health compared to other users who have similar driving conditions in the focus groups [F2] and the first usability test [EV1-1]. Not to mention the feedback from the same usability test, the users felt proactive to take action when they saw the degradation speed compared to the other [EV1-3], indicating that this information does not only enhance the user understanding but also encourage them to preserve their battery better [EV2-3]. The users also found it useful to have an expected degradation trend since it could be used as a reference and proof in the case

that potential issues happen to their battery [EV3-3]. Therefore, an expected degradation trend should be provided along with the SoH percentage figure to enhance a better understanding of battery health, serve as a reference for better assessment, and encourage the users to take better care of their battery.

DR5: Provide additional explanation regarding SoH information
Apart from the percentage figure of battery health, explaining the importance of battery health maintenance and the cause of deterioration is considered beneficial to the users. The information regarding the importance of battery health maintenance can answer the question of why the rest of the information matters and why they should continue following the information over the time of their usage [EV3-2]. In addition, the cause of deterioration was reported as beneficial to perceive along with the SoH percentage figure [F2], [EV1-1]. Therefore, displaying the necessity of battery health maintenance and the cause of deterioration along SoH percentage figure will be valuable for the users in multiple ways, not only enhancing user understanding of battery health but also encouraging more battery maintenance over time.

DR6: Present clear and actionable tips
Providing an expected degradation trend and additional explanations regarding battery health can effectively encourage users to take care of battery health. To facilitate the users to take better care of the battery health. However, to further support the users regarding the best practices, a list of tips should be provided to serve as guidance for maintaining battery health practically. This information was derived from multiple sources. One of the findings from the questionnaire revealed that only half of the respondents read the manual on the website [Q1], however, they would likely take actions more if they were properly notified or informed [Q5]. This was emphasised by many participants from focus groups and the first usability test that a list of actions for battery preservation would be beneficial for them rather than seeing only the percentage of battery health [F2], [EV1-1]. The list of actions should also be personalised or tailored based on user behaviour, ensuring that only relevant and useful information is presented to the users [EV2-8]. Rather than that, they prefer a list of actions to be displayed on the same screen as degradation history since the combination of both can improve user understanding of battery health and encourage them to take action to preserve their battery [EV1-3].

DR7: Offer historical data and prediction
According to the results from various usability tests, it is suggested to offer historical data and predictions of battery health in addition to the main SoH information. Offering historical data and prediction of battery health is considered advantageous to the users, especially for the second users who would like to buy a second-handed car, since it allows them to have a general overview of battery health over time and the direction of the degradation in the upcoming future [EV3-3]. While many participants mentioned that it is interesting to see historical data and prediction for comparison [EV1-4], some users stated that this information is not required and it is sufficient to be located in one layer down or sub-menu from the main screen [EV2-6]. Therefore, presenting battery health history and prediction is useful, but should rather be placed inside a sub-menu for individuals who are interested in monitoring

the battery health over time.

7.2.5.3 Visualisation of SoH Information

The following recommendations are designed to enhance the presentation of battery SoH information inside the BEVs. This list proposes strategies to effectively display SoH data, including utilising visualisation, organising into an overview and expandable view, as well as personalising the information based on user's behaviour. With these design recommendations, the goals of effectively conveying SoH information, enhancing the user's interpretation and understanding, as well as user experience will be achieved.

DR8: Present the SoH information with visual explanatory
It becomes apparent that visualisation plays a vital role in presenting the SoH information. Incorporating visual explanatory elements, such as illustrations, charts, and graphs, as part of the SoH information was highly recommended and rated by the majority of the users [F3]. Utilising visualisation techniques not only enhances user perception and understanding but also increases the clarity of the SoH information [B4]. An obvious example is the usage of a progress bar along with text-based information to illustrate battery health percentage and status. The user confirmed that it is clearer and easier to understand from their perspective [EV1-2], [EV2-1]. In addition to the form of visualisation, colour coding of the visualisation was preferred by multiple users since it enhances the user's perception, interpretation, and understanding of the presented information [EV2-2]. Apart from the progress bar, the gauge chart for visualising degradation speed was also mentioned as well-represented, providing clear insights about degradation to the users [EV2-4]. Moreover, according to the feedback from the third evaluation, the users highlighted that visualisation is highly important since it provides better context as well as enhances their understanding of the SoH information [EV3-5]. Therefore, it is essential to include visually explanatory elements at an optimal level in the design concept to ensure that the SoH information will be easily accessible and understandable to the users.

DR9: Organise additional and detailed information in an expandable view

The key information should be presented upfront while the detailed and supplementary information is preferred to be displayed in an expandable view. As mentioned by multiple users in the focus groups [F3], they prefer the SoH information to be arranged into two layers: overview and expandable view, since it can create a user-friendly and easily understandable screen which provides a positive user experience to them. Similar to the feedback from the third evaluation [EV3-4], participants indicated that well-organised structures and an appropriate amount of supplementary information can enhance their understanding of overall battery health conditions. The detailed and supplementary information is considered essential since it can provide better context, knowledge, and understanding regarding SoH. Additional information to enhance users' understanding was also common among competitors and non-competitors in technology industries, and this was confirmed against benchmarking [B5]. Therefore, this approach of displaying and organising the information ensures that the users can easily access and understand the SoH information at a glance while having an alternative to read more detailed information if preferred.

DR10: Tailor the SoH information to the users driving behaviour
To ensure high user satisfaction with the SoH feature, it is recommended to tailor or personalise the information to the user's behaviour. As mentioned in the focus groups [F5], the users preferred the information to be particularly adjusted based on their behaviour. Additionally, the users responded positively to the list of actions that were tailored based on their previous behaviour, as indicated by high average scores from the last evaluation [EV3-6]. With personalisation, the users stated that they can easily follow the tips for battery maintenance. Therefore, this particular approach can ensure that only relevant and useful information is delivered to the users, based on their style, behaviour, and preference.

7.2.5.4 Recommendations

Regarding recommendations for battery maintenance, a suggestion of providing general recommendations inside BEV is proposed, serving as a reference for the users as well as providing easy access to the information. With this approach, the users are well-equipped with essential guidance for battery maintenance, which can enhance the overall user experience with the BEVs.

DR11: Provide general recommendations as reference
To facilitate the users in preserving their batteries, a list of general recommendations regarding battery maintenance is suggested to be provided as a reference. According to the findings from the questionnaire [Q1], the result revealed that nearly 50% of the users never accessed the manual on the website. With this regard, having a set of general recommendations available on the infotainment screen inside the car is considered useful. It also appears to be common to provide static recommendations regarding battery maintenance practices inside the vehicle, as benchmarking from the competitors in the automotive industry [B3]. By including the list of recommendations in the design concept, the users found it more easily accessible than provided on the website, and it helpful for them to understand the factors that can potentially affect their battery health [EV2-10], [EV3-7].

8

Discussion and Conclusion

This chapter discusses several aspects of this thesis, starting with the work process and execution and then discussing the research findings. It also outlines the limitations and challenges encountered, as well as ethical considerations and future work. The chapter ends with the conclusion of this thesis.

8.1 Discussion

The discussion section reflects on the work process, research findings, and the limitations and challenges faced during the project. Ethical considerations and future work are also discussed.

8.1.1 Work Process

The study on the battery SoH feature for EVs was a clear example of a wicked problem [31] for several reasons. First and foremost, the battery health of a BEV is not a well-known concept nowadays, and the consequences of battery degradation are poorly understood by the general public, given that BEVs is a relatively new trend. Previous studies have highlighted users' difficulties in understanding EV-specific information in the driver interfaces [26], [27]. Furthermore, there were few use cases and previous research on the subject, as well as no user-centric references to serve as examples and guidance. As a result, it was challenging to display a new feature in the car, which is still in the research and innovation process, combined with the end user, who does not have a clear general idea about the necessity and usage of that feature.

When it comes to the various interaction design approaches used in this thesis, the research through design approach was ideal for a novel design concept of battery SoH, as there was little previous research available, and it was needed to research the topic from different perspectives. It was possible to narrow down the potential solution to this wicked problem by designing and receiving critiques of the proposed design concept (based on usability testing). This user-centred design study involved the user throughout the entirety of the design process. Involving users throughout the design process was critical, as different evaluations revealed broader perspectives on the topic.

