

Designing Infotainment Interfaces to Enhance Electric Taxi Drivers Charging Understanding

Master's thesis in Interaction Design and Technologies

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ABSTRACT

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Abstract

As the shift toward battery electric vehicles (BEVs) accelerates, electric taxi drivers are facing new challenges, with long operating hours having a direct impact on the number of times the vehicle needs to be charged. The achievement of optimal charging is influenced by a variety of factors, such as the state of charge of the battery, the temperature, and the charging capacity, which are not necessarily common knowledge for many drivers. This thesis investigates how in-car user interfaces can better support electric taxi drivers in understanding and managing the charging process to achieve efficient fast charging.

A user-centered research approach was used to explore the barriers to efficient fast BEV charging. The process involved literature reviews, interviews with taxi drivers and technical experts, surveys, and benchmarking of existing vehicle interfaces. Personas, user journey maps, and a requirement list were developed to ground the design process in real world needs. Based on this foundation, initial concepts were conceived through collaborative brainstorming and their feasibility was evaluated with experts. These concepts were further developed into low-fidelity prototypes and refined in three design iterations, incorporating user feedback from both electric taxi drivers and regular BEV drivers.

Through the findings, eight design recommendations were formulated aimed at guiding the development of user interfaces designed for BEV charging. These include principles such as providing contextual and transparent information, reducing cognitive load by unifying and prioritizing key charging metrics, and ensuring interface flexibility. Although the proposed solutions were tailored for electric taxi drivers, the insights reflect broader challenges relevant to the larger BEV user base.

This thesis contributes to research on the user experience of electric vehicles, highlighting how interface design can enable drivers to make informed charging decisions. The resulting recommendations can serve as a foundation for future infotainment interface development, both in commercial and private BEV contexts.

Keywords: electric vehicle, user experience, infotainment system, electric taxi driver, fast charging, interaction design, user-centered design

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Adam El Jabaoui & Sofia Sjöblad, Gothenburg, 2025-06-13

List of Abbreviations

ABRP	A Better Route Planner
AC	Alternating Current
BEV	Battery Electric Vehicle
CSD	Center Stack Display
DC	Direct Current
E-taxi	Electric Taxi
EV	Electric Vehicle
GHG	Greenhouse Gas
ICEV	Internal Combustion Engine Vehicle
InfoVis	Information Visualization
IxD	Interaction Design
kW	Kilowatt
kWh	Kilowatt-hour
OEM	Original Equipment Manufacturer
PHEV	Plug-in Hybrid Electric Vehicle
RQ	Research Question
RtD	Research through Design
SEQ	Single Ease Question
SOH	State of Health
SOC	State of Charge
SRQ	Sub Research Question
SUV	Support Utility Vehicle
TOT	Time on Task
UCD	User-Centered Design
UI	User Interface
UR	User Recommendation
UX	User Experience
ZEZ	Zero Emission Zone



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1

Introduction

Over the years, there has been a noticeable increase of Electric Vehicles (EV) in the market, not only for personal use but also for commercial purposes, including the integration of EVs into taxi fleets. The shift from internal combustion engine vehicles (ICEV) to EVs reflects a growing commitment to addressing environmental challenges and reducing greenhouse gas (GHG) emissions. With the transportation sector contributing around 20–30% of global emissions, cities like New York, London, and Shenzhen have taken planning measures to integrate EVs into their taxi networks as an approach to promote cleaner, more sustainable urban transportation [1].

1.1 Research Problem

Electric taxi drivers have significantly different needs to that of a private user due to the nature of their work (3.1.2). With long operational hours, having a direct impact on the amount of times the vehicle needs to be charged (3.1.3).

While numerous studies have shown the use of electric vehicles in the taxi profession is environmentally efficient and can be both financially feasible and profitable, [2][3][4][5], challenges remain. Most notably, battery charging remains a central challenge in the adoption of electric taxis (e-taxi), primarily due to their limited range. This leads to frequent charging needs and extended charging durations [6][7][5][2].

Various solutions have been proposed to improve charging efficiency for e-taxis, including charging strategies such as proactive partial charging (př charging) [8] and infrastructure planning approaches such as optimal siting and sizing of charging stations [9]. These methods address broader aspects of charging logistics, focusing on systemic or infrastructural level rather than through the car's infotainment system.

1.2 Research Objective

This study narrows its focus to the driver experience, adopting a user centered approach that examines how in-car infotainment systems can support the management of the charging process. In particular, it explores how the design of infotainment system interfaces can effectively communicate key charging information to help e-taxi drivers understand the charging journey, alleviating uncertainty and frustration. The final objective is to provide a solution and design recommendations that allow e-taxi drivers to manage charging more efficiently by guiding them to achieve efficient charging through improved understanding, learning, and action.

1.3 Research questions (RQ)

To guide this study and structure the investigation, we defined the following research questions:

RQ1: What barriers prevent electric taxi drivers from fully understanding the charging journey?

- **SRQ:** How do these barriers affect decision-making before and during charging?

RQ2: What design improvements and recommendations to the infotainment system can enhance drivers' understanding of the charging process?

1.4 Delimitations

To ensure a clear research scope, we have established a set of delimitations for this study.

Vehicle type: This study focuses on BEVs, and thus the findings may not be applicable to drivers of Plug-in Hybrid Electric Vehicles (PHEV) or other non-BEV users.

User group and geographic context: The user group is e-taxi drivers operating in Gothenburg, Sweden. As a result, the findings may be influenced by specific characteristics of the city, such as infrastructure, climate, and traffic. These factors may limit the generalization of the results to other regions with different characteristics.

Time of operation: The study includes taxi drivers who primarily work during daytime hours, as the research was conducted during the day. Therefore, the findings may not be generalizable to nighttime drivers, whose charging behavior, customer demand, and access to charging infrastructure may differ significantly.

Scope: This study focuses specifically on how the in-car infotainment system can support e-taxi drivers in the charging journey. Broader systemic or infrastructural issues identified, while acknowledged, fall outside the scope of this research.

Design solutions: Any proposed interface design solutions are conceptual and developed as a part of this thesis. They are not ready for commercial use and would require further testing, validation, and refinement in real-world conditions before potential implementation.

1.5 Expected Contributions

This study contributes to the evolving research on BEV user experience (UX) by focusing on the needs of e-taxi drivers. Through direct contact with this unique user group, the study provides qualitative insights into the specific challenges taxi drivers have when managing the charging process. By narrowing the scope to the role of the in-car infotainment system, the study highlights an underexplored opportunity for improving charging efficiency and user understanding through improved interface design.

The research presents conceptual interface design solutions that demonstrate how charging power and speed information can be communicated transparently and efficiently. These prototypes serve not only as design concepts explored within the context of this

thesis, but also provide a foundation for future development and user testing. In doing so, the study offers practical design recommendations that can inform automotive UX and infotainment system design.

Finally, the study offers context-specific insights into the experiences of e-taxi drivers operating in Gothenburg, providing valuable knowledge for stakeholders such as city planners, charging infrastructure providers, and automotive companies seeking to develop more user-centered charging solutions.

2

Background

To understand the charging process of BEVs and the factors influencing charging time, it is essential to understand the underlying mechanics. This chapter begins by introducing BEVs, with a focus on battery technology, charging systems, and the key factors that impact charging performance. Following this, the role of Human-Machine Interfaces (HMIs) in EVs is discussed, particularly how they support drivers in managing charging-related information. Lastly, the chapter concludes with an overview of commercial EVs and presents Volvo Cars, the collaborators of this study.

2.1 Battery Electric Vehicles

BEVs exclusively use electrical energy from an on-board battery pack for propulsion. As a result, the vehicle does not require a combustion engine, fuel tank, or exhaust system [10]. Compared to combustion engine vehicles, BEVs can achieve up to three times greater energy efficiency [10].

2.1.1 Battery and State of Health

Lithium-ion batteries are widely used in BEVs due to their ability to store high energy density compared to other battery types, such as leadacid batteries and nickel-based batteries [11]. Two key metrics are used to monitor battery status: State of Charge (SOC) and State of Health (SOH).

SOC quantifies the remaining energy capacity in a lithium-ion battery and is displayed as the percentage of the total usable capacity. In contrast, SOH measures the battery's condition and aging, and is also displayed as a percentage value, but relative to the battery's original capacity.

The decrease in a battery's SOH results from two main forms of aging: cycle aging, which is influenced by factors such as SOC, charge and discharge current, and voltage limits during operation; and calendar aging, which occurs over time even when the battery is not in active use. As the battery degrades, its ability to hold the charge and deliver power diminishes, which shortens its driving range, charging efficiency, and overall performance in EVs [12].

2.1.2 Charging

One of the key differences between EVs and traditional ICEVs, lies in how they are refueled. The battery pack in EVs can be charged using two main methods: AC (alternating

current) and DC (direct current). DC charging, commonly known as fast charging, significantly reduces charging time. Fast charging, classified as Level 3, is a type of charging that has power levels exceeding 50 kilowatt (kW) [13]. Although, the time required to fully charge an EV is affected by both the battery's capacity and the charging station's power output. For example, to charge a battery with a capacity of 36 kilowatt-hours (kWh) in 20 minutes, it would require a station capable of supplying over 100 kW [14]. However, even if a charging station is capable of delivering high power, the actual charging speed also depends on whether the car can accept the maximum supply [15].

2.1.3 Factors Influencing Charge Time

Several factors influence the time required to fast-charge an EV. These include driving style, battery preconditioning, SOC, and battery temperature, among others [16], these factors influence the vehicle's ability to receive high power during charging [15]. Understanding how different factors impact charging may help drivers optimize their charging strategies to reduce overall charging time.

2.1.3.1 Preconditioning

Preconditioning, the process of heating or cooling the battery to an optimal temperature before charging, is a common feature in modern EVs to improve charging efficiency. A study by [16] highlights that preconditioning can reduce charging time by up to 60%. However, the authors also emphasize the importance of minimizing the duration for which the battery is kept at its optimal temperature, as the energy required to maintain it increases linearly. Additionally, they explain that a battery can warm up in different ways other than preconditioning. One way is by driving at higher speeds, which generates heat due to energy losses in the battery. Another way is by initiating charging at a lower SOC, such as 10%, because the battery can handle a higher charging current at this level. This higher current naturally produces more heat, helping the battery warm up on its own during charging.

2.1.3.2 Mitigating Lithium Plating in EV Batteries

While fast charging is more time-effective it does pose higher risk for battery degradation. Charging at faster rates leads to lithium plating i.e., the buildup of metallic lithium on the surface of the battery's anode, which causes reduced battery life and limited fast charging capability. Lithium plating is further increased by charging at low temperatures or a high SOC.

In EVs, how the battery discharges is influenced by the driver's driving habits, while the charging process follows preset rules established by the manufacturer [17]. In order to mitigate the issue of lithium plating, the constant current constant voltage (CCCV) charging technique has become the standard in battery management systems. The charging is divided into two stages, where in the first stage, the battery is charged with a constant current (CC) until it reaches a certain SOC level and switches to constant voltage (CV), initiating the second phase. The purpose of the second phase is to slow down the charging process once the SOC reaches around 80%. During the initial stage of fast charging, a high amount of power is delivered quickly. However, continuing to charge at

this high rate beyond 80% increases the risk of lithium plating, which can degrade the battery [18].

2.1.3.3 Battery Temperature

Ambient temperatures impact the temperature of the battery. The temperature of the battery has significant role on the time taken to charge. Fast charging, which normally takes 30 minutes to reach 80% SOC at room temperature, can extend to up to 90 minutes when the temperature is low [17]. Another study ran an analysis of data collected from Nissan Leaf taxis in New York and found at 0°C ambient temperature, fast charging slowed down significantly, leading to 22-36% less charge gained in 30 minutes [19].

2.2 Automotive Human-Machine Interfaces

HMIs in vehicles refer to the systems through which drivers interact with their vehicles. While many functions and information are consistent across all vehicle types, EVs introduce additional elements. These include metrics such as SOC, SOH, and Charging Power (kW). As a result, dedicated interfaces and components, such as charging views, which users use to monitor and manage their charging, have been developed to support users in managing their vehicle. As an example, users will typically check the information on SOC level and estimated range displayed on the HMI, to make the decision on when to charge their vehicle while driving [20]. However, since some drivers may lack the mental models needed to understand battery-related concepts, it is important that this information is presented in a way that is intuitive and easy to grasp [21].

2.3 Commercial EVs

Commercial EVs refer to vehicles used for work-related purposes rather than personal use. This category includes company fleets, service vehicles, public transport, and shared mobility solutions. Depending on the intended purpose of the vehicle, drivers may have significantly different driving and charging habits compared to that of an average EV driver. As described in section 3.1.3, it can be observed that e-taxi drivers face a set of challenges due to the nature of their work.