When reflecting on the methods used in the design process, some methods were more beneficial than others. Since it was a wicked problem with many stakeholders and uncertainties involved, a lot of time was spent reviewing the literature and confirming the gathered data with the experts. The expert interviews were helpful in confirming insights from the literature review and learning more details from the technical perspective. Being able to talk to experts in an unstructured interview allowed us to establish more common ground on the topic. However, this method also added additional difficulties in framing the research problem. The topic is complex and uncertain, but the received information was mainly from a technical standpoint, so the technical feasibility was prioritised over the design during the interviews. Benchmarking was expected to have a greater impact on the design process, but due to the novelty of the topic, the scarcity and diversity of competitors' designs had little influence on the project. However, it was beneficial to analyse competitors from various industries. Regarding the evaluation stage of the design concept, it is important to note that iterating several times on the design provided valuable insights and allowed improved significantly the design concept. It was interesting to observe how some aspects, for example, the notifications, were perceived positively in the first iteration, while in the third iteration, some participants had other preferences about it. This proves the importance of iterating and confirming the findings repeatedly, regardless of the users' agreement on a specific aspect of design. The recruitment of participants for the focus group and the user tests took a considerable amount of time; however, if more time or easier recruitment were available, more iterations would have been beneficial in refining the design concept.

8.1.2 Results

According to the results of the investigation on presenting battery SoH inside the vehicle, several insights were discovered and analysed throughout the study. Despite the regulation for SoH to be displayed on the vehicle, the users highly expressed their desire to access and monitor the SoH information from multiple platforms, including a mobile application. With high demand for multi-platform integration, these findings reflect the significance and necessity of accessing the battery SoH from various platforms as well as highlighting the benefits of having control over the information and avoiding sharing the information with external or third-party applications.

The findings in this thesis also align with the outcomes from the Volvo Cars' prestudy, which were presented in Section 2.2.1. To begin, similar to this thesis' findings, the respondents of the interview study were interested in seeing more information regarding possible actions to protect the battery, including how and why those actions affect their cars battery life. Secondly, the respondents were interested in seeing SoH information on the infotainment screen, but also on the phone. Moreover, they also preferred the information not to be displayed all the time, but in the form of a notification instead. However, further global study and investigation should be conducted to validate if the solution is feasible and compatible with other markets and regions.

Despite the focus of this thesis being on the BEV leasers within Volvo Cars, it was also interesting to discover that many individuals care about the battery health of the BEVs. However, the results revealed that the users prefer not to change their actions due to the belief that sufficient care has already been taken, indicating a lack of a clear baseline on how to take care of the BEV's battery. This issue can be addressed by providing a clear baseline and supportive guidance to the users, which can be done through functionality that offers personalised actions and a list of general recommendations. On the other hand, some individuals expressed a low level of interest in battery health preservation due to their short-term leasing. This finding indicated that the car ownership status influences the level of interest in battery health information regardless of where the information is displayed, as well as the level of motivation to preserve battery health of the BEV. This concern goes beyond system functionality and more towards societal awareness of the importance of battery health monitoring and maintenance, which cannot be solved via technical functionality. While this thesis focuses on the visualisation of the SoH information to enhance user understanding rather than increasing general awareness of battery health, it is considered beneficial to acknowledge motivation towards battery preservation from their perspective.

The deliverable is a list of design recommendations formulated from user-centred research. However, implementing these recommendations is considered challenging, not only due to the technical feasibility of gathering the data to serve as a baseline but also because of legal considerations and excessive disclosure of the SoH information that could potentially impact the company in terms of the reputation and warranty commitment. A possible solution for data collection to formulate a baseline is balancing the population data with the theoretical model derived from the company, ensuring the flexibility of the information and availability of the baseline across regions. As the SoH information is sensitive and closely connected to the warranty of the vehicle, it is recommended to find a balance between providing sufficient information regarding SoH and minimising the information that could impact the warranty issues. Having the information with a high level of accuracy and certainty could be a workaround to this issue. These solutions are based on current perspectives and understanding. However, further research, investigation, and validation from internal entities within the company are required to ensure that the solution is effective and aligned with the company's objectives and standards.

8.1.3 Limitation and Challenges

Similar to any research, investigating the approaches to effectively present the SoH information faced several challenges and limitations. The objectives of this sub-section are to transparently present actual constraints that happened during the process as well as identify the impact on the research's scope and findings. Three limitations were mentioned in this sub-section, including time constraints, resource availability, and participant diversity and bias.

Time Constraints
The five-month time frame of the thesis limits the opportunities to conduct more iterations in the development phase to refine the prototypes based on the feedback.

Regarding this constraint, the wording was not properly and adequately polished to provide a better understanding to a vast majority of the users. For instance, the section name of the recommended actions could be revised to be more appropriate and easily understood by many users for better clarity. Moreover, the notification frequency could have been properly tested with more options of frequency and a larger user group, to ensure that this information was delivered in an appropriate frequency. Lastly, the proposed design concept was designed to focus on understandability and usability rather than the aesthetics of the user interfaces, which could be revised professionally if time allowed.

Resource Availability
This research was conducted in collaboration with Volvo Cars internal collaborative development fleet which was the target user in this thesis. Involving them as participants approximately for a period of 20-30 minutes each was considered a significant resource allocation for the team. The availability of the participants was subject to their schedules and time, which can directly impact the study's progress. Consequently, the process was slightly delayed due to the time-consuming nature of recruiting, coordinating, and reserving their availability as participants of the study. This limitation highlights not only the importance of effective planning ahead of time but also the flexibility in terms of resources, ensuring that the number of participants is sufficient and meets the expectations throughout the research process.

Participant Diversity and Bias
As mentioned, the user group of this thesis is a group of Volvo Cars employees who lease a BEV company's produced vehicle, including Volvo's XC40 Recharge, C40 Rechargeable, EX30, as well as Polestar 2. According to the research, the majority of the users who are leasing the BEV are male in the age range of 50-59 and are working mainly in the engineering sector of the company. Additionally, all of them are part of Volvo Cars internal collaborative development fleet, so they might be more biased and more involved in maintaining the battery of their vehicle. One of the examples is that some feedback was given from the engineer or employee's point of view, not the customer's perspective.

In order to minimise this constraint, an extra pre-screening step was added to ensure that the group of participants in each session was as diverse as possible. For instance, different genders, ages and professions are considered to ensure more diversity. However, there are still some limitations regarding this topic. With the same background, knowledge, work experience, and interest in vehicles, it could raise bias in terms of the user perspective, lead to less diversity, and potentially impact the directions and findings of the thesis. In other words, this also means that feedback and insights might not reflect the perspectives of BEV leasers in public, and the findings might not be applied to a broader range of BEV drivers in other countries or regions.

8.1.4 Ethical Considerations

With the goal of providing users with valuable SoH information, several ethical challenges were encountered and should be taken into consideration thoroughly. One of the most critical ethical concerns was the risk of distracting or overwhelming drivers with a high volume of information. The concept was designed by focusing primarily on safety, ensuring that the battery SoH display did not divert drivers' attention away from the road and that the information was easily digestible. Regarding this concern, silent notifications in the period of every six months were chosen to reduce distractions and the mental workload of the users during the journey. Moreover, displaying the SoH information on the infotainment screen is another way to offload the drivers mental workload while driving. Both alternatives were aligned with the research on reducing mental workload to promote safe driving practices and traffic [55], [56]. While dynamic recommendations or real-time and context-based recommendations were suggested by Eider & Berl [24] and preferred by several users during focus groups, the decision was made against their implementations and needs due to the concern about higher cognitive load and distraction for the drivers. Minimising the driver's distraction can ensure that the valuable and insightful SoH information will be efficiently delivered while maintaining high safety and providing good driving experience.

Moreover, providing detailed SoH information may also lead to users feeling responsible for battery care, which can have a negative psychological impact on the user. The priority was to empower drivers while minimising stress and guilt, with a conscious decision to avoid manipulative practices. The goal of the design was to avoid blaming or holding the user responsible for the entire degradation process, as battery degradation is also a natural process. However, feeling responsible and stressed about battery health might vary depending on the user.

Even though using colour coding from orange to green on the visualisation received positive feedback from the participants who took part in the evaluation of the design concept, because red would have been too alarming, the accessibility is an aspect that should be improved to make it more accessible for users with colour blindness. Although orange, green and red have a very strong symbolic association, it would be beneficial, if given more time, to investigate the design with other colour-blind-friendly colours.