2.4 Volvo Cars

Volvo Cars is a multinational car manufacturer originating in Gothenburg, Sweden. While the company has a long history of producing ICEVs, dating back to 1927 [22], they have committed to transitioning into a fully electric car company. In 2020, Volvo Cars released its first fully electric SUV (Sport Utility Vehicle), and by 2030, it aims to manufacture only EVs [23].

Although the final solution is designed to be compatible with any car model, this study uses the Volvo EX30's center stack display (CSD), along with its associated design guidelines and components, as a reference example to visualize the final concept (See 2.1). The CSD is a 12.3" tablet integrated into the infotainment system, positioned in the center of the dashboard of the vehicle. From the CSD, drivers can adjust settings, get an overview

2. Background

of the vehicle, navigate using Google Maps, and more [24]. The current charging settings allow users to view the current battery level, amperage, charging status, start or stop charging, limit the electrical current for AC charging, and manage charging schedules [25].

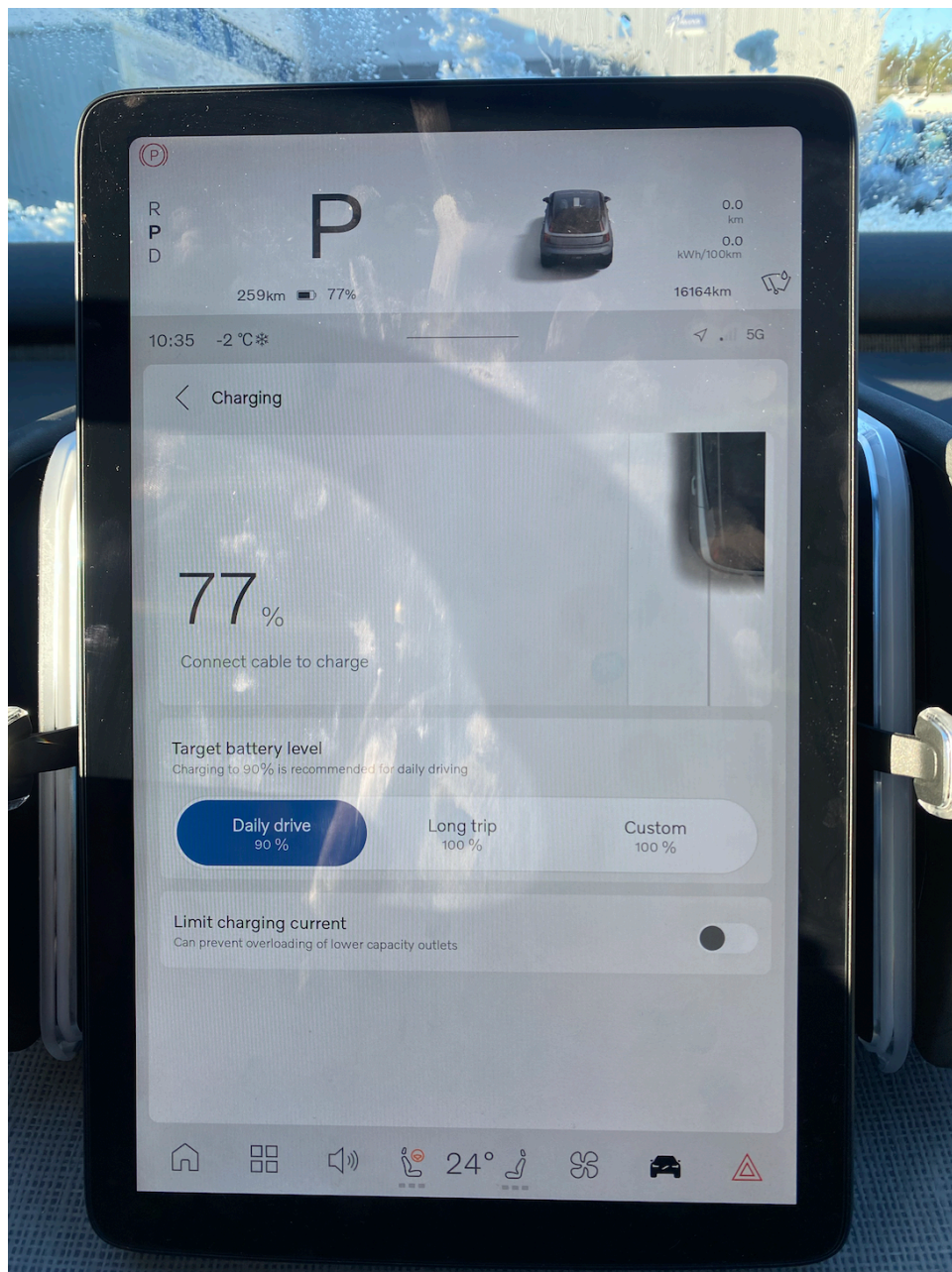


Figure 2.1: CSD in the Volvo EX30

3

Related Work

In this section, we explore studies on Electric taxis (e-taxi), examining taxi drivers' objectives, working patterns, and charging and driving behaviors. We also discuss the challenges they face, the habits they develop, and the incentives designed to support the adoption of e-taxis in Sweden.

3.1 Electric Taxi

The issue of global warming has made the reduction of air pollutants an important policy focus in urban areas [2]. Studies have highlighted that the promotion of EVs in the transportation sector will excessively reduce GHG emissions and decrease the dependence on fossil fuels. Taxis, in particular, are major contributors to roadside pollution and GHG emissions. Consequently, electrifying the taxi fleet has been proposed as an effective solution strategy to mitigate these issues[6].

Hagman and Langbroek discuss the conditions for e-taxi drivers in the Stockholm region. They mention that, despite the environmental benefits of EVs, the shift to EVs in the taxi industry has been relatively slow due to challenges, such as range limitations, charging, and cost issues. However, they also point out that in certain cases, EVs compete with ICEVs due to their lower operational costs. This makes EVs particularly suitable for taxi companies, which often operate with high annual mileage and relatively short trip lengths. The authors argue that the switch to EVs could be particularly attractive for taxi companies [3].

E-taxi drivers also exhibit distinct driving and charging patterns compared to personal EV users and other non-personal EV drivers. These differences arise from the unique nature of taxi operations, including work schedules, time pressure, and specific objectives.

3.1.1 E-taxi Objectives

Public vehicles, unlike private cars, have different user groups with different requirements and interests. Taxi drivers operate their vehicles several hours per day, and they have to earn their living while driving [7]. However, it is also important to recognize that there are various actors in the e-taxi industry with different objectives and conditions as well. For instance, drivers invest their time, but are not required to make capital investments like carriers. However, both carriers and drivers have the objective to maximize revenue in order to maximize profits and wages, especially if wages are linked to revenues [3].

3.1.2 Work Nature and Schedule

The work nature of taxi drivers is very unique. Taxis do not operate on a fixed schedule but rather on a variable one. However, these schedules are time rigid, meaning the drivers have limited flexibility to take breaks and charge their vehicle [9]. Generally taxis have two types of stationary stops, breaks and shift changes [7]. Some e-taxi drivers work in shifts (dual-shift taxis) operating continuously, sometimes operating the vehicles for two shifts per day [26][3].

Additionally, taxis typically have high annual mileage and relatively short trip lengths [3] and their salaries are based on the daily revenue they gather from driving customers [27].

3.1.3 Charging

Several psychological factors play a significant role in the use of e-taxis. Taxi drivers prioritize performance, which is closely linked to mileage anxiety, charging facility access, recharge times, and operational costs. To improve the performance of e-taxis, manufacturers must focus on developing innovative energy management technologies that reduce recharge times and improve operational efficiency [6].

3.1.3.1 Challenges

E-taxi drivers face several challenges related to charging, which can significantly impact their operations and revenue. The time spent charging can affect working hours and cause potential revenue loss [5][6], as drivers are only able to charge during stationary time, unable to serve passengers during these intervals [7]. This limitation becomes even more significant, since salaries are based on daily revenue gathered, effectively making charging unpaid work time [3]. This issue is particularly significant for dual-shift e-taxi drivers, where limited time between shifts makes charging even more difficult [3][26].

Rigid schedules further complicate the charging process, limiting charging flexibility. Range anxiety can be exacerbated for drivers who are less flexible in their charging behavior [9]. The need for more thoughtful planning around charging also creates additional stress for taxi drivers [3].

In a field study [28], it was found that despite initial assumptions that overnight charging would suffice for a full day's driving, drivers often engaged in opportunity charging during the day to extend range and increase revenue. Drivers explained that spotting a fast charger presented a strategic opportunity to recharge and access longer, better paid trips. However, even with access to fast chargers, the time spent charging remained undesirable, indicating that it continued to be a source of friction in daily operations. In some cases, between one to six times a month, drivers prioritized fast charging over accepting available rides, regardless of their current SOC ([28]). Furthermore, the study revealed that each of the two participating drivers declined approximately five rides due to insufficient battery range ([28]).

Building on this, one challenge is the unpredictability of passenger bookings. Since drivers often do not know the exact destination of a trip at the time of booking, they may face situations where the available battery range is insufficient to complete the trip, and the trip must be declined, affecting revenue [3]. In some cases, small battery size and the

need for frequent charging can exacerbate this issue by increasing the risk of running low on energy too often, leading to further revenue loss [7].

Running out of battery is a critical issue, resulting in loss of earnings for the rest of the shift, however, this worst case scenario can be mitigated by the availability of fast charging options [3]. The implementation of large-scale fast charging points at the waiting site can reduce time expense and improve practicality of e-taxi drivers [29]. However, even with fast charging, charging typically exceed one hour [6]. E-taxis also require more frequent charging compared to their petrol or diesel counterpart, with each charging session taking between 30 to 60 minutes, making frequent charging a limitation in itself [5]

A survey revealed that the majority of drivers (44.27%) considered 20 minutes the longest acceptable charging time per shift. This preference was linked to the fact that the majority of participants (36%) deemed 250 km per full charge as the minimum acceptable range. In fact, 65% of drivers were found to prefer longer range over faster charging times, indicating that many find charging as inconvenient or time consuming. Long charging times and range limitations remain key obstacles for the broader acceptance of e-taxis [7].

Lastly, carriers and drivers have some different objectives. One study states that there is a danger that driver's charging behavior will not be optimized considering time gains and monetary costs. Many drivers are willing to pay a premium for ultra fast charging stations, to minimize downtime, though the cost is generally borne by the carriers [27].

3.1.3.2 Habits

Due to the nature of the e-taxi drivers work, the objectives and the challenges with charging, their charging habits are affected. E-taxi drivers rely on DC charging during shifts to reduce downtime [4], and tend to recharge their vehicles during idle hours to ensure sufficient energy for passenger transport, mitigating range anxiety [29]. Temporal charging behavior is affected by passenger demand, with most charging occurring late at night or during shoulder periods when there is less passenger requests, to minimize lost income [4]. However, in Stockholm, e-taxi charging was observed primarily from early morning to early afternoon, aligning with Zero Emission Zone (ZEZ)((3.1.5) orders that peak during those hours [27].

Charging strategies and behavior also vary by taxi type and operational factors. Some drivers prioritize predictability and efficiency by adhering to fixed location and schedules, while others adopt flexible charging and driving behavior. For instance, single shift taxi drivers tend to charge outside peak demand to take advantage of station availability during shoulder hours [26]. Hagman and Langbroek identified three main charging strategies during the shift: charging during lunch breaks, charging during quieter hours while waiting for customers (sometimes coinciding with lunch breaks), leading to many but short duration charging events, and lastly combining charging with visits to fitness clubs, for which some carriers provided memberships [27].

The time at which e-taxi arrives at the charging station is influenced by the SOC [9]. Many drivers charge their vehicles when the SOC falls below a certain threshold, and then make a full charge. This behavior helps decrease the frequency of charging visits and reduces time spend at charging stations [8]. This fully recharging strategy could also be done to minimize uncertainty [26]. One study found that 59% of drivers charged

between 30% and 50% SOC, while only 4% allowed SOC to fall below 20%. Nearly all (99.26%) waited until the SOC exceeded 90% before ending their charging sessions [29].

Unlike private EV users, who primarily charge at home overnight, e-taxi drivers must charge during shifts [27]. Tesla e-taxis required about 1.5 hours of charging per shift [3], whereas dual- and single-shift taxis had a mean charging duration of approximately 3 hours [26]. Most e-taxis recharge their vehicles two [29][26] to four times per day [4], often returning to recharge their car after each shift [29]. The study by [29] did not focus on DC charging.

3.1.4 Driving behavior

The underlying assumption is that the usage behavior of e-taxis may differ from that of conventional taxis, due to factors such as extended charging times and shorter driving range of e-taxis [7]. Due to the long charging time, e-taxi drivers require careful planning of charging times and locations within their operational schedules to avoid conflicts with peak demand periods and areas, and potential shift changeovers. This not only affects profit perception, but can also affect behavior like passenger seeking strategies, and relocation dispatches [26].