Compliance with General Data Protection Regulation (GDPR) was maintained during data collection and interaction with research participants, ensuring data privacy and security. No sensitive information was requested from the participants during the questionnaires, interviews and user testing, and all collected data was processed anonymously. Participants were also informed about the procedure, and informed consent was obtained from every participant involved in this research.

8.1.5 Future Work

Further research on the notifications

As mentioned earlier in [DR3], the findings confirmed that the notifications about battery health analysis were found useful as reminders to maintain awareness of battery health. However, there were discrepancies regarding user preference on the frequency of the notifications. While some participants preferred to receive notifications for a time period of six months, other participants indicated that they would prefer to receive only when the degradation does not perform as expected. Regarding this, a study should be conducted to investigate user preference for periodic notifications further or explore what is an optimal frequency in this context.

Polishing wording

During evaluations, there were several critiques regarding the language used in the design concept. Most of the critiques were on the personalised tips section which did not properly convey a sense of personalisation to the users. Some of the participants mentioned that they did not perceive this section as personalised even though it was explicitly stated in the text, while others interpreted this section similarly to the list of general recommendations, not the actions that were tailored to their driving behaviour or the actions that they should be taken into consideration. Even though revising the wording and relocating this section to be part of the degradation could improve user understanding of this section. However, the name of this section was considered relatively long compared to the other sections, and it could impact the level of interest in this information. Additionally, some descriptions of the recommendations were unclear and might be misleading to the users. As a result, the wording should be revised to ensure that it is understandable and conveys the same meaning to a vast majority of users in the future. Apart from polishing comprehensive wording, this information should be validated to ensure that the information is aligned and compiled with legal requirements as well as the company's objectives and standards.

Research with a larger sample size and diverse group of users

As this research focused specifically on BEV leasers who live in Sweden, expanding the scope to include research with larger and more diverse groups of users will be interesting, such as different age ranges, diverse backgrounds, and geographical locations. This approach could potentially unveil insights or universal patterns beyond boundaries and market-specific user preferences. Therefore, conducting wider research on the SoH topic could lead to a promising global solution rather than solutions tailored to market-specific segments and also enable users worldwide to access the in-vehicle SoH functionality.

Enhance user awareness on battery health maintenance

To increase user awareness of battery health maintenance for leasers, the solutions can go far beyond the functional design of the user interfaces, and more towards marketing campaigns, financial commitments, or educational training for the leasers. A possible solution could be including battery health maintenance agreements in a leasing contract to emphasise the importance of battery health maintenance and have a commitment to preserving the battery health of the vehicle throughout the leasing period. By concerning user awareness of battery health and proactively addressing this issue, further research regarding battery SoH could be how to empower users to actively monitor and maintain battery health to extend battery lifespan and optimise their car performance.

8.2 Conclusion

The aim of this thesis was to investigate the battery SoH feature that should be displayed on vehicle monitors according to the new legislation. This thesis conducted a study with 15 participants, using a user-centred design approach to develop and refine prototypes for displaying battery SoH information, which led to the formulation of the final design recommendations that can improve user understanding and engagement with BEV health maintenance.

It was important in this research to focus on the user-centric perspective and investigate what information about the battery SoH is suitable to enhance user experience and provide a helpful and useful set of information that will enrich users' knowledge about the battery SoH. The Double Diamond design process [62] was followed in order to conduct this research accordingly to investigate the first research question:

> *"What information should be displayed to enhance user understanding of battery health in order to prevent excessive degradation and promote best practices?"*

During the initial stage of the research, a literature review, expert interviews, questionnaires and focus groups were conducted to explore the complexities of this topic. All the data collected helped to create a user requirement list, which was used to develop the first design concept in the form of a prototype. It was observed not only in the focus group but also in the evaluation of the first prototype that the percentage was not enough for the user to understand the battery status of their BEV. Through the iterative process of developing, analysing and evaluating two more prototypes, the design recommendations were refined to improve the user's understanding and experience of the battery SoH feature while also being useful and helpful in guiding the user to follow best practices to preserve their battery health. This led to investigate further the second research question:

> *"What are design recommendations for displaying the battery SoH information to enhance the in-vehicle experience for BEV drivers?"*

The focus of the research was to explore the information that the users needed to see to better understand their battery state, culminating in 11 design recommendations that can be considered when designing or researching this topic in the future. It is important to highlight that additional research is required to delve deeper into determining the frequency and style of the notifications, which could not be concluded during this study. Furthermore, future research should include a larger sample of users, involving different ages and countries, as well as investigating not only the leasers but also the owners of BEVs. Despite many limitations and challenges, the thesis was successfully delivered, serving as a guide or foundation of how the SoH should be implemented from the user perspective in the next step. Overall, the aim of the study was to highlight the importance of the user-centric perspective when designing the new battery SoH feature for the EVs.

Although there is a clear regulation regarding battery SoH nowadays, it has been seen through this research that a more user-centric perspective is necessary for the user to be more aware and empowered to understand their BEVs's health. It is also expected that more research will be conducted on this topic in the future, as BEVs are growing in popularity and user awareness of battery health will not only enhance the usability but also promote a more sustainable driving, which could potentially have a more positive sustainable impact in the future.

Bibliography

[1] C. A. R. Board. "Data standardization requirements for 2026 and subsequent model year light-duty zero emission vehicles and plug-in hybrid electric vehicles." Accessed: February 11, 2024. (2022), [Online]. Available: https://shorturl.at/bnNX0.

[2] U. Nations. "United nations global technical regulation on in-vehicle battery durability for electrified vehicles." Accessed: February 11, 2024. (Mar. 2022), [Online]. Available: https://unece.org/sites/default/files/2023-01/ECE_TRANS_180a22e.pdf.

[3] Volvo Cars, *Our story*, https://www.volvocars.com/intl/v/our-story, Accessed: 2024-02-12, 2024.

[4] Volvo Cars, *Volvo cars reconfirms its commitment to sustainability with new ambitions and a focus on biodiversity*, https://www.media.volvocars.com/global/en-gb/media/pressreleases/322528/volvo-cars-reconfirms-its-commitment-to-sustainability-with-new-ambitions-and-a-focus-on-biodiversit, Accessed: 2024-02-12, 2024.

[5] Volvo Cars, *Volvo cars to be fully electric by 2030*, https://www.media.volvocars.com/global/en-gb/media/pressreleases/277409/volvo-cars-to-be-fully-electric-by-2030, Accessed: 2024-02-12, 2021.

[6] Polestar, *Polestar welcomes geely's long-term commitment to its development*, https://investors.polestar.com/news-releases/news-release-details/polestar-welcomes-geelys-long-term-commitment-its-development, Accessed: 2024-02-12, 2024.

[7] Volvo Cars, *Volvo cars 2023 profit increases by 43 percent to deliver a record year in the company's 97-year history*, https://www.prnewswire.com/news-releases/volvo-cars-2023-profit-increases-by-43-percent-to-deliver-a-record-year-in-the-companys-97-year-history-302050221.html, Accessed: 2024-02-12, 2023.

[8] Global Market Insights, *Automotive subscription services market*, https://www.gminsights.com/industry-analysis/automotive-subscription-services-market, Accessed: 2024-02-12, 2024.

[9] Zion Market Research, *Car subscription market*, https://www.zionmarketresearch.com/report/car-subscription-market, Accessed: 2024-02-12, 2024.

[10] T. Liljamo, H. Liimatainen, M. Pöllänen, and R. Viri, "The effects of mobility as a service and autonomous vehicles on peoples willingness to own a car in the future," *Sustainability*, vol. 13, no. 4, p. 1962, 2021.

[11] Volvo Cars, *Care by volvo*, https://www.volvocars.com/se/care-by-volvo/?gad_source=1&gclid=CjwKCAiA_aGuBhACEiwAly57MSC4FfQvdxjC51rRkNEDedtWbj5BACIQQwmhmoCIpiectVYEqUoYmRoCiUQQAvD_BwE&gclsrc=aw.ds, Accessed: 2024-02-12, 2024.

[12] S. Manzetti and F. Mariasiu, "Electric vehicle battery technologies: From present state to future systems," *Renewable and Sustainable Energy Reviews*, vol. 51, 2015.

[13] I. Aijaz and A. Ahmad, "Electric vehicles for environmental sustainability," *Smart Technologies for Energy and Environmental Sustainability*, pp. 131–145, 2022.

[14] P. S. Angeline and M. N. Rajkumar, "Evolution of electric vehicle and its future scope," *Materials Today: Proceedings*, vol. 33, pp. 3930–3936, 2020.

[15] A. Ajanovic and R. Haas, "On the economics and the future prospects of battery electric vehicles," *Greenhouse Gases: Science and Technology*, vol. 10, no. 6, pp. 1151–1164, 2020.

[16] A. Faraz, A. Ambikapathy, S. Thangavel, K. Logavani, and G. Arun Prasad, "Battery electric vehicles (bevs)," *Electric Vehicles: Modern Technologies and Trends*, pp. 137–160, 2021.

[17] R. Xiong, L. Li, and J. Tian, "Towards a smarter battery management system: A critical review on battery state of health monitoring methods," *Journal of Power Sources*, vol. 405, pp. 18–29, 2018.

[18] L. Ungurean, G. Cârstoiu, M. V. Micea, and V. Groza, "Battery state of health estimation: A structured review of models, methods and commercial devices," *International Journal of Energy Research*, vol. 41, no. 2, pp. 151–181, 2017.

[19] Y. Liu, C. Liu, Y. Liu, F. Sun, J. Qiao, and T. Xu, "Review on degradation mechanism and health state estimation methods of lithium-ion batteries," *Journal of Traffic and Transportation Engineering (English Edition)*, 2023.

[20] B. Yang, Y. Qian, Q. Li, *et al.*, "Critical summary and perspectives on state-of-health of lithium-ion battery," *Renewable and Sustainable Energy Reviews*, vol. 190, p. 114 077, 2024.

[21] J. Zhao and A. F. Burke, "Electric vehicle batteries: Status and perspectives of data-driven diagnosis and prognosis," *Batteries*, vol. 8, no. 10, p. 142, 2022.

[22] M. A. Hannan, M. H. Lipu, A. Hussain, and A. Mohamed, "A review of lithium-ion battery state of charge estimation and management system in electric vehicle applications: Challenges and recommendations," *Renewable and Sustainable Energy Reviews*, vol. 78, pp. 834–854, 2017.

[23] G.-w. You, S. Park, and D. Oh, "Real-time state-of-health estimation for electric vehicle batteries: A data-driven approach," *Applied energy*, vol. 176, pp. 92–103, 2016.

[24] M. Eider and A. Berl, "Dynamic ev battery health recommendations," in *Proceedings of the Ninth International Conference on Future Energy Systems*, 2018, pp. 586–592.

[25] V. Cars, *Xc40 recharge pure electric recommendations for high voltage battery*, https://www.volvocars.com/uk/support/car/xc40-recharge-pure-electric/article/bd79b9d8f5cb406ec0a801516e61d3b1, Accessed: 2024-02-12, 2023.

[26] 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*, 2011, pp. 177–184.

[27] I. Neumann and J. F. Krems, "Battery electric vehicles–implications for the driver interface," *Ergonomics*, vol. 59, no. 3, pp. 331–343, 2016.

[28] Z. Wang, S. Zeng, and J. Guo, "Understanding the influence of state of health on the range anxiety of battery electric vehicle drivers," *IET Intelligent Transport Systems*, vol. 15, no. 2, pp. 286–296, 2021.

[29] M. Eider, B. Sick, and A. Berl, "Context-aware recommendations for extended electric vehicle battery lifetime," *Sustainable Computing: Informatics and Systems*, vol. 37, 2023.

[30] C. A. R. Board. "Zero emission vehicle program." Accessed: February 7, 2024. (2022), [Online]. Available: `https://ww2.arb.ca.gov/our-work/programs/zero-emission-vehicle-program/about`.

[31] H. W. Rittel and M. M. Webber, "Wicked problems," *Man-made Futures*, vol. 26, no. 1, pp. 272–280, 1974.

[32] A. G. Mirnig, A. Meschtscherjakov, D. Wurhofer, T. Meneweger, and M. Tscheligi, "A formal analysis of the iso 9241-210 definition of user experience," in *Proceedings of the 33rd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems*, ser. CHI EA '15, Seoul, Republic of Korea: Association for Computing Machinery, 2015, pp. 437–450, ISBN: 9781450331463. [Online]. Available: `https://doi.org/10.1145/2702613.2732511`.

[33] M. Gualtieri, "Best practices in user experience (ux) design," *Design compelling user experiences to wow your customers*, pp. 1–17, 2009.

[34] A. Cooper, R. Reimann, D. Cronin, and C. Noessel, *About Face: The Essentials of Interaction Design*. John Wiley & Sons, Incorporated, 2014.

[35] H. Sharp, J. Preece, and Y. Rogers, *Interaction Design: Beyond Human-Computer Interaction*, 5th. Hoboken, NJ, USA: John Wiley & Sons, Incorporated, 2019.

[36] A. Chammas, M. Quaresma, and C. Mont'Alvão, "A closer look on the user centred design," *Procedia Manufacturing*, vol. 3, pp. 5397–5404, Dec. 2015. DOI: `10.1016/j.promfg.2015.07.656`.

[37] J.-Y. Mao, K. Vredenburg, P. W. Smith, and T. Carey, "The state of user-centered design practice," *Commun. ACM*, vol. 48, no. 3, pp. 105–109, Mar. 2005, ISSN: 0001-0782. DOI: `10.1145/1047671.1047677`. [Online]. Available: `https://doi.org/10.1145/1047671.1047677`.

[38] R. Pea, "User centred system design - new perspectives on human/computer interaction," *J Educ Comput Res*, vol. 3, Jan. 1987.

[39] J. Zimmerman and J. Forlizzi, "Research through design in hci," in *Ways of Knowing in HCI*, J. S. Olson and W. A. Kellogg, Eds. New York, NY: Springer New York, 2014, pp. 167–189, ISBN: 978-1-4939-0378-8. DOI: `10.1007/978-1-4939-0378-8_8`. [Online]. Available: `https://doi.org/10.1007/978-1-4939-0378-8_8`.

[40] J. Zimmerman, J. Forlizzi, and S. Evenson, "Research through design as a method for interaction design research in hci," in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, ser. CHI '07, San Jose, California, USA: Association for Computing Machinery, 2007, pp. 493–502, ISBN: 9781595935939. DOI: 10.1145/1240624.1240704. [Online]. Available: https://doi.org/10.1145/1240624.1240704.

[41] C. Frayling, "Research in art and design," *Royal College of Art Research Papers*, vol. 1, no. 1, pp. 1–5, 1993.

[42] J. M. Lee and D. Y. Ju, "Classification of human-vehicle interaction: User perspectives on design," *Social Behavior and Personality: an international journal*, vol. 46, no. 7, pp. 1057–1070, 2018.

[43] P. K. Murali, M. Kaboli, and R. Dahiya, "Intelligent in-vehicle interaction technologies," *Advanced Intelligent Systems*, vol. 4, no. 2, 2022.

[44] V. Elangovan and A. Shirkhodaie, "A survey of imagery techniques for semantic labeling of human-vehicle interactions in persistent surveillance systems," *Proceedings of SPIE - The International Society for Optical Engineering*, vol. 8050, May 2011. DOI: 10.1117/12.887019.

[45] X. Sun, H. Chen, J. Shi, W. Guo, and J. Li, "From hmi to hri: Human-vehicle interaction design for smart cockpit," in Jun. 2018, pp. 440–454, ISBN: 978-3-319-91243-1. DOI: 10.1007/978-3-319-91244-8_35.

[46] H. INTERNATIONAL. "Harman demonstrates advanced connected car platform for industry-leading intelligent cockpit." (Apr. 2017), [Online]. Available: https://news.harman.com/releases/harman-demonstrates-advanced-connected-car-platform-for-industry-leading-intelligent-cockpit.

[47] M. Akamatsu, P. Green, and K. Bengler, "Automotive technology and human factors research: Past, present, and future," *International journal of vehicular technology*, vol. 2013, 2013.

[48] J.-A. Kim, H.-J. Na, D.-H. Cho, Y.-H. Shin, S.-J. Park, and J.-H. Kim, "Development of questionnaire for automobile seat comfort evaluation," *Science of Emotion and Sensibility*, vol. 13, no. 2, pp. 381–390, 2010.

[49] C. H. Jeong, B. S. Kim, S. B. Yu, D. Suh, M. Kim, and M. Suh, "In-vehicle display hmi safety evaluation using a driving simulator," *International Journal of Automotive Technology*, vol. 14, pp. 987–992, 2013. [Online]. Available: https://api.semanticscholar.org/CorpusID:255561822.