A study found that e-taxi drivers primarily operate through reservation via telephone or website, and on-site calling, rather than roaming the streets for passengers mainly due to range constraints. They would wait at locations such as transportation junctions, parking lots, and arterial streets [29]. Another study found that e-taxi- and ICEV drivers do not share the same pick up patterns across the city of Stockholm. A pattern of higher E-taxi pick ups could be seen in areas with presence of a fast charging station [3].

In Beijing, by the end of 2014, 2,550 e-taxis operated both in urban and suburban areas, except for Mentougou. Urban e-taxis had greater mobility, but drivers rarely ventured beyond the city due to range anxiety, as urban areas had better charging infrastructure [29]. Additionally, another study found that e-taxis driving patterns were influenced by charging station locations, with drivers tending to operate near these stations. A lack of sufficient charging stations contributed to range anxiety. As a result, e-taxis had smaller coverage areas, shorter trips, and less route flexibility, typically operating within a 4.91 km range between OD (origin and destination) [30].

Furthermore, some e-taxi drivers concentrate their operations in inner-city ZEZ (3.1.5) to maximize efficiency by actively seek ZEZ orders [27].

3.1.5 Incentives

In regions like Sweden, favorable government policies help offset time losses from charging, making it easier for e-taxi drivers to earn a higher revenue [6].

The initiative Nollzon (ZEZ) in Sweden, is aimed at boosting the demand for e-taxis. ZEZ compensates for e-taxis higher investment cost and additional time cost needed for charging. Organizations that have joined ZEZ will automatically prioritize e-axis in their booking system, reducing their waiting time per booking and increasing their likelihood to get prebooked (ZEZ order) compared to ICEV taxis [3][27]. Furthermore, in Arlanda (international airport of Stockholm) there is a queuing system based on vehicle emission

and drivetrain technology, therefore e-taxis have the shortest queuing time, being able to pass the queue in many cases [3].

While other incentives, such as the bonus-malus system in which BEVs are subsidized with 60,000 SEK and company BEVs are qualified for a 40% tax discount [31], we have focused on incentives specific for e-taxis in Sweden.

4

Theory

This section introduces the relevant design theories and frameworks that form the theoretical foundation for this research. The concepts of user experience design, user-centered design, interaction design, research through design, design thinking, user interface design, and information visualization are introduced which are used to guide the design process.

4.1 User Experience Design

UX can be defined as an experience that "encompasses all aspects of the end-user's interaction with the company, its services, and its products." [32]. UX can be divided into seven key factors: useful, useable, findable, credible, desirable, accessible and valuable [33]. Useful refers to whether the product effectively fulfills its intended purpose. A usable product allows users to achieve their goals efficiently and effectively. Findable means that users can easily locate the product or the information they need. Credible indicates the trustworthiness and reliability of the product. Desirable is reflected in the product's brand image and aesthetics, making it appealing to users. Accessible ensures that the product can be used by people with a wide range of abilities and disabilities. Lastly, a product is valuable if it provides significant benefits and value to the user. In the context of this research, these key factors will be used as a reference to guide the development of the solution, ensuring that it addresses the UX.

4.1.1 User-Centered Design (UCD)

Design is not always intuitive, which can leave users frustrated and unable to complete a task. UCD is a design approach based on the iterative involvement of end users, ensuring their feedback shapes the evolution of the design [34] to enhance its usefulness and usability [35], ultimately improving the overall UX [33].

A key aspect of UCD is understanding who the users are and how to involve them in the design process. Users can generally be categorized into three types:

- Primary Users - Those who directly use the product.
- Secondary Users - Those who will occasionally use the product or use it through an intermediary.
- Tertiary Users - Those affected by the use of the artifact or make decisions about its purchase.

The importance of UCD lies in the involvement of users in the design process, whether that is by consulting users about their needs and involve them at specific times during the design process, or involve them as partners with designers throughout the design process for greater influence on the design [34].

Reflecting this approach, our study involves e-taxi drivers as primary users, ensuring the solution directly addresses their specific needs. Ordinary BEV drivers are considered secondary users, as they fast charge less frequently, and therefore use the product only occasionally.

4.1.2 Interaction Design

Interaction Design (IxD) is the design of interactive products and services, focusing on how users engage with and experience them [36]. While some definitions focus on the design of products that are interactive, other focus on the interaction with computer based systems [37]. As a subdiscipline of UX design, IxD plays an important role in shaping the way users interact with a product. UX design entails shaping the experience of using a product, and a big part of that involves the needed interaction between the user and the product [36].

For this study, the solution is evaluated through user interaction with a UI through a screen display, focusing how users engage with the interface and how the interaction and overall UX can be improved.

4.2 Research Through Design

RtD is an approach where the design process is guided by scientific methods to gather insights about the specific context for which the design is intended [38]. This approach focuses on proposing designs for the future, based on information gathered from the stakeholders, insights from behavioral theory, and modern technology [39]. While RtD may resemble design practice, it is more systematic and reflective with detailed documentation [39]. However, unlike traditional scientific theories, RtD is often generative rather than falsifiable, making it difficult to evaluate using conventional scientific criteria. As a result, some scholars have proposed standardizing RtD to establish clearer methodologies and evaluation frameworks [40].

This study applies the RtD approach by developing a design artifact grounded in real-world insights, primarily gathered through interviews. A systematic and reflective design process, consisting of iterative prototyping, evaluations, and analysis, is conducted to generate a set of design recommendations that contribute to design knowledge.

4.3 Design Thinking Theory

There are many definitions of design thinking. However, a generally accepted definition has yet to emerge. Many of the early prominent practitioners have not offered a detailed definition [41]. The first design thinking research symposium was an exploration of research in designing and design methodology, viewed from a design thinking perspective,

and since then many models of design thinking have emerged [42]. Design thinking explores both the problem and solution spaces, unlike science, where the problem is fixed. It combines divergent thinking (exploration) and convergence thinking (synthesis) to generate viable and novel solutions [43]. The design thinking process can have anywhere from three to seven phases. However, we focus on the five stage design thinking model proposed by Hasso Plattner Institute of Design. The five stages proposed are Empathize, Define, Ideate, Prototype, and Test [44].

In the context of this study, the Empathize stage is reflected in interviews with taxi drivers and BEV users to understand their needs, pain points, and charging behavior in real-world contexts. The Define stage involves the creation of design artifacts such as personas, user journey maps, and user requirements to frame the problem statement. During the Ideate stage, initial design concepts are developed, through brainstorming, to address the identified needs. The Prototype stage involves the creation of the interactive prototypes, and lastly, the Test stage consists of user evaluations to gather feedback and inform further refinements.

4.3.1 Divergence and Convergence

Design thinking can be described as the sequence of the diverging and converging of solutions. In the diverging phase, choices are created, while in the converging phase, choices are made. Diverging is considered as the generation of ideas while converging as the selection of ideas [45]. For instance, in the double diamond (5.1), you first diverge in the explore phase (Empathize), and then you converge in the define phase (Define). In the second diamond, when it comes to product design, divergence can expand the search scope of solutions, so as to find more creative design ideas and convergence can help find suitable sub solutions and evaluate the optimal design scheme from multiple alternatives [46].

4.4 User Interface Design

The UI is the part of the computer system that the user interacts with in order to achieve their tasks and goals. The use of computer systems has increased, making the importance of a good UI even more significant. A well-designed UI should be easy, natural, and engaging [47]. A common UI for software applications is a graphical user interface (GUI). Graphical design methods typically follow a design process that is catered towards the visual communication, which includes using established design guidelines, usability criteria and task-oriented knowledge [48]. The solution of this study is intended for the UI of the CSD in an EV, aiming to follow established guidelines and best practices for GUIs to improve usability and ensure effective interaction.

4.5 Information Visualization

InfoVis refers to the use of computer-supported interactive visual representation of data to enhance cognition. InfoVis leverages the dynamic, interactive, and cost-effective capabilities of computer graphics to develop new external tools that enhance cognitive abilities. The focus is on gaining insight through visualization, viewing it as a means to improve

understanding rather than simply creating visual artifacts ([49]). A commonly held view in InfoVis is that visualization should present data as clearly as possible, avoiding distracting visual elements and irrelevant information. By optimizing the cognitive efficiency of the external representation, designers can enhance a visualization's ability to support fast and accurate communication of information ([50]).

In the context of this study, the InfoVis in the CSD has a significant impact on how charging-related data is interpreted by users. A primary goal is to display information in a way that users can easily interpret and act on. Furthermore, the user evaluations are used not only to test usability but to understand how visual elements were interpreted, allowing for iterative refinement of the visual encoding.

5

Methods

In this section, we outline the key methodologies used in our study. Our approach follows the Double Diamond framework, ensuring a structured and iterative process. Additionally, the specific methods applied in each phase are described.

5.1 The Double-Diamond

The double-diamond is a standardized design methodology developed by the Design Council and it is defined by 4 key phases: discover, define, develop and deliver. The discover phase is dedicated to establishing user needs. In the define phase, the discovered needs are analyzed and refined into an end goal or brief. The develop phase is dedicated to iterative development and testing. Lastly, the deliver phase is when the final product is launched [51].

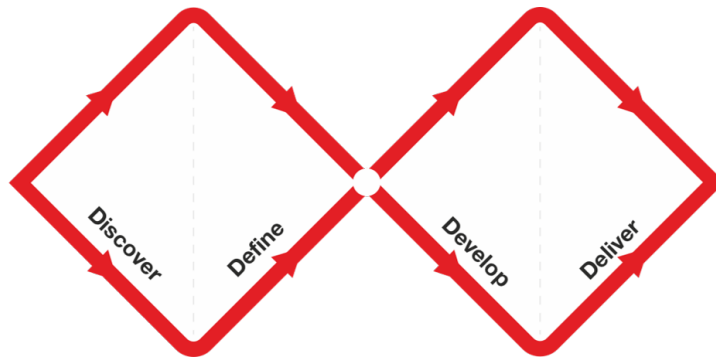


Figure 5.1: Double Diamond Design Process. Source: Design Council [52]

5.2 Methods For Discover

5.2.1 Questionnaire

A questionnaire is a list of questions [53] administered to respondents with the aim of gathering useful and accurate information from them to pass on to the inquirer [54]. It is the primary method for collecting quantitative, primary data in a standardized manner, ensuring consistency and coherence for analysis [53]. The first step in designing a questionnaire is to determine what data is needed [54]. Questionnaires can typically include four types of questions: contingency questions, matrix questions, closed-ended

questions, and open-ended questions. While questionnaires are generally cost-efficient, being inexpensive to design and administer, they can also be time consuming [53].

5.2.2 Interview

Interviews are an effective method for gathering qualitative data, particularly when seeking to explore opinions on complex and sensitive issues. Interviews provide a means to access individuals' thoughts and perspectives on matters that are not directly observable. The goal of interviews is to uncover what is in someone's mind, allowing the respondents viewpoint to emerge. When conducted properly, achieving cooperation, interviews can give high quality, reliable information, as they offer the opportunity to clarify, amend or probe deeper if initial responses seem inadequate or incorrect. Additionally, Interviews are flexible, as they can be adapted to suit the level and personality of the respondents [55].

There are several types of interviews, ranging from informal to formal. Informal interviews are adaptable to the individual situation, allowing respondents to feel more relaxed and unassisted. On the other hand, structured interviews follow a predetermined set of questions with each respondent, making it easier to organize and quantify the findings [55]. Between these two extremes, lies semi-structured interviews, which combine elements of both. These interviews offer flexibility, allowing the interviewer to ask open-ended questions within a structured framework [55][56].

Saturation in qualitative research is important, making sure additional data do not lead to any new insights (codes) leading to new emerging themes [57]. However, interviews can be time-consuming, and if a large number of interviews are conducted, the research may become expensive in terms of time and resources. This increases the risk of having small, potentially unrepresentative samples [55]. To avoid these challenges we aimed at managing around 15 respondents.

5.2.2.1 Expert Interview

These interviews focus on individuals who are experts in their respective domains and have specialized knowledge. Interviewing experts offers several advantages, providing insights into micro-processes and decision-making, contributing to context-specific information, and helping interpret correlations in analyzed data. Expert interviews are typically conducted in a semi-structured format, with predefined questions. Since it can be challenging to reach a large number of experts, and because their insights may be affected by personal biases or limited representativeness, combining expert interviews with another qualitative data collection method can help reduce bias and strengthen the validity of the findings. [58]

5.2.3 Focus Groups

A focus group is a qualitative method where a small group of selected participants discuss and evaluate a specific topic, guided by a moderator who facilitates interaction and keeps the discussion aligned with the research goals. This approach enables the collection of diverse viewpoints simultaneously and allows participants to reflect on and build upon each others ideas. Focus groups are considered cost-effective and can reveal user needs and potential issues that may not emerge through other methods. [59].

5.2.4 Literature Review

A literature review summarizes and evaluates the state of knowledge or practice on a particular subject and is used to address the concept of a contribution to knowledge. It can serve as an end in and of itself, a preliminary stage in a larger research project, or a component of a finished report. Its purpose is to help situate your proposed project in relation to existing knowledge and to show what new conclusions might result from your research. Additionally, a literature review helps identify the claims made in a literature and assess the strength of the support offered for those claims [60].

5.2.5 Data Analysis

Data gathered from data collection often takes the form of words, texts, and sometimes images. This data is analyzed through a process of transformation and interpretation [61].

The analysis begins by organizing the data, such as identifying codes in transcripts. These codes are then grouped into categories, which are further refined to develop overarching themes. This process ultimately provides a summary of the data [61].

The researcher plays a crucial role in interpreting the data. Since the analysis inevitably involves subjective decisions, it is important to document the process to ensure a clear audit trail [61].

5.2.6 Benchmarking and rating tools

Benchmarks are a tool for competitive comparison and evaluation of competing systems or components according to specific characteristics [62]. Benchmark scores serve as a measure of performance [63].

Tools for the non-competitive system evaluation and comparison can be defined as rating tools, which are intended for a standardized method of evaluation e.g. for research purposes. Rating tools can also be standardized and should generally follow the same design and quality criteria as benchmarks [62].

5.3 Methods For Define

5.3.1 Affinity Mapping

Affinity mapping is an intuitive data analysis technique used to identify themes by organizing collected data points into distinct clusters based on their affinity. The process of creating an affinity diagram begins by writing down the observations, interview quotes, or other collected data points from the user studies on individual notes. These notes are then spatially grouped together based on their similarities [64].

5.3.2 Personas

A persona is a description of a user's characteristics and their goals. The purpose of using a persona is to help designers understand the users behavior patterns and can be used

to guide design decisions. Typically a persona includes a picture and text description of the user and is based on data from user studies [64].

5.3.3 Requirements

A requirement is a specific need or constraint that a design must satisfy to be considered successful. Requirements can be identified through reading and interpreting documentation, design artifacts, and technical constraints. These requirements guide decisions throughout the design process.[65]

5.3.4 Requirement Prioritization

Requirement prioritization is used to organize requirements according to priority based on the stakeholders point of view. There are various established techniques that can be used to prioritize requirements, one being the MoSCoW prioritization technique. MoSCoW is a technique used to prioritize requirements by organizing into them four hierarchical categories: must have, should have, could have and won't have [66].

5.4 Methods For Develop And Deliver

5.4.1 User Journey Map

A user journey map illustrates the process a user goes through when interacting with a product or service. User journey mapping focuses on understanding relevant user processes in order to identify areas that require further user research. The goal is to quickly understand relevant user processes and identify and plan necessary UX activities [67].

5.4.2 Brainstorming

Brainstorming is a method for generating ideas, increasing creative efficacy, or finding solutions to problems, either individually or in groups. In this case, the brainstorming is conducted in a group of two, the authors of this thesis. The basic procedure involves posing a clear problem, question, or topic and then asking the group to generate solutions or ideas without criticism or limitations on the type or number of ideas (diverge). Finally, the group discusses, critiques and prioritizes the brainstorming results for later action (converge) [68].

There are three fundamental principles for group brainstorming:

- Aim for quantity - The goal of brainstorming is quantity. The primary criterion for the success of brainstorming is the number of ideas generated.
- Defer judgment about the quality of ideas - Do not criticize the ideas of others, either implicitly or explicitly.
- Encourage new and wild ideas - Ideas can be generated by synthesizing, stretching, applying metaphors, or improving existing ideas.

Brainstorming is commonly used in the early to middle stages of product development, though it is applicable whenever a new idea or solution to problems are required.

There are various types of brainstorming methods, such as brainwriting, where participants write ideas down instead of speaking them out loud, and braindrawing, where participants sketch or draw ideas rather than writing them [68].

5.4.3 Prototyping

A prototype is an artifact that approximates a feature of a product, service, or system. It serves as a pre-production representation of a concept, enabling designers to explore, communicate, and test design ideas. Prototypes play a crucial role in the design process by facilitating refinement, communication, exploration, and active learning. They help validate requirements, identify design flaws, test usability, explore new concepts, and enhance designers' understanding of complex phenomena. Prototypes allow for the exploration of new concepts through both divergence and convergence, which is important in the early stages of design. Furthermore, prototyping provides an opportunity for designers to learn from failure, re-evaluate concepts, and improve them [69].

The prototyping process varies across industries, with distinct strategies depending on whether the goal is to achieve specifications or to explore and develop new concepts [69].

5.4.4 Heuristic Evaluation

Heuristic evaluation is a method that identifies usability problems. It is conducted by evaluators who judge an interface according to their own opinion based on certain guidelines. The guidelines can be established usability heuristics. An evaluation session typically lasts 1-2 hours, where the evaluator refers to a list of usability principles, such as Nielsen's 10 usability heuristics [70], while interacting with the interface. A task list and heuristic-based questions can be used to guide the evaluation. The experimenter is present during the session and can answer questions or give hints if the evaluator asks for it. During the evaluation, the evaluator's comments are either written down or spoken aloud and recorded by the experimenter. Each usability problem is noted along with the heuristic it refers to. [71].

5.4.5 Usability Testing

During usability testing, participants are invited to either perform some pre-defined tasks or freely interact with the product while being observed. The aim is to identify any errors or difficulties arising when interacting with the product. The task-completion time, number of errors and number of completed tasks are examples of data that is recorded during the sessions [72].

5.4.6 Think-Aloud

The think-aloud technique is a qualitative data collection method in which participants express verbally their thoughts about their interaction experience. This allows researchers to gain valuable insights into the user's perspective on tasks, design, expectations, likes, dislikes, and more. The technique is particularly useful during prototype walkthroughs or UX inspections, as it helps uncover usability issues and user reasoning behind certain actions. Additionally, the think-aloud method is effective in assessing emotional impact,

since it captures the user's internal thoughts and feelings. Overall, it is a powerful tool for any UX evaluation involving user participation ([73], p.440-441).

6

Time Plan

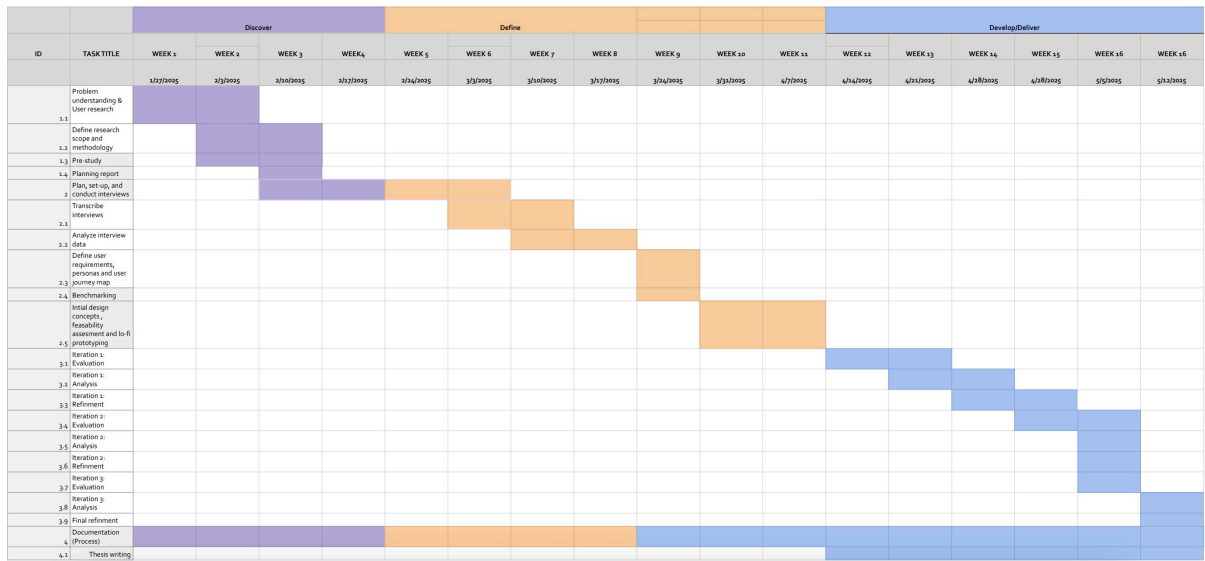


Figure 6.1: Time Plan

7

Process And Results

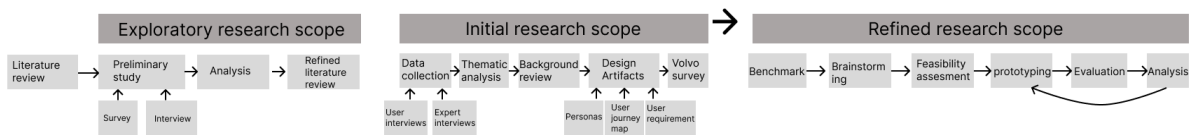


Figure 7.1: Process

7.1 Exploring

The aim of the exploring phase was to gain a foundational understanding of the research domain, identify existing knowledge gaps, and gather initial user insights to inform and refine the research direction.

The exploring phase involved three main activities: a broad literature review, a preliminary study (pre-study), and a focused literature review. These were conducted to form foundational knowledge, gather preliminary user insights, and deepen understanding of key themes. Each component informed the next, ensuring that findings guided the direction of the research.

7.1.1 Broad literature review

Aim

The aim of the broad literature review was to gain an overview of existing research on EV use in taxi operations, identify common found challenges, and find gaps in the current knowledge. This helped us understand what has already been studied, what remains underexplored, and guided the initial direction of our research.

Process

To conduct the broad literature review, we used Google Scholar to search for articles related to the chosen scope related to non personal EV use. By reviewing numerous articles, we were able to identify existing challenges, recurring themes, and potential gaps in the current body of research. This helped us pinpoint areas that had not been extensively explored and provided a foundation for narrowing our research focus.

Results

The broad literature review helped us define a user group: e-taxi drivers operating shared vehicles. While the e-taxi drivers may not be experts in a technical sense, they are considered expert users since they interact with these vehicles intensively within a professional context. Their everyday use gives them practical knowledge which is considered grounded and relevant even though not formal expertise, therefore making them a unique group with potential for further research, particularly on shared EVs in taxi operations.

The review revealed several recurring themes and challenges related to EV use in taxis. While some research has addressed range inaccuracies and found that they are generally not an issue for experienced users, it was also noted that range estimation is typically based on the vehicles previous driving patterns. Since many taxi drivers share vehicles, a potential problem arises: the inaccuracy of range estimation might be amplified in shared operations. Our pre-study therefore focused on the following research gap:

Range estimation and driver trust in shared vehicle operations.

7.1.2 Preliminary Study

The aim of the preliminary study was to assess the relevance and feasibility of our provisional research direction by exploring the research gap identified through the literature review, focusing on range estimation and its impact on dual shift e-taxi drivers. The goal was to validate an initial RQ and gather early insights to refine the main study's direction.

The pre-study involved two main activities: surveys with taxi drivers in person and an interview with an EV expert. We used a structured set of questions for both. E-taxi drivers were approached directly in the field, while the expert was contacted through professional networks. All responses were gathered for analysis later.

7.1.2.1 Taxi survey

Aim

The aim of the taxi survey was to get insights from e-taxi drivers about their experiences with EVs, focusing on range estimation and shared vehicle use. This to help confirm the initial research scope from the literature review, while also leaving potential to uncover any additional or larger issues. By conducting face-to-face surveys, the goal was to explore practical challenges and refine the study's research focus.

Process

We conducted face-to-face surveys with five e-taxi drivers in central Gothenburg. The drivers were approached during breaks while waiting for customers. The in-person method helped address language barriers and digital literacy issues, enabling better communication and greater trust, which improved data reliability. The questionnaire, created in Google Forms, was administered orally due to the participants' preferences and environmental setting. The survey consisted of five closed-ended questions and one open-ended question for general comments. However, the oral format led to richer responses, with participants elaborating on the closed-ended questions as well.

Additionally, no recordings were made, as this was not specified in the consent form in the questionnaire, and the outside environment in the central city presented challenges for sound quality. Responses to the multiple-choice questions were documented manually, and participant statements (extra comments) were noted down, where possible, and confirmed during the interview.

Participant ID	BEV experience as a taxi
1	-
2	2
3	4
4	2
5	4 months

Table 7.1: Experience with BEVs e-taxi survey

Analysis

The quantitative data was automatically graphed by Google Forms and thus, we were able to use the graphs to examine the data. The quantitative data provided insight into whether the drivers shared the same views.

The qualitative data, consisting of additional comments noted down during the oral survey, were transferred onto individual post-it notes in FigJam. Once all comments had been transferred, both researchers collaboratively reviewed the notes, discussing each one to identify similarities and potential groupings. These groupings led to the emergence of themes (see 7.2). Where needed, the themes were further refined and regrouped to better reflect the meaning in the participants responses.