[50] N. Gkikas, *Automotive ergonomics: Driver-vehicle interaction*. Apr. 2016, pp. 1–194.

[51] G. Marquart, C. Cabrall, and J. de Winter, "Review of eye-related measures of drivers mental workload," *Procedia Manufacturing*, vol. 3, pp. 2854–2861, 2015.

[52] D. De Waard and K. Brookhuis, "The measurement of drivers' mental workload," 1996.

[53] T. Butmee, T. C. Lansdown, and G. H. Walker, "Mental workload and performance measurements in driving task: A review literature," in *Proceedings of the 20th Congress of the International Ergonomics Association (IEA 2018) Volume VI: Transport Ergonomics and Human Factors (TEHF), Aerospace Human Factors and Ergonomics 20*, Springer, 2019, pp. 286–294.

[54] F. P. da Silva, "Mental workload, task demand and driving performance: What relation?" *Procedia-Social and Behavioral Sciences*, vol. 162, pp. 310–319, 2014.

[55] W. Piechulla, C. Mayser, H. Gehrke, and W. König, "Reducing drivers mental workload by means of an adaptive man–machine interface," *Transportation Research Part F: Traffic Psychology and Behaviour*, vol. 6, no. 4, pp. 233–248, 2003.

[56] T. C. Lansdown, N. Brook-Carter, and T. Kersloot, "Distraction from multiple in-vehicle secondary tasks: Vehicle performance and mental workload implications," *Ergonomics*, vol. 47, no. 1, pp. 91–104, 2004.

[57] S. Card, J. Mackinlay, and B. Shneiderman, *Readings in Information Visualization: Using Vision To Think*. Jan. 1999, ISBN: 978-1-55860-533-6.

[58] R. Spence, *Information visualization*. Springer, 2001, vol. 1.

[59] T. Munzner, *Visualization Analysis and Design* (AK Peters Visualization Series). CRC Press, 2014, ISBN: 9781466508934. [Online]. Available: `https://books.google.se/books?id=dznSBQAAQBAJ`.

[60] M. Wybrow, N. Elmqvist, J.-D. Fekete, T. Landesberger, J. Wijk, and B. Zimmer, "Interaction in the visualization of multivariate networks," in Apr. 2014, pp. 97–125, ISBN: 978-3-319-06792-6. DOI: `10.1007/978-3-319-06793-3_6`.

[61] D. C. Jonathan Ball. "The double diamond: A universally accepted depiction of the design process." (Oct. 2019), [Online]. Available: `https://www.designcouncil.org.uk/our-resources/archive/articles/double-diamond-universally-accepted-depiction-design-process`.

[62] D. Council. "Framework for innovation." (unknown), [Online]. Available: `https://www.designcouncil.org.uk/our-resources/framework-for-innovation/`.

[63] B. Hanington and B. Martin, *Universal Methods of Design, Expanded and Revised*. Quarto Publishing Group USA, 2019, ProQuest Ebook Central. [Online]. Available: `https://ebookcentral.proquest.com/lib/chalmers/detail.action?docID=6039458`.

[64] A. Bogner, B. Littig, and W. Menz, "Introduction: Expert interviews — an introduction to a new methodological debate," in *Interviewing Experts*. London: Palgrave Macmillan UK, 2009, pp. 1–13, ISBN: 978-0-230-24427-6. DOI: `10.1057/9780230244276_1`. [Online]. Available: `https://doi.org/10.1057/9780230244276_1`.

[65] D. H. Stone, "Design a questionnaire," *BMJ (Clinical Research Ed.)*, vol. 307, no. 6914, pp. 1264–1266, 1993. DOI: `10.1136/bmj.307.6914.1264`. [Online]. Available: `https://doi.org/10.1136/bmj.307.6914.1264`.

[66] R. Krueger and M. Casey, *Focus Groups: A Practical Guide for Applied Research*. SAGE Publications, 2014, ISBN: 9781483354095. [Online]. Available: `https://books.google.se/books?id=tXpZDwAAQBAJ`.

[67] G. Guest, E. Namey, and K. Mckenna, "How many focus groups are enough? building an evidence base for nonprobability sample sizes," *Field Methods*, vol. 29, Apr. 2016. DOI: `10.1177/1525822X16639015`.

[68] A. Lucero, “Using affinity diagrams to evaluate interactive prototypes,” in *Human-Computer Interaction – INTERACT 2015*, J. Abascal, S. Barbosa, M. Fetter, T. Gross, P. Palanque, and M. Winckler, Eds., Cham: Springer International Publishing, 2015, pp. 231–248, ISBN: 978-3-319-22668-2.

[69] S. Blomkvist, “Persona an overview,” 2002. [Online]. Available: https://api.semanticscholar.org/CorpusID:13518131.

[70] A. Cooper, *The Origin of Personas*. 2003. [Online]. Available: https://books.google.se/books?id=NqlBtwAACAAJ.

[71] J. T. Catanio, “Requirements analysis: A review,” in *Advances in Systems, Computing Sciences and Software Engineering*, T. Sobh and K. Elleithy, Eds., Dordrecht: Springer Netherlands, 2006, pp. 411–418, ISBN: 978-1-4020-5263-7.

[72] 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://doi.org/10.1108/14635770810876593.

[73] “The benchmarking book,” in T. Stapenhurst, Ed., Butterworth-Heinemann, 2009, ISBN: 978-0-7506-8905-2. DOI: https://doi.org/10.1016/B978-0-7506-8905-2.00031-2. [Online]. Available: https://www.sciencedirect.com/science/article/pii/B9780750689052000312.

[74] S. Wah Fong, E. Cheng, and D. Ho, “Benchmarking: A general reading for management practitioners,” *Management Decision*, vol. 36, no. 6, pp. 407–418, 1998. DOI: 10.1108/00251749810223646. [Online]. Available: https://doi.org/10.1108/00251749810223646.

[75] D. Kanungo, *UX Decoded: Think and Implement User-Centered Research Methodologies, and Expert-Led UX Best Practices*. BPB Publications, 2022, p. 186, ISBN: 9789355512215.

[76] C. Wilson, *Brainstorming and Beyond: A User-Centered Design Method*. Elsevier Science, 2013, ISBN: 9780124071667. [Online]. Available: https://books.google.se/books?id=YsnKE2JdlsQC.

[77] G. D. S. Kit. “Crazy 8s.” (Accessed: 2024).

[78] Y.-K. Lim, E. Stolterman, and J. Tenenberg, “The anatomy of prototypes: Prototypes as filters, prototypes as manifestations of design ideas,” *ACM Trans. Comput.-Hum. Interact.*, vol. 15, no. 2, Jul. 2008, ISSN: 1073-0516. DOI: 10.1145/1375761.1375762. [Online]. Available: https://doi.org/10.1145/1375761.1375762.

[79] C. Dordlofva and P. Törlind, “Evaluating design uncertainties in additive manufacturing using design artefacts: Examples from space industry,” *Design Science*, vol. 6, May 2020. DOI: 10.1017/dsj.2020.11.

[80] J. Landay and B. Myers, “Sketching interfaces: Toward more human interface design,” *Computer*, vol. 34, no. 3, pp. 56–64, 2001. DOI: 10.1109/2.910894.

[81] M. Nikoli, S. kec, T. Martinec, and N. Horvat, “The role of sketching activities and outcomes in conceptual design phase,” *Proceedings of the Design Society: International Conference on Engineering Design*, vol. 1, no. 1, pp. 399–408, 2019. DOI: 10.1017/dsi.2019.43.

[82] M. Lupetti, "Shybo design of a research artefact for human-robot interaction studies," *Journal of Science and Technology of the Arts*, vol. 9, p. 57, Dec. 2017. DOI: 10.7559/citarj.v9i1.303.

[83] J. Nielsen. "Thinking aloud: The #1 usability tool." (2012), [Online]. Available: https://www.nngroup.com/articles/thinking-aloud-the-1-usability-tool/.

[84] Microsoft Corporation. "Microsoft 365," Microsoft Corporation. (20XX), [Online]. Available: https://www.microsoft.com/en-us/microsoft-365/.

[85] RealTimeBoard, Inc., *Miro online whiteboard*, Accessed: 2024-04-27, 2024. [Online]. Available: https://www.miro.com.

[86] S. P. Dow, K. Heddleston, and S. R. Klemmer, "The efficacy of prototyping under time constraints," in *Proceedings of the seventh ACM conference on Creativity and cognition*, 2009, pp. 165–174.

[87] J. Nielsen, "Why you only need to test with 5 users," *Nielsen Norman Group*, Mar. 2000. [Online]. Available: https://www.nngroup.com/articles/why-you-only-need-to-test-with-5-users/.

[88] C. W. Turner, J. R. Lewis, and J. Nielsen, "Determining usability test sample size," *International encyclopedia of ergonomics and human factors*, vol. 3, no. 2, pp. 3084–3088, 2006.

[89] R. Alroobaea and P. J. Mayhew, "How many participants are really enough for usability studies?" In *2014 Science and Information Conference*, IEEE, 2014, pp. 48–56.

[90] *Figma*, https://www.figma.com.

[91] P. Laubheimer, "Beyond the nps: Measuring perceived usability with the sus, nasa-tlx, and the single ease question after tasks and usability tests," *Nielsen Norman Group*, Feb. 2018. [Online]. Available: https://www.nngroup.com/articles/measuring-perceived-usability/.

[92] K. Fesenko, *Avatars generator figma plugin*, https://www.volvocars.com/uk/support/car/xc40-recharge-pure-electric/article/bd79b9d8f5cb406ec0a801516e61d3b1, 2022.

A

Appendix: Questionnaire

Introduction and Consent
You are invited to participate in a research study on a master thesis of MSc in Interaction Design and Technologies, Chalmers University of Technology, collaborated with Volvo Cars. The aim of the study is to develop design recommendations for the display of battery SoH from a user-centred design perspective.

The study will take approximately 6 minutes and your participation in this study is completely voluntary. You are free to choose whether or not you will take part in the study. You have the right to withdraw from the study at any time, including withdrawal of any information provided. The answers from the questionnaire will be collected during the study for further analysis.

We will present you with a questionnaire which is divided into three sections. All collected data will be treated as confidential and stored securely. It will be anonymous and not contain any identifying information about you. If you agree on this, please provide your consent below.

Contact us:
Liina Tumma - liina.tumma@volvocars.com
Natthamon Pongchanchai - natthamon.pongchnchai@volvocars.com

Note that this questionnaire is completely anonymous and no personal details will be collected.

Statement of understanding and consent*

- I have read and understood the participant form, and I have had the opportunity to ask questions if necessary.
- I understand that my participation is voluntary and that I am free to withdraw at any time during the study without giving any reason. If I withdraw my data will be removed and destroyed.
- I understand that the data collected in this study will be used as detailed in the participant information form.
- I agree to participate in this study, and I consent to the publication of the results of the study with the understanding that anonymity will be preserved.

- The study is being carried out by Liina Tumma and Natthamon Pongchanchai. They can be contacted via email above.

○ Yes, I consent.

○ No, I do not consent.

Section 1: car information

1. Are you living in Sweden and leasing a battery electric vehicle? *

○ Yes

○ No

2. Please select your vehicle: *

○ XC40 Recharge (EX40)

○ C40 Recharge (EC40)

○ EX30

○ Polestar 2

○ Other

3. Why did you choose to lease the battery electric vehicle? * (free text)

For how long have you had this vehicle? *

○ Less than 6 months

○ 6-12 months

○ 12-18 months

○ More than 18 months

4. How frequently do you use the car? *

○ Daily

○ Once or a few times a week

○ Once or a few times a month

○ Once or a few times a year

○ Rarely

5. What are the main reasons for using the car? *

○ Commuting to work

○ Leisure

○ Both

○ Other

Section 2: battery health

6. Choose your knowledge level about the battery of an electric vehicle. *
(Know nothing) 1 2 3 4 5 6 7 8 9 10 (Expert)

7. Please select the factors that you think affect the health of the battery. You can choose all the options that seem suitable. *

- ☐ Climate
- ☐ Fast charging
- ☐ Type of tires
- ☐ Driving behaviour
- ☐ High percentage of charge
- ☐ Use of infotainment (navigation, music, movie, etc.)
- ☐ Battery aging
- ☐ Other

8. Have you ever read the section about the recommendations for electric vehicle batteries for your car in the Volvo Cars manual? *

- ○ I didnt know about it
- ○ I know it exists but I didnt
- ○ I did

10. If you did, how useful and applicable do you think those recommendations are? *
(Not at all useful) 1 2 3 4 5 6 7 8 9 10 (Extremely useful)

11. How much do you care about the health of the battery of your car? *
(Don't really care) 1 2 3 4 5 6 7 8 9 10 (Do care a lot)

12. What are the actions that you take to care for the health of the battery? You can choose all the options that seem suitable. *

- ☐ Avoid fast charging when possible
- ☐ Charge up to 80% instead of 100%
- ☐ Keep the charge above 20%
- ☐ Aim for a 40-60% charge for parking over a month
- ☐ Charge continuously for longer parking
- ☐ Charge continuously in temperatures above 30 ℃

- ☐ Pre-condition the car in cold weather
- ☐ Use ECO mode for driving
- ☐ I don't take any specific actions for battery maintenance
- ☐ Other

13. Now that you have more knowledge about battery care, how would you behave? And why? *
(free text)

14. What would motivate you to care about your battery's health? You can choose all the options that seem suitable. *

- ☐ Environmental benefits
- ☐ Cost savings
- ☐ Extending vehicle lifespan
- ☐ Maintaining performance and reliability
- ☐ I am not motivated to maintain battery health
- ☐ Other

15. If you would like to know more about the battery health, how would you like to receive or see the information in the vehicle? You can choose all the options that seem suitable. A picture of the screens is provided in Figure A.1 *

Figure A.1: Screen types in the vehicle

- ☐ Static feedback on steering screen
- ☐ Static feedback on infotainment screen
- ☐ Pop-up notification on steering screen

- ☐ Pop-up notification on infotainment screen
- ☐ Audio feedback
- ☐ Haptic feedback
- ☐ Other

16. When would you like to get the information about the battery health while being in the car? You can choose all the options that seem suitable. *

- ☐ While driving
- ☐ While charging
- ☐ While parking
- ☐ Other

Section 3: Demographics

17. What is your age? *

- ○ 18-29
- ○ 30-39
- ○ 40-49
- ○ 50-59
- ○ 60-69
- ○ 70 or older

18. What is your gender? *

- ○ Woman
- ○ Man
- ○ Other
- ○ Prefer not to say

19. What is your country of origin? *
(free text)

20. What is your department in Volvo Cars? *

- ○ Legal and Corporate Governance
- ○ Engineering and Operations
- ○ Commercial Operations
- ○ People Experience

- Communication
- Finance
- Quality
- Sustainability
- Design
- Other

21. Where is your office located? *

- Gothenburg
- Lund
- Skövde
- Stockholm
- Olofström
- Hällered
- Other

B

Appendix: Focus group protocol

1. Introduction
Thank the participants for joining and making a short introduction to the project. Present and summarise the consent form together with the questionnaire form.

2. Ice-breaking
Please feel free to introduce yourself and what car you are currently leasing.

3. Focus group
Now, we are finally ready to start with the first scenario, which will be based on an imaginary situation before you lease a battery electric vehicle. Imagine that you are about to lease a new battery electric vehicle. There is a new condition that has been introduced for electric vehicle leasing. The same as with the mileage allowance, the battery health has a maximum wear allowance of 5% during the two years of leasing. So you should return the car with 95% or more of battery health. As a Volvo cars employee, you find it a good way to promote battery maintenance, since it will not only benefit the company when selling second-hand value cars but also the environment, which you care about a lot.

Scenario 1: Before leasing

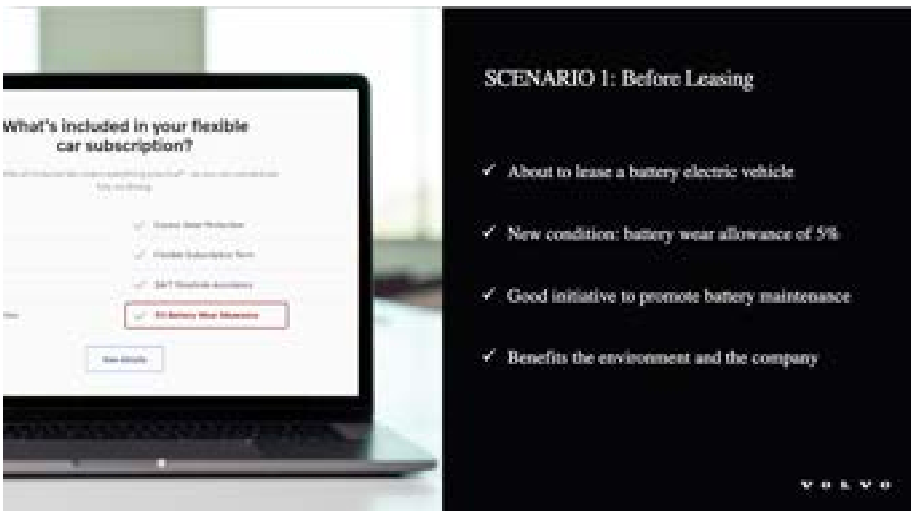


Figure B.1: Focus group: presentation of the first scenario to the participants of focus group

Imagine that you are about to lease a new battery electric vehicle (Figure B.1). There is a new condition that has been introduced for electric vehicle leasing. The same as with the mileage, the battery health has a maximum wear allowance during the two-year period of leasing. The battery wear allowance is 5%, so everybody should return their car with 95% or more of battery health.