Results

A total of 3 main themes were identified during the qualitative analysis:

- Inaccurate range estimation and familiarity with real-world performance**
 Although the drivers generally mistrusted the range estimation, as shown in the quantitative data, where all five participants reported having only somewhat to little trust, and noted that discrepancies between the estimated and actual range occurred sometimes (2 participants), always (2), or often (1). The qualitative data indicated that this was not a significant issue. The e-taxi drivers were familiar with their vehicles' actual performance and were able to manage range expectations accordingly, possibly due to experience, the majority having 2-4 years of BEV experience.

If there is 290 km (range estimation), maybe I have 245 or 250 - noted comment

- Charging** A number of issues (sub themes) were related to the need for charging (main theme):

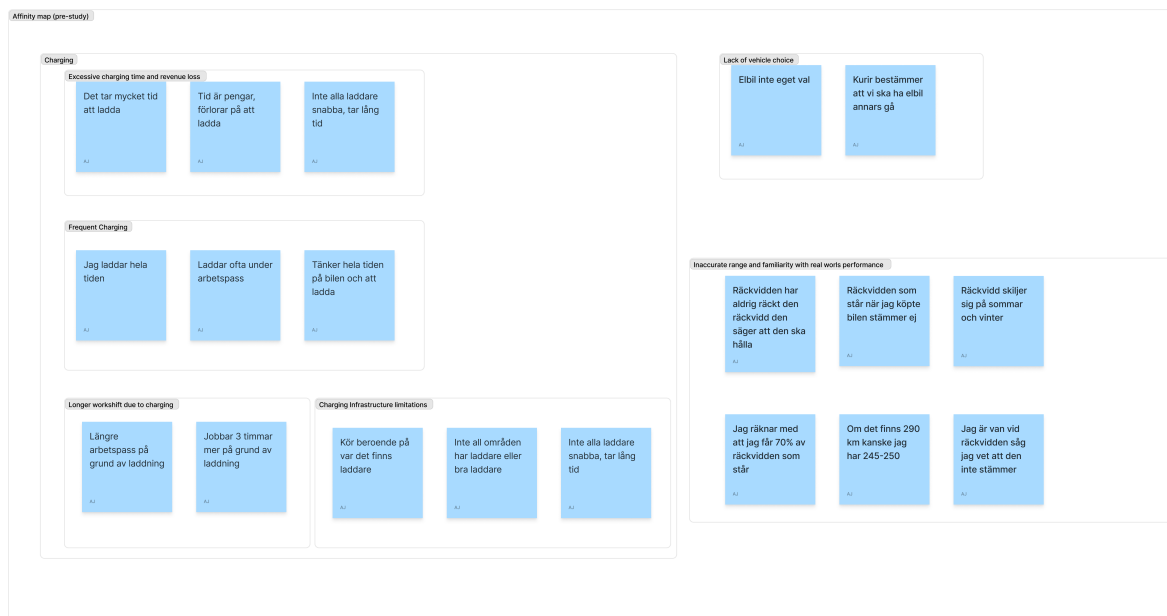


Figure 7.2: Affinity map pre-study

- **Frequent charging and mental load:**
Drivers frequently need to charge their vehicles throughout the day, which can lead to a mental load from always having to think about charging.
- **Excessive charging time and revenue loss:**
The time required to charge the vehicle results in significant downtime, which can impact drivers' ability to generate income.
- **Longer work shifts due to charging:**
As a result of charging, drivers work extended hours to make up for lost time.
- **Charging infrastructure limitations:**
Drivers noted that the availability of charging stations were unreliable or insufficient, especially in certain areas, adapting by staying near locations with good charging station infrastructure.
- **Lack of vehicle choice**
It was expressed that using EVs was not a personal choice but a mandate from the taxi fleet.

7.1.2.2 Expert interview

Aim

The aim of the expert interview was to gain a broader understanding of EVs, with a particular focus on their use in professional and shared-driving contexts. This is to further validate the research scope, explore the identified research gap, and uncover related issues for potential refinements. The experts input aimed to complement the findings from the taxi driver survey and provide a broader, industry-based perspective on the insights gathered.

Process

An asynchronous interview was conducted with a BEV expert at Mercedes-Benz USA. The asynchronous format was necessary because the expert's responses had to be reviewed and approved internally by Mercedes. This approach allowed for thoughtful, accurate input while respecting corporate protocols.

Communication took place via email, where 18 interview questions, a consent form, a demographic survey, and the interview's purpose were sent for approval. Once approved, the expert provided written responses in a returned document.

Profession (Title)	Industry Sector	Years of BEV Experience as a Taxi
Senior Manager Electrical Drive	Automotive	23

Table 7.2: Demographic table of technical experts

Analysis

Despite thematic analysis traditionally being designed for multiple interviews, it was suitable here due to the rich, detailed nature of the single expert interview, which provided enough depth to identify meaningful themes (7.1.2.2).

The process began with multiple readings of the full transcript to become familiar with its content. During the final reading, key segments were highlighted and afterwards annotated with code labels based on their topics. All codes were generated inductively, reflecting the topics raised by the interviewee, rather than being derived from a pre-existing theory or our interview questions.

After coding the entire transcript, the codes were reviewed and discussed, leading to the emergence of themes where multiple segments shared the same code or had similar codes. These themes were further refined through discussion to ensure they accurately represented the underlying data. Finally, the findings of each theme were condensed by writing brief summaries in our own words while ensuring staying grounded in the expert's responses.

Results

The analysis of the interview resulted in several key findings. The summaries for each theme are as follows:

Fast charging and infrastructure remain key challenges for EV adoption. Reliable, accessible, and secure charging networks are essential. Fast charging plays a critical role in minimizing downtime and supports operational efficiency, while technologies like dynamic wireless charging present promising solutions for long-term scaling.

"Optimize vehicle downtime by investing in higher charging speed capability on the vehicle as well as a fast-charging station on the infrastructure side. Dynamic wireless charging presents a futuristic opportunity to significantly reduce charging downtime, once the technology and costs challenges are fully optimized."

"Battery degradation and maintenance is a concern in high-power charging/discharging environments", especially for work vehicles that are in constant use. The high-voltage battery accounts for 3040% of the total vehicle cost, making its longevity critical. Following OEM maintenance schedules and best practices can help preserve battery health.

Sustainability in EVs is improving through advances in battery recycling, second-life applications, and more durable battery chemistry. These developments help reduce environmental impact across the vehicle lifecycle and align EV adoption with long-term climate and resource goals.

"Advances in high voltage battery recycling and second-life applications are improving the sustainability of BEVs."

Range and range estimation is influenced by multiple factors, including driving behavior, weather, terrain, speed, and use of features like climate control. In multi-user vehicles, estimation can be inaccurate if it relies on one drivers habits. Some BEVs adjust instantly using driver profiles.

"Important parameters include [...] driving behavior, temperature extremes, weather, traffic, climate control, and speed."

Range anxiety is common among first-time BEV users, rural and low-income drivers, and long-distance commuters. Education, better UI, and infrastructure improvements are important for addressing this.

"Range anxiety affects different demographics first-time BEV drivers, long-distance commuters, rural drivers, low-income drivers, late adopters."

UI/UX advancements such as real-time charging station info, predictive and dynamic route planning, and personalized driving modes help mitigate range and time anxiety without changing technical calculations.

"Yes, UI enhancements can help: Predictive route planning [...] dynamic route planning"

Work environments require EVs to support multiple drivers, fast turnaround times, and high uptime. Features like durable design, fast charging, predictive range estimation across driver profiles, and clear charging procedures are critical to reduce time and range anxiety in fleets and shared use cases.

"To successfully integrate BEVs into shared work environments, consider the following best practices: Ensure the selected vehicle meets the driving range requirements for all weather conditions [...] Provide BEV training to ensure all drivers understand operation and maintenance, including charging procedures [...] Optimize vehicle downtime."

7.1.2.3 Thematic comparison

Aim

The aim of the thematic comparison was to validate and enrich the insights gathered from the taxi survey by cross-referencing them with expert perspectives. The comparison would help to identify which issues should be prioritized in the next stages of the research.

Process

To analyze the key themes from both the taxi survey and the expert interview, we first identified the most prominent and relevant theme in the taxi survey. The primary theme was charging, which was divided into the subthemes: frequent charging, longer work shifts, and excessive charging time and revenue loss. As our research approach is user-centered, focusing on the issues most relevant to the users, we selected charging as the main theme to explore. We then compared this theme with the expert interview to see whether the expert also highlighted similar concerns or provided additional relevant insights in their responses.

Results

The comparison revealed that both the taxi survey and expert interview highlighted the importance of charging infrastructure and limited range as critical concerns.

Charging

In the taxi survey, concerns regarding frequent charging, longer work shifts, and excessive charging time were mentioned. Drivers expressed frustration with how these inefficiencies disrupted their work. Taxi drivers highlighted the unreliability and insufficient availability of charging stations, forcing them to stay near known stations. This limited their operational flexibility.

The expert interview confirmed these issues, particularly for shared-use vehicles like taxis, e.g. highlighting charging infrastructure limitations as a major barrier. The expert also noted that dynamic wireless charging could reduce downtime and battery degradation from fast charging, which could worsen range limitations. The expert also mentioned reliable charging infrastructure as crucial for fleet adoption, advocating for fast, reliable charging to minimize downtime. Further, the expert noted these issues, with others, as hurdles to EV adoption and noted the importance of addressing consumer needs for the charging experience.

"While the BEV market is thriving, with significant advancements in battery and power electronics technology, charging infrastructure, and consumer adoption, several opportunities remain. These include improving efficiency, enhancing battery technology, and reducing costs; increasing charging speed, security, and reliability; and most importantly addressing different consumers needs for driving range and charging experience."

Main findings

The insights gained from the pre-study enabled us to refine our problem statement and narrow the focus of our investigation. With a more clearly defined research gap and scope related to fast charging for e-taxi drivers, we then carried out a second, more targeted literature review.

7.1.3 Focused literature review

Aim

The aim was to examine existing studies within the narrowed research scope of fast charging for e-taxi drivers, allowing us to explore the state of the art relevant to our refined research focus.

Process

This focused review was conducted in Google Scholar, where we used specific keywords related to our revised research focus to help us gather literature directly relevant to our final problem area.

Results

See Chapter 3 for the full results of the literature review.

7.1.4 Main Findings

The exploration phase provided insights that helped shape the original direction of this study. The broad literature review helped us familiarize ourselves within the field and identify an initial focus. The pre-study then refined this focus through early user insights, and the focused literature review allowed us to identify a specific research gap within the refined scope, finally, leading to the formulation of our initial RQs:

RQ1: What are the barriers that limit e-taxi drivers from reaching optimal conditions for time-efficient direct current (DC) charging?

RQ2: What features in energy management interfaces can be implemented to overcome the barriers and promote time-efficient DC fast charging?

- What features can support optimal battery preconditioning to minimize charging duration?
- What features can improve SOC management to minimize charging duration?

7.2 Understanding

The aim of this part of the study was to gain deeper insights into the identified research gap related to fast charging. We interviewed e-taxi drivers in the Gothenburg area and two technical experts from Volvo Cars. By interviewing both taxi drivers and technical experts, we were able to understand the optimal charging behaviors for fast charging and the technical constraints involved, while also identifying the practical challenges taxi drivers face. This allowed us to explore whether there is a window of opportunity to align driver behavior with technical best practices, in order to improve charging efficiency.

The interviews were semi-structured, with the interview questions serving as a guide. Follow-up questions were asked when participants needed to elaborate further. We created separate interview templates and consent forms, one for taxi drivers and one for each technical expert. This allowed us to tailor the questions to each group, as we aimed to

explore different perspectives. For the technical experts, we asked for consent to include their job titles. All interviews were conducted in Swedish to reduce potential language barriers and ensure participant comfort, with the exception of one taxi participant who preferred English.

The interview templates were revised by our supervisors at Volvo Cars and Chalmers and were updated according to their feedback before the interviews were conducted. Prior to each interview, participants were informed about the study’s purpose and provided with a consent form, agreeing to participate and for their data to be processed.

7.2.1 Taxi Driver Interviews

Aim

The interview questions aimed to explore the barriers that limit e-taxi drivers from achieving optimal conditions for fast charging, as well as the challenges and experiences e-taxi drivers face when charging during their work shifts. We defined our target group as taxi drivers who operate BEVs and use fast charging. Notable to mention once again, is that we considered this user group as expert users, being experts in the practical, everyday usage of BEVs and fast charging in a professional, high-demand environment.

Participants

The study included 18 male participants, aged between 25 and 77, with the majority (6 participants) falling in the 30-39 age range. Most participants had 1-2 years of EV experience as a taxi driver (9 participants), and the rest had less than a year (6 participants) or 2-5 years of experience.

Charging frequency varied, with 8 participants charging once per shift, and some charging up to three times or more. The majority used Tesla cars (14 participants), with a few driving Volvo, Volkswagen, and Mercedes.

Additionally, 9 participants had university degrees, 4 had high school education, and 5 had primary school education. Half of the participants owned their taxi car, and most (17 participants) always drove the same car. See table 7.3 and 7.4 for the demographic data.

ID	Age	Gender	Education	Owns the Taxi	Always Drives Same Car	Years as Taxi Driver	Years with BEV	Car Model	Charges per Shift	Charging Type
1	52	M	University	No	Yes	20	0.5	Tesla	2	DC
2	35	M	University	No	Yes	11	>1	Tesla Y	2	DC
3	45	M	University	Yes	Yes	1.5	>1	Tesla	2	DC
4	77	M	University	No	Yes	45	2	Volkswagen ID.4	1	DC
5	43	M	High School	Yes	Yes	1	1	Tesla	1.5	DC
6	42	M	Secondary School	Yes	No	13	2	Tesla, Nio	2	DC
7	30	M	High School	Yes	Yes	1	1	Tesla	1.5	DC
8	31	M	Secondary School	No	Yes	5	1	Tesla Y	1	DC
9	63	M	Secondary School	No	Yes	26	>1	Tesla	1	DC
10	32	M	University	Yes	Yes	2	1.5	Tesla Y	1	DC
11	25	M	University	Yes	Yes	2	2	Tesla Model 3	1	DC
12	34	M	Secondary School	No	Yes	3	3	XC40 2022	3.5	DC
13	63	M	High School	Yes	Yes	30	>1	Tesla Y	1.5	DC
14	30	M	University	No	Yes	2	1	Tesla Y	1	DC
15	50	M	High School	No	Yes	14	4	Volvo XC40	2.5	DC
16	40	M	Secondary School	No	Yes	>1	>1	Tesla Y	3	DC
17	55	M	University	Yes	Yes	20	5	Tesla S	1	DC
18	62	M	University	Yes	Yes	25	2	Mercedes EQE 300	1	DC

Table 7.3: Participant Demographics

Demographic	Value	Frequency
Age	20–29	1
	30–39	6
	40–49	4
	50–59	3
	60–69	3
	70–79	1
Gender	Male	18
	Female	0
EV Experience	< 1 year	6
	1–2 years	9
	2–3 years	1
	3–4 years	1
	> 5 years	1
DC Charging Frequency	Once per shift	8
	Twice per shift	7
	Three times per shift	2
	More than three times per shift	1
Car Brand	Volvo	2
	Tesla	14
	Volkswagen	1
	Mercedes	1
Highest Attained Education	Primary School	5
	High School	4
	University	9
Owns the Taxi Car	Yes	9
	No	9
Always Drives the Same Car	Yes	17
	No	1

Table 7.4: Participant Demographics Frequency

Process

To recruit participants, convenience sampling was employed by visiting a Tesla Super-charging station, Circle K- and OKQ8 charging stations, where we approached taxi drivers directly, as seen in 7.3. Since Tesla stations typically have more chargers than other networks, recruiting participants there was easier, resulting in a majority of our sample being Tesla drivers. We visited the charging stations between 10 AM - 3 PM on five separate occasions.



Figure 7.3: Tesla SuperCharging Station

Before the interviews, taxi drivers were asked to respond to an oral questionnaire, collecting demographic information (C.1). The aim of this was to provide context about the participant's backgrounds, which could influence how they perceived and answered the interview questions (see 7.3. This information allowed us to track diversity within the sample, ensuring representation from a range of subgroups. Most importantly, it enabled a demographic comparison (7.2.2).

The interviews were conducted with a sample of 18 taxi drivers. Three of the interviews were cut short due to the drivers receiving customer bookings. However, they were still included in the thematic analysis as they provided relevant and valuable data within the available time. The interviews were based on 18 predefined questions (See Appendix C.1) and were recorded and later transcribed for analysis.

One researcher conducted the interview, while the other recorded and observed the participants, taking notes on behaviors and non-verbal data that could not be captured through voice recording.

Analysis

In order to define relevant themes from the taxi driver interviews, a thematic analysis was performed. Each interview audio file was initially transcribed using Microsoft Word AI Transcriber. We then manually reviewed and refined each transcript while listening to the corresponding audio. This allowed us to improve the accuracy of the transcripts and become familiar with the data.

Following the familiarization phase, we began the process of semantic coding. The transcripts were imported into FigJam, an online collaboration platform. Due to the rather large quantity of data collected, it was easier to perform the coding analysis digitally rather than on physical post-it notes. As we listened to the audio and read through the transcripts, we created digital post-it notes with annotations next to relevant parts of the transcript. Each interview transcription was assigned a different post-it note color to

ensure traceability back to individual interviews in the later stages of the analysis. These notes represented our initial codes, short paraphrased or in vivo segments, that captured the semantic meaning of participants statements. At this stage, we did not apply any theoretical framework or interpretive lens; our aim was to capture what was said rather than deduce hidden meaning.

To enhance coding reliability and minimize individual bias, both researchers independently coded the same set of interviews. We then met across a couple of sessions to compare post-it notes and assess where we overlapped or diverged. When both researchers had noted similar notes for the same section of the interview, we treated them as confirmation that the idea was clearly present in the data. In these cases, we kept just one version, usually the one that was most clearly worded, sometimes refined, to reduce repetition.

If only one of us had written a particular note, we discussed whether it represented a semantic code or an unintended interpretation. If we agreed it was grounded in what was actually said, we included it. If not, we revisited the relevant section of the transcript to determine whether the idea could be substantiated.

This process helped us reduce the overall number of post-it notes, refine their content if needed, and ensure that all retained codes were jointly agreed upon. We did not assign code labels beyond the phrasing of the post-it notes themselves. The retained notes, once confirmed and occasionally reworded, served as our final set of semantic codes. This approach ensured that our coding remained grounded in what participants actually said, avoiding interpretive bias and the introduction of latent codes.

After consensus coding, we proceeded with affinity mapping (see 7.4) to collate our semantic codes and organize them into themes. Using FigJam, we arranged all retained post-it notes across a digital canvas, which allowed us to visually scan for similarities, overlaps, and recurring ideas across participants. Initially, we grouped together codes that expressed similar content or referred to the same topic to identify patterns. These clusters became our provisional subthemes. We then reviewed the subthemes, refined them, and later re-mapped them, this time focusing on identifying relationships between the subthemes. Through this process, subthemes that shared conceptual ground were grouped together, creating initial main themes. The iterative mapping process involved multiple rounds of review. Some subthemes or themes were merged, split, re-framed or removed. After refinement, the final themes were then defined and compiled into a codebook to provide structure to the analysis.

Results

A total of 14 themes were derived from the thematic analysis (see Appendix D for a list including subthemes), which are listed and described in this section.

Charging planning and timing: This theme focuses on the need for flexible charging planning, often based on work schedules and downtime. Taxi drivers typically plan charging during quieter hours, at the end of their shifts, or during breaks. However, challenges arise when routes or customer bookings are unpredictable, making it hard to plan ahead. Charging decisions are usually based on battery levels and upcoming destinations. Drivers rely on monitoring their SOC and range estimates, using tools like Google Maps



Figure 7.4: Affinity mapping for thematic analysis

to find nearby charging stations on long trips. Planning becomes harder during peak hours or long routes, requiring careful time management to avoid disruptions. See 7.5.

Cognitive Load: This theme is about the mental effort drivers face when managing the battery and charging of their EV. Participants often worry about the battery running low, especially during long trips, and feel stressed from having to constantly keep track of the SOC. Planning when and where to charge takes time and focus, which adds pressure, especially for taxi drivers who are often in a hurry. All of this creates mental strain and makes it harder to concentrate on other parts of their job. See 7.6.

Customer Constraints: This theme highlights how customer-related expectations and time pressures limit when and how drivers can charge their EVs. Drivers often have to interrupt or avoid charging in order to take new rides or stay on schedule. Some mention that customers dislike waiting during charging, especially if they have appointments or are on short trips. As a result, drivers try to minimize charging time or avoid charging altogether when a passenger is in the car. See 7.7.

Range Limitations and Performance: This theme is about the limitations drivers experience with the range and performance of their EVs. Participants mention that the actual driving range is often shorter than what is promised, and the estimated range is not always reliable. Many express a desire for longer range, especially in colder weather, which significantly reduces battery performance. Fast charging can not be avoided even though it may harm battery health, leading to more frequent charging. These factors affect how drivers plan their workdays and contribute to uncertainty about how far they can drive without interruption. See 7.8.

UI And InfoVis: This theme is about how drivers interact with the car's UI and the information provided to support charging. Participants rely heavily on SOC, and navigation tools to decide when and where to charge. While some find useful tips in the system, like preconditioning the battery or locating nearby stations, others feel the

Participant ID	Quote
P15	"You always have to plan ahead before starting work. For example, between six and nine in the evening, theres a lot to do in the taxi industry. Then from around nine or ten until one, it slows down, so thats when you take the opportunity to charge."
P11	"It depends on where you're going. If it's a long trip, it can be hard to plan (charging) [...] but most of the time we have short trips, so then it works out fine."
P16	"I have to plan, have to. Sometimes it can be difficult, sometimes there's a lot of work, many orders, and I need to charge [...] especially during the time from three to four, or three to five"
P14	"Right now I'm on break so when I'm back at my job, then again we basically have a shift (Västtrafik travel service shift), not like one drive, we have a shift for three, five hours. so we have to plan according to our shift. We have multiple kind of customers, so in these five hours, I have to manage where, like if I go to Halmstad or (unheard), where can I to stop and charge my car? Where can I find a fast charger"
P9	"No, I have to plan (charging), otherwise you can lose out [...] You know, in the morning you can't plan because you never know where you'll end up, like long or short trips. So it depends, but I still have to plan the time I'll charge."
P3	"Yes (encounter issues planning), It takes time, that's just how it is, sometimes it needs time [...] It's just that you have to plan all the time, everyday"

Table 7.5: Quotes from taxi drivers related to charging planning and timing

Participant ID	Quote
P7	"If I have a lot of work, the first thing I think about is charging."
P4	"It's that range anxiety they talk about, 10% doesn't feel good."
P18	"It reduces stress if it's faster (charging), really." "The car warns you when it reaches a certain percentage. The car says it's time to charge, plus I always have to stay alert to it."
P8	"If I go to Mariestad or Skövde, I check how many kilometers it is, and then I see, aha, there's a fast charger, then I can relax."
P5	"It has happened that I have been outside (Gothenburg) and there's only one charger, and it's really bad. It affects everything - stress, time, everything."

Table 7.6: Quotes from taxi drivers related to cognitive load

information is limited, unclear, or not helpful for optimizing charging. Many supplement the cars system with external apps like Chargefinder to get more accurate or updated

Participant ID	Quote
P2	"If I have long drives, it gets difficult (with charging), you know, you have to stop at some station and charge, and if you then have a customer, it becomes a hassle."
P8	"They dont accept (that youre charging) while driving sometimes - you know, school transport, when the students have to get to school, or someone has a doctors appointment."
P4	"If I get a ride, I cancel and then charge somewhere else later."
P16	"Sometimes I have a customer who wants to go to [x], I once came here to charge and he got angry."
P17	"If you get a ride outside (the city), you can not say to the customer, Please sit in the car while I charge a bit, it doesnt work. People who take taxis need to go somewhere, an errand or work or wherever, they need to be on time."

Table 7.7: Quotes from taxi drivers about customer-related challenges

Participant ID	Quote
P1	"I think the batteries deteriorate day by day. I mean, when I got the car it was pretty new, I think one month old, and then I could charge it up to 480 km per day. Now I can only charge to 420 after six months, so in a year I dont even know if Ill be able to charge to 300."
P14	"In the winter, like it is -35, -30 degrees there, even with 100% battery we can only drive maximum 150km, 140km, so it is impossible to do the job"
P7	"If the battery allowed you to drive the car 700 km or 70 to 80 (swedish) miles, that would be good. Because theres no customer that we would drive more than 70 (Swedish) miles."
P8	"If I drive over 80100, 110 (km/h), it consumes a lot more, maybe double. It says 400 km here, but thats not true. I might only be able to drive 200 km in reality."
P12	"The temperature when it's cold consumes more battery, however, I don't know if it affects charging, but I don't think so"

Table 7.8: Quotes from taxi drivers about range limitations and performance

information. A lack of clear guidance on features like battery warming or ideal SOC levels for charging leaves some drivers guessing. See 7.9.