As a Volvo cars employee, you find it a good way to promote battery maintenance from the leasers since it will benefit not only the company when selling second-hand value cars but also the environment. Taking in mind this scenario, we would like you to discuss:

“What would help and encourage you to keep your battery health?”

“In what form would you like to see the battery health?”

Scenario 2: First time in the car

Figure B.2: Focus group: presentation of the second scenario to the participants of focus group

We can move to a second scenario, which is going to be about the first time you are in the car. Imagine that you are sitting down in the car for the first time (Figure B.2). You know that Volvo Cars has a manual about all the factors that might affect battery health (show the manual). As a reference, we provide you with a list of recommendations that help preserve the battery health of the car (show recommendations). So while you sit in the car for the first time, you realize how hard it is to keep track of this information and how easy it will be to forget it, because these recommendations can be applied to so many different situations, such as driving, parking and charging. Taking in mind this scenario, we would like you to discuss:

“Would it be helpful to see these recommendations?”

“What would you like to see? When and how?”

Scenario 3: First time in the car
Scenario 3 is about the case where you have been leasing your car for one year. Imagine that you are now very comfortable with battery maintenance B.3). However, you just remembered that you havent checked for the battery health in a long period of time. You started wondering how good you are doing so far or if there is any change that needs to be made to adjust your behaviour. Based on this scenario we would like you to discuss:

"What would you like to see for this assessment?"

"When and how would you like to see it?"

Figure B.3: Focus group: presentation of the third scenario to the participants of focus group

4. End
Thank the participants. Ask if they are willing to have a follow-up evaluation of the prototypes. If participants are interested in the topic, we are willing to send the final report to them once the master thesis is done.

C

Appendix: Evaluation 1

Instructions

We will present to you our concept design on battery health of a battery electric vehicle which will be shown on the infotainment screen of the car. Our concept design is in the development phase. If you feel like exploring a button or functionality please feel free to say so. You will be given four different tasks followed by a questionnaire and follow-up questions Please speak out loud while performing the task. For example, you can point out things that surprise you positively or something that is confusing you while performing the tasks.

Scenario 1

You have been driving your battery electric vehicle for a year and you have been hearing people talking about the battery health status of battery electric vehicles. You have just parked your car and you are waiting for your friend. You want to check the state of the battery now that you have time.

TASK 1: Battery health in percentage

1. **Perform the task:** Investigate the status of your battery health. Describe what you see and think.
2. **Questionnaire:** Please fill out the following questionnaire. Please decide spontaneously. See Figure C.1 for the questionnaire.
3. **Interview:**
    - Tell me about the status of your battery health, and whether you feel like you understand it.
    - How likely are you to take action to slow down the degradation of your battery?

TASK 2: Battery health and speed of degradation

1. **Perform the task:** Investigate the speed of degradation. Describe what you see and think.
2. **Questionnaire:** Please fill out the following questionnaire. Please decide spontaneously. See Figure C.1 for the questionnaire.

3. **Interview:**
    - How do you think the status of your battery health will change as time goes on?
    - Do you feel like the degradation speed helps you to understand the battery health better?
    - How likely are you to take action to slow down the degradation of your battery?

TASK 3: Battery health, speed of degradation and tips

1. **Perform the task:** Investigate the speed of degradation. Describe what you see and think.
2. **Questionnaire:** Please fill out the following questionnaire. Please decide spontaneously. See Figure C.1 for the questionnaire.
3. **Interview:**
    - Do you feel that you are empowered to, and have enough knowledge to take care of your battery?
    - How likely are you to take action to slow down the degradation of your battery?

Scenario 2

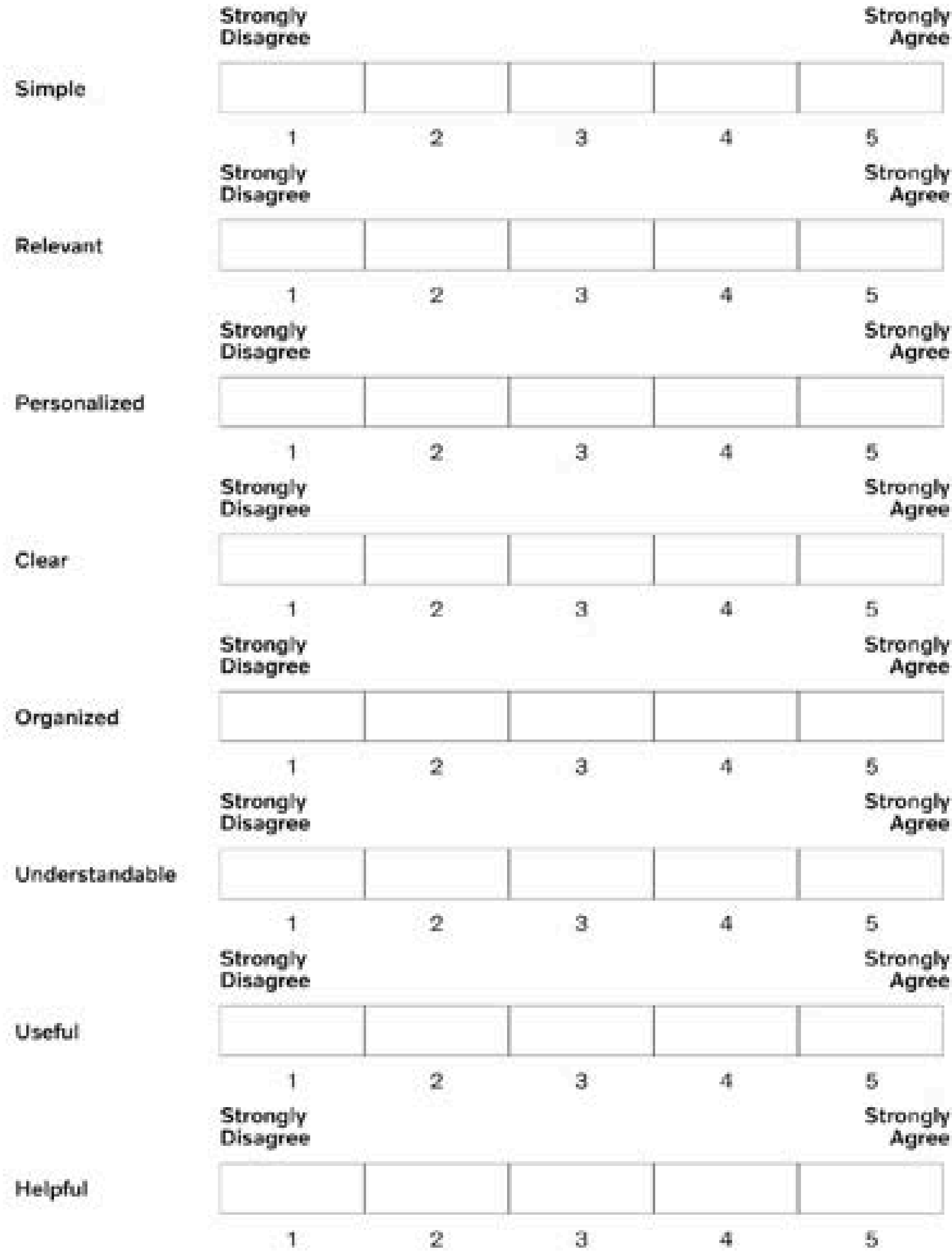
Its been several months since you checked the state of your battery health. After you park your car, you receive this notification.