Charging Station Accessibility and Efficiency: This theme highlights users' concerns about the availability, location, and speed of charging stations. Many prefer Tesla chargers due to reliability and short wait times, but accessibility remains a challenge, especially outside city centers like Gothenburg. Drivers often need to take detours or wait

Participant ID	Quote
P5	"You can set it yourself, for example 20%, then the car tells you it's time to charge"
P7	"Sometimes I drive with low charge, and it sends me a message on the screen and phone that it's dangerous for the battery." "It shows kilometers and it shows percentage, but it's always the percentage that matters, the km isnt accurate, it depends on how you drive."
P10	"Yes, there are (charging tips in the car), but not much that can actually help."
P8	"Yes, Charge Finder, it's perfect for me [...] Google Maps, I mean you can use it, but with this app (Charge Finder), I can also see how I can pay"
P2	"Yes, it would be better if it (car) said that (charging will be faster at 20%), but it doesnt. Its just advanced, you have to keep track of this icon, like the battery or kilometers."
P17	"The only thing you can do is read the instruction manual, but that is not for fast charging"
P8	"Yes, they have such information, they say to charge to 80 (%), to try charge at a Tesla Supercharger and such, or they say to warm up the battery"
P7	"When come to charge and connect, it says here: the battery temperature is lower therefor charging will be slower, but I think that's only for Tesla, I don't know if other cars have it, I called my friend and talked to him about it, he told me it's the first time he hears that we can heat the battery (precondition)"
P10	"No (uses Google maps in) the phone. In the phone, Google Maps, it updates everyday, so it's very good [...] No, they (Google maps in car) don't update very day"

Table 7.9: Quotes from taxi drivers about UI And InfoVis

in line, which disrupts efficiency. There is a desire for more centrally located, fast charging stations, particularly near customer hubs. Many express a need for home charging options to reduce dependence on public infrastructure and improve convenience during long trips or low-demand work periods. See 7.10.

Navigation for Preconditioning: This theme is about how drivers use navigation systems to precondition their vehicles battery before charging for faster and more efficient charging. Many users actively use built-in navigation to trigger battery preheating while driving to a charging station, especially in cold weather. The process is generally seen as easy and effective, with noticeable benefits in charging speed. However, some users are unaware of the feature, status, or forget to activate it, indicating a need for clearer communication or prompts in the system. See 7.11.

Participant ID	Quote
P1	"I would really like to have more charging stations, and that would change things. I mean, if Im in the city waiting for a customer, I want to be able to charge there, so Im not wasting time. But to come here and charge, half an hour here, half an hour back, plus the time here."
P4	"It would be good if there were (charging stations) in the city center, but that will never happen." "Yes, this is the cheapest, 2.50 per kWh [...] so I want to charge here (Tesla Supercharger). Theres usually plenty of space, but twice a week its too crowded and I have to go to another station."
P14	"Only Circle K has 400 kW, so we want more fast chargers around."
P5	"Fixing a home charging spot, that would help a lot."
P13	"Where I charge is at Tesla, and theres only one in Gothenburg and one in Kungälv, thats very few, not many at all."

Table 7.10: Quotes from taxi drivers on charging station accessibility and efficiency

Participant ID	Quote
P6	"When you set, for example, that you're going to charge, it heats up the battery by itself, and when you arrive it becomes fast charging."
P7	"Tesla has a system when you want to charge, you choose the station [...] then battery starts to preheat [...] it helps to fast charger [...] I use it like that (via the map), but maybe there are some people who dont know about it (preconditioning) [...] but it's only if it is cold, if it's warm it doesn't matter, I can charge [...] when you work the battery is warm but in the mornings during winter, it is always cold [...] No (battery temperature is not shown in car screen)" .
P11	"Yes, because its Google Maps, so you just enter a charger and it heats the battery for you." "It always works." "Yes (always easy to use)."
P5	"Does it warm up or cool down? I thought it cooled down?"

Table 7.11: Quotes from taxi drivers on navigation and preconditioning

SOC-Based Charging Habits: This theme highlights the charging habits taxi drivers have developed in relation to the cars SOC. The taxi drivers usually charge their car at 20-30% and limit the charging to around 80%, noting that fully charging the battery takes too long and may negatively affect battery health. However, they try to maintain a relatively high battery level to be prepared for operations. See 7.12.

Concerns and Barriers to EV Integration: This theme addresses the limitations that EVs have for taxi driver operations. Participants expressed that the long-distance rides are not suitable for e-taxis, and is more suited for a combustion engine car. Another concern was the expensive battery replacement. Additionally, some participants were not aware of the negative impacts of fast charging often can have on the battery. See 7.13.

Participant ID	Quote
P1	"So I always have to be charged, its not ideal to tell a customer in the car that I need to go to a charging station. They dont like that, so the battery always needs to be over 5060%."
P9	"If I get close to 20%, I have to charge before the next customer because I don't know where I'll end up, so I have to charge."
P6	"But they recommend from 10 to 80%. You should always charge like that with Tesla cars. It should not be under 10% and not over 80%, it damages the car."

Table 7.12: Quotes from taxi drivers on SOC

Participant ID	Quote
P17	"There are some places where theres no charging. Charging is only available in the city, outside of it, there isnt any. What am I supposed to do? Diesel is available everywhere."
P7	"Electric cars dont fit with the taxi business. Never. I can tell you two, three things. The first thing is look, I said at the beginning (of the interview) that 25 minutes is enough to charge the car, but thats for private use, not for work, like taxis.The second thing, you have a battery, and the battery is very expensive. I think it costs 160 to 200 thousand crowns. If it breaks, its a disaster."
P8	"Sometimes we dont get long trips. Some rides we simply dont get. Thats why maybe someone else gets a 400 km ride maybe the diesel cars take them. You know, they see that you have an electric car, so they skip the order, thinking you wont make it with the customer. So it really holds me back."
P14	"As taxi drivers, we don't like electric cars but it's compulsory from the government to use electric cars for [contracted transportation services], that's why we use electric cars, otherwise there is no reason to use these cars"

Table 7.13: Quotes from taxi drivers on concerns and barriers to EV adoption

Charging Speed and Station Preferences: This theme addressed the time it takes to charge the EV. A majority of the participants perceived the time taken to charge as too long and it was found that participants chose their station based on how fast the car can charge there, so a charger with a high power supply. However, there was a minority who expressed that the time was acceptable. Participants were also aware that charging speed was faster when the SOC was lower, and slowed down the higher the SOC reached. It was also noted that the ambient temperatures during the winter months caused slower charging times and led to a higher frequency of charging. See 7.14.

Participant ID	Quote
P10	"I have free charging for one year since there was a campaign when I bought the car (Tesla), but look now it doesn't work (low kW), it is not good, sometimes I want to work quickly so I leave this (Tesla Supercharger) and go to other stations. OKQ8 they have very fast chargers, they are better"
P4	"It is completely acceptable (charging time). I mean, that's what I think, but others say that half an hour, I don't get paid for it. But one the other hand, I'm a pensioner too, so I'm not so stressed about waiting".
P1	"It takes way too long time (for the car too charge) especially when we work with it"
P15	"When it is under 50 (%) it charges fast until it reaches 80, when it comes to 80 it slows down, so it takes time"
P8	"I work in the morning, that is what's preventing me, it is very cold and the charging is very, very slow"
P18	"5 minutes of charging at most, but there are no cars that can handle that [...] That's really what I need, efficient charging rather than thinking about anything else. As a consumer, I want the service to be very fast so that I can continue my journey."

Table 7.14: Quotes from taxi drivers on charging speed and station preference

Charging Capacity and Power Variability: Participants expressed that kW affects charging speed, and that it is primarily the charging stations kW output that determines how fast charging occurs. Thus, participants want charging stations with high kW output. However, it was also expressed that the kW the car receives is inconsistent and does not match the advertised capacity and the reason for that discrepancy is uncertain, but some noted that higher SOC lead to lower kW being received as well as when the charging station is shared with another car, but no information was provided in the infotainment. See 7.15.

Driving Pattern/Style: This theme addresses how different driving styles affect the battery consumption and efficiency of the car. Participants noted that highway driving, especially at higher speeds, drains the battery significantly faster than city driving and participants preferred driving in the city for better efficiency. It was expressed that the range on a charged battery is limited and is even further reduced in the winter. It was also noted that preconditioning and extra equipment consumes extra energy. See 7.16.

Economic Impact on Charging: This theme addresses the economic impacts charging has for taxi drivers. Participants expressed that they are unable to work when due to low battery and have to deny customers, and there is an opportunity cost with the time spent charging. Additionally, the charging time is not compensated, and therefore it is taken from their own time. However, there are incentives for EVs such as having priority in the queue for customers and discounted charging at Tesla stations for Tesla cars. See

Participant ID	Quote
P4	"It can be between 20-25 kW, up to 70-80 kW. Even though it says up to 150 kW, it has never gone over 80 kW anywhere." "No (does not know why)"
P10	"It gives 50, but its supposed to be 150 [...] I dont know why, sometimes there are a lot of cars here and it gives 150. Other times, like now, I come here and there arent many cars, but still, it only gives 51/50 kW. That doesnt work."
P15	"It (charging speed) depends on the capacity of the charger. There are some, they have 150 (kW), some have 50, those who have 50 don't charge fast" "I don't know why (it charges slower at times), it has something to do with the capacity"
P12	"They say half an hour (to charge), but already when you connect it for charging, it doesn't receive the full kW [...] I choose the fastest chargers but it doesn't receive the full kW [...] the car manufacturer can answer why it is like this, those who have knowledge of the battery, I have no idea but as I said, I can only see how much it gives, It has 150, but I only receive 50"
P11	"I receive (max kW) when I have below 10%" "I charge mostly when I have below 10% to charge as fast as possible"
P16	"Tesla (supercharger) is not fast, Cirkle K and OKQ8 are faster, 150kW [...] Here (Tesla Supercharger) Look it is 42 kW [...] I don't know actually (why there are such variations)".
P18	"If there is a station which gives 100kW/h, it can't give more than 45, 50kW a hour, if there are two stations who charge together."
P14	"No, we cant adjust it. We just plug in and it charges according to the station's speed. We cant adjust the speed"

Table 7.15: Quotes from taxi drivers on Charging Station Capacity and Power Variability

Participant ID	Quote
P3	"If you drive a bit fast, if you drive over 70 (km/h), it consumes more charge. If you drive at 70, you can save battery, 70 is good for that. Its most important to drive between 70 to 80 km/h."
P10	"They say 400 (km) range but it's maybe 300, 280 when you drive outside of town"

Table 7.16: Quotes from taxi driver on driving style

7.17).

On-site Charging Issues: This theme focuses on the challenges that occur at the station, including the challenges with payments. There are various vendors that require

Participant ID	Quote
P2	"Yeah, if the battery is low and I get a ride while Im still charging, I have to turn it down. Or if I get a long-distance ride, like to Skåne, and I only have 20% or 30%, or even 50%. With 50% I can drive to Malmö, for example, but if I only have 20%, I have to turn the ride down."
P2	"It is unpaid (time spent charging) because almost all taxi drivers work on commission"
P4	"In the airport, the electric cars have priority"
P14	"If we spend an hour charging, it's part of the job, but during that hour, we miss out on a lot of rides and no one pays us for that hour, so it's like a waste of time"
P1	"We've had a discussion with the union, and those of us who use electric cars don't want them because 60 hours of my working time each month goes to charging, and I don't get paid for it"
P8	"It's really tough when you go on long trips and then have to return home. You don't get paid for the hours you spend waiting. Maybe you end up working for two hours, but still you don't get compensation, no salary"

Table 7.17: Quotes from taxi driver on economic impact

a subscription, making the process more complex. Additionally, the charging stations themselves sometimes malfunction and drivers have to re-plug the charger more than once or move to another station, and often they are not informed of why it was unsuccessful. See 7.18.

Observations Additionally, two key themes emerged from observational data during the interviews.

Observation 1 One observation involved three participants interacting with the set target slider, which adjusts the charging percentage (set at 80% for all participants initially). The participants attempted to demonstrate how charging time increases significantly at higher percentages, and in doing so, all three engaged in excessive interaction with the slider and possible mental load.

They repeatedly dragged the slider to a higher percentage, released the slider to see the updated time, and particularly in two cases, dragged it again to an even higher percentage and setting it, before finally returning the slider to the original target. A key usability issue emerged: the updated time would not display until the user explicitly released the slider to set the new target, leading to cognitive recognition, a detail that was not immediately clear. As a result, we observed signs of confusion and frustration in all three participants during this task.

Observation 2 Another key theme that emerged from the observation was that multiple taxi drivers charged their vehicle at stations that offered more power than their cars could receive. All drivers recruited at charging stations other than Tesla Supercharger were

Participant ID	Quote
P18	"But it happens often that they break, some stations are out of order, others are occupied."
P10	"Nothing, it just says you have not connected correctly, try again"
P8	"Sometimes it hassles, you connect the car, it doesn't work, you return the cable and try multiple times, sometimes you become very angry also. It doesn't work for 10-15 minutes at some places [...] no, the car doesn't say (why it's not working)"
P7	"There are charging stations everywhere, there is Supercharger for Tesla, there is Cirkle K, OKQ8, IONITY. The others you just need to become a member of them or order a card"
P18	"The subscriptions for charging stations vary, so there is no collective method to be able to use all stations, regardless of the company. That is what's needed, a collective method, a card or app or something that works for all. That would be good to avoid chasing certain stations and miss others"

Table 7.18: Quotes from taxi driver on on-site issues

using chargers with capacities exceeding their vehicles maximum DC charging capability. For instance, both Volvo drivers had vehicle models whose highest powertrain option supports a maximum of 200 kW charging capacity ([74]). However, they were charging at stations capable of delivering up to 300 kW.