TASK 4: Notifications

1. **Perform the task:** Investigate the notification. Describe what you see and think.
2. **Questionnaire:** Please fill out the following questionnaire. Please decide spontaneously. See Figure C.1 for the questionnaire.
3. **Interview:**
    - How do you feel about receiving a notification with the status update of your battery health?
    - How frequently would you like to receive the notification?
    - How likely are you to take action to slow down the degradation of your battery?
    - Do you have any additional comments?

Questionnaire for every task

Based on the task you carried out, the information presented is: ___________



	Strongly Disagree 1	2	3	4	Strongly Agree 5
Simple					
Relevant					
Personalized					
Clear					
Organized					
Understandable					
Useful					
Helpful					

Figure C.1: Example of questionnaire form for the first evaluation

D

Appendix: Evaluation 2

Instructions

We will present to you our concept design for battery health of a battery electric vehicle which will be shown on the cars infotainment screen.

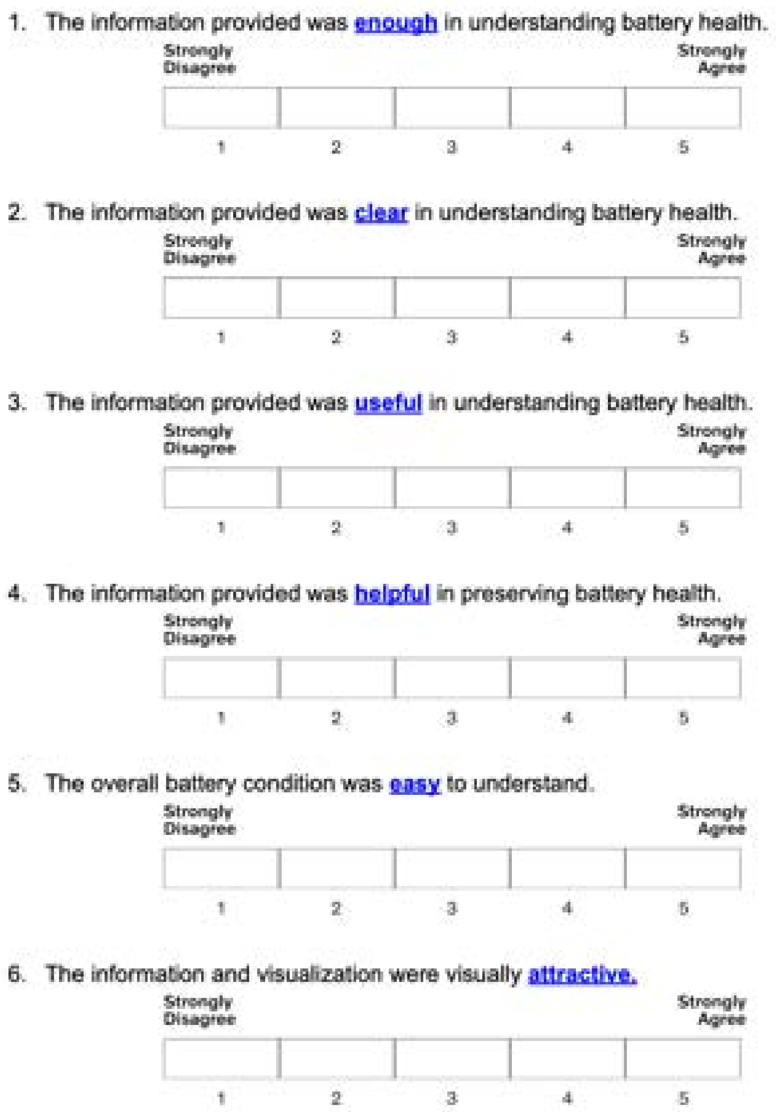
Scenario

Please imagine that you have been driving your battery-electric vehicle for a year. After you park your car, you receive a new notification. Please explore the design concept. You are seeing it for the first time, please investigate the information that is provided on the screen. Describe what you see and explain your understanding of the current state of your batterys health.

1. **Explore design:** Explore the design of the battery's state of health. Describe what you see and think.
2. **Interview:**
    - **Battery Health**
        - How do you understand and interpret your battery health status? Is it clear?
        - Does the visualisation enhance your understanding of battery health?
    - **Degradation Speed**
        - How do you understand the degradation? Is it clear?
        - Does the visualisation enhance your understanding of degradation speed?
    - **Degradation History**
        - How do you understand the historical data? Is it clear?
        - Does the visualisation enhance your understanding of your batterys degradation over time?
    - **Personalised Tips**
        - Do you understand what factors have influenced your batterys degradation speed? Are the tips clear?

- **All Recommendations**
  - Do you find it helpful to have access to all the recommendations on this screen?
  - Is it clear how to interpret and use the recommendations?
- **Overall**
  - How well do the provided pieces of information support or complement each other?
  - Is there anything else that you think might help you better understand the health of your battery?

3. **Please rate the design on a scale from 1 to 5 on the questionnaire as in Figure D.1**



1. The information provided was enough in understanding battery health.
Strongly Disagree 1 2 3 4 5 Strongly Agree

2. The information provided was clear in understanding battery health.
Strongly Disagree 1 2 3 4 5 Strongly Agree

3. The information provided was useful in understanding battery health.
Strongly Disagree 1 2 3 4 5 Strongly Agree

4. The information provided was helpful in preserving battery health.
Strongly Disagree 1 2 3 4 5 Strongly Agree

5. The overall battery condition was easy to understand.
Strongly Disagree 1 2 3 4 5 Strongly Agree

6. The information and visualization were visually attractive.
Strongly Disagree 1 2 3 4 5 Strongly Agree

Figure D.1: Example of questionnaire form for the second evaluation

E

Appendix: Evaluation 3

Scenario
Consider that you are driving to the city centre to meet a friend. You have just parked your car and are waiting for your friend inside the car. You notice a SILENT notification on your infotainment display. You open the notification centre and you see that the new notification is about your battery health.

Please explore the notification and all the information that it contains. You can interact with the design and click and explore all the buttons that you see. Describe what you see.

1. **Explore design:** Explore the design of the battery health. Describe what you see and think.
   - **Battery Health**
     - How do you understand and interpret your battery health status?
   - **Degradation**
     - How do you understand the degradation and factors that influence your degradation?
     - Do you understand what to do?
   - **Degradation History**
     - How do you understand the historical data?
   - **All Recommendations**
     - Do you find it helpful to have access to all the recommendations on this screen?
   - **Overall**
     - Does the visualisation enhance your understanding of battery health?
2. **Questionnaire:** Please fill in the questionnaire on a scale from 1 to 5. See Figure E.1 and E.2 for the questionnaire.

1. Based on the screen I have explored, I prefer battery health information to be displayed on the infotainment screen.

Strongly Disagree				Strongly Agree
1	2	3	4	5

2. I think that the information I've seen about battery health should be available on multiple platforms, such as infotainment screen and mobile application.

Strongly Disagree				Strongly Agree
1	2	3	4	5

3. I think the additional information contained within the information button helps me understand the overall battery health status.

Strongly Disagree				Strongly Agree
1	2	3	4	5

4. I find it important to include the reason why I should maintain the battery health, which is located within the information button.

Strongly Disagree				Strongly Agree
1	2	3	4	5

5. Looking at the information provided, it is well-organized for both overview and expandable view.

Strongly Disagree				Strongly Agree
1	2	3	4	5

6. I find it useful that the information includes a visual representation, such as a graph or a chart, to help me understand the content better.

Strongly Disagree				Strongly Agree
1	2	3	4	5

Figure E.1: Example of questionnaire form for the third evaluation

7. I find it useful to compare my battery health to the overall expected degradation trend.

Strongly Disagree — Strongly Agree

1	2	3	4	5

8. I find it useful that the recommended actions are tailored to my driving behaviour.

Strongly Disagree — Strongly Agree

1	2	3	4	5

9. The recommended actions are clear and will help me maintain the health of my battery.

Strongly Disagree — Strongly Agree

1	2	3	4	5

10. I find it useful to have historical data and predictions about my battery degradation.

Strongly Disagree — Strongly Agree

1	2	3	4	5

11. I don't mind receiving periodic notifications about my battery health.

Strongly Disagree — Strongly Agree

1	2	3	4	5

12. I find it useful to have general recommendations as a reference.

Strongly Disagree — Strongly Agree

1	2	3	4	5

Figure E.2: Example of questionnaire form for the third evaluation (continue)