Similarly, while some Tesla drivers used Tesla Superchargers that exceeded their vehicles' peak charging capability, this behavior might be attributed to the convenience of the Tesla charging network for Tesla cars. However, one Volkswagen driver, whose vehicle was capable of receiving a maximum of 170 kW ([75]), was recruited charging at a Tesla station capable of delivering 250 kW ([76]).

These observations are further supported by interview data. For example, found in the theme "Charging speed and station preference" (7.2.1), three Tesla drivers, whose vehicles were capable of receiving up to 250 kW, reported preferring Cirkle K or OKQ8 stations. These stations were perceived as faster due to their higher advertised output, being up to 400 kW, compared to Tesla Superchargers, which peak at 250 kW, despite their cars not being able to utilize this extra capacity.

Several drivers also expressed the belief that a higher kW rating directly translates to faster charging found in the theme "Charging capacity and power variability" (7.2.1). One Mercedes driver, whose car is capable of charging at a maximum of 170 kW ([77]), explicitly stated that *"the higher the kW, the faster the charging"*, referencing figures like 400 kW. Another participant who can be argued to have the same belief was a Tesla driver, who was recruited at a 400 kW Circle K charging station located just 2.8 km from a Tesla Supercharger offering 250 kW (which had available spots at the time, as it was observed in ChargeFinder) even though the maximum his vehicle could receive is 250 kW ([78]).

P18: 150 kW exists, 200 exists, the strongest is 400 kW, the stronger the station, the faster it becomes

P14: Yes, yes (willing to drive further for faster charging stations) [...] Only Circle K has 400 kW, so we want more fast chargers around [...] Yes, it [car] can receive 400

7.2.2 Demographic comparison

Aim

The aim of the demographic comparison was to identify potential correlations between user demographics (7.2.3) and the themes that emerged from the user interview. Specifically, it allowed for a more structured exploration of how different demographic factors, such as age, education level, or BEV experience influence the participants' experiences and viewpoints regarding the subjects of the study.

Process

During the thematic analysis of the user interview, we applied color-coding to the post-it notes based on the interview they originated from. We then reviewed the themes and noted the color of the post-it notes associated with each theme. For each theme, we noted the participant IDs linked to the relevant post-it notes. Next, we examined the demographic data for those participants to determine if any correlations existed between the theme and specific demographic groups. For instance, if a particular theme contained seven notes, five of which came from participants over the age of 50, this suggested a possible relationship between age and that theme. Although this method did not involve formal statistical analysis, it provided a clear and practical way to explore how participants' demographic backgrounds might have influenced their experiences and perspectives.

Results

No statistically significant correlations were found between user demographics and the identified themes. Participants from diverse backgrounds, such as age, education level, and experience with EVs, were generally represented across the same themes and sub-themes. This suggests that the themes may reflect common experiences rather than being related to specific demographic groups.

Some correlation patterns were observed in relation to the car model. For example, of the 14 participants who mentioned preconditioning the battery before fast charging via the navigation system, 10 were Tesla drivers. Of the remaining four, one Mercedes driver also preconditioned, while the two Volvo, and one Volkswagen, drivers did not. However, the sample lacked sufficient diversity in car model, with 14 out of 18 participants driving Teslas. As a result, any correlations in this area should be interpreted cautiously and may require further investigation to confirm.

Additionally, one other demographic variable, gender, lacked sufficient diversity in the sample, making meaningful correlation analysis for this not feasible.

7.2.3 Technical Expert Interviews

Aim

The aim of the technical interviews was to gain a clearer understanding of the technical constraints related to EVs and charging. One expert specialized in charging systems, while the other focused on battery technology. We chose to interview both, as battery dynamics play a significant role in charging performance. Since the goal was to gather factual insights from domain experts rather than subjective opinions, and both participants were highly experienced, two interviews were sufficient.

Profession (Title)	Industry Sector	Years of EV Experience
Technical Expert	Automotive	23
Technical Expert	Automotive R&D	EV: 6-7, PHEV: 15

Table 7.19: Demographic table of technical experts

Process

The experts were recruited through email, and the interviews were held in meeting rooms at the Volvo Cars office in Gothenburg. The interview sessions lasted for 1 hour each. Prior to the interview, the experts were informed of the purpose of the study and interview, and were given a consent form and demographic survey to complete. For the charging system expert, a set of 16 questions were curated with a focus on factors that affect charging speed that the driver could influence. For the battery technology expert, a set of 18 questions were used with a greater focus on the battery's role in charging. Both interviews were recorded using an audio recording device to be later transcribed for analysis.

Analysis

For the analysis of the technical interviews, an inductive thematic analysis was employed. As there was no predefined hypothesis or framework being tested, an inductive approach was appropriate to allow themes to emerge directly from the data.

The audio files were transcribed using Microsoft Word AI Transcriber and transferred into Figjam. A consensus coding was performed as described in 7.2.1. After which, the codes were then used to create affinity map, where similar codes were grouped together, following the same process as in 7.2.1.

Results

The thematic analysis resulted in five emerging themes, which are presented and described in this section.

External Factors and Infrastructure: This theme emphasizes the need for an improved allocation of resources at charging stations, such as selecting a charging station based on the car's capacity. Additionally, as of now, there are different apps for payment

depending on the vendor, and it was noted that a centralized payment system would improve UX. See 7.20.

Participant ID	Quote
P1	"you will still not be able to receive more than 150 kW, so you might as well go to a 150 kW charger instead of a 300 kW one."
P2	"All the payment systems and how different they look, it's really a jungle. Compared to when you go to a gas station where all the card machines look the same, all the pumps look the same, you just get it."

Table 7.20: Quotes from experts on choosing a charging station and payment systems

UI & Communication: There is a lack of clear guidance on optimal charging practices, and how factors like temperature and SOC affect efficiency. To avoid confusion and ensure consistency, standardized and well-defined metrics should be integrated into the UI. See 7.21.

Participant ID	Quote
P2	"Whats tricky about giving too much information about batteries is that there are so many metrics that aren't standardized. That means you can describe them in different ways, and they can mean slightly different things, so theyre not always comparable between different brands and so on. And there's a risk that people might misinterpret the information. I think thats actually a big part of the issue."

Table 7.21: Quotes from experts on battery information

Charging Capabilities & Technical Factors: Charging speed is mainly influenced by temperature and SOC. Since each vehicles battery chemistry differs, optimal charging conditions cannot be generalized. However, performance can be improved from the user's end through preconditioning and avoiding high SOC. See reftab:tech3-quotes).

Preconditioning: Preconditioning is a great tool for improving charging speed, but there could be improvement on the transparency, control, and system integration of the function. See 7.23.

User Behavior and Needs: Users have different needs (eg., private driver vs. commercial driver) and therefore the UI should adapt to the user, not the other way around, by providing advanced or personalized settings as well as transparent guidance, the user can utilize the car to its best. See 7.24.

7.2.4 Background Review

Aim

The aim of the background review was to identify existing solutions and unresolved challenges within the identified themes, ensuring the study focuses on UI-related gaps

Participant ID	Quote
P1	"Generally speaking, it's better to plug in when the battery level is low. Whether that's at 5 %, 10 %, 15 %, or 20 % - that can vary. But you definitely shouldn't charge at 50 %, that's just a general rule. If you really want to optimize, though, it depends quite a lot." "If the station is occupied, the output will drop, so it's better to choose a station that's less popular, if it's equivalent. [...] some chargers have a cabinet with two cables, so it might be that you can receive 200 or 300kW from it, but it is divided equally on the two cables [...] you should (therefore) go to the one (cabinet) that doesn't have a car, since then you don't have to split the effect with someone"

Table 7.22: Quotes from experts on the variation in cars

Participant ID	Quote
P2	"I think mostly that they just need to understand that it consumes energy when they do it. [...] Is there a button (manual preconditioning) of course users will use it and get higher energy consumption [...] and we won't know how much to precondition to" "I think it really comes down to energy consumption. If it weren't for the energy usage, we would always make sure the car is preconditioned and optimize the whole balance. If you need to precondition a lot, it can take several kWh just to heat the battery."

Table 7.23: Quotes from expert on preconditioning

Participant ID	Quote
P1	"They (professional drivers) have much greater knowledge and need to be able to adjust settings, maybe there should be something like an 'Advanced' mode"
P2	"We might be preheating unnecessarily because we assume the driver is doing something they might not actually be doing. It might be better if the driver actively presses a button and says, Im going to fast charge."

Table 7.24: Quotes from expert on user group & UI

where improvements are still needed.

Process

The method was not purely a background review but also included exploratory comparisons with other systems. We compared the Volvo UI to other systems (e.g., Tesla, ChargeFinder, A Better Route Planner (ABRP)) where appropriate, to identify differences, best practices, or superior features in competing solutions.

We first identified the themes that could be addressed through UI improvements and solutions. These included UI and InfoVis, On-site charging issues, Charging capacity and

power variability, Navigation for preconditioning and Charging planning and timing (see 7.2.1).

The review was then carried out online, using keywords related to the issues within each theme to assess existing solutions or gaps, as well as reviewing other cars, either through research or hands-on, when available. For mobile applications, we downloaded and reviewed them to compare with in-car UI.

Results

Charging planning and timing:

Most progress was found in this area with apps like ABRP and even the in-car navigation systems such as Google Maps offered some charging planning functions. However, the difficulties in planning charging sessions reported by e-taxi drivers in this theme appeared to be more related to the nature of their work rather than the UI limitations.

On-site charging issues:

Payment difficulties were commonly reported, with users mentioning the fragmented payment options across different charging providers. Tesla stations were noted as smoother due to streamlined payment processes for Tesla cars. A need for a common payment system was identified. However, the background review revealed ongoing efforts are addressing this, such as "Plug and Charge", aiming to simplify payments and working toward unified solutions. However, the issue related to lack of error information when starting a charging session presented an opportunity, as charging stations and cars, including Volvo, were found to lack a descriptive error message when something goes wrong initiating a charging session.

Navigation for preconditioning:

Some drivers lacked awareness of the battery preconditioning feature. Found in the review, some manufacturers provide manual controls with clearer status indicators for preconditioning. Volvos implementation is limited in informing the user of the status, progress, and existence of the preconditioning feature. An exception is the EX30 model, which displays a notification when preconditioning is triggered via navigation (see 7.5). Overall, Volvo lacks a dedicated manual button or clear UI feedback on this function, indicating room for improvement.

UI and InfoVis:

Many participants used external apps due to missing features in the in-car navigation, such as payment details at charging stations. The app "Chargefinder" was frequently mentioned. During the review, we reviewed the app in comparison with the Volvo in-car navigation system, and found more information in the app such as payment info, and clear visual indicator of station speed (see 7.6). This highlighted opportunities to improve Volvos in-car navigation UI by integrating such found features. Additionally, Teslas vehicles were praised for providing charging tips, which Volvo cars were found to currently lack, this as well presented an opportunity (see 7.7).

Charging capacity and power variability:

Little has been done to address the lack of transparent information about charging power fluctuations and discrepancies during charging sessions. The review found that few vehicles effectively communicate this to users, representing a significant opportunity for UI improvements.

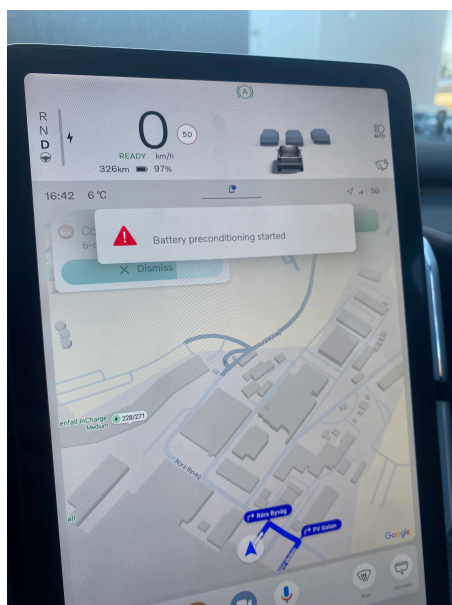


Figure 7.5: EX30 preconditioning notification

7.2.5 Main Findings

A total of 14 themes emerged from our analysis. However, the combined scope of these themes were too broad to explore within the time frame of our project. Therefore, we narrowed the focus, first by selecting themes that could be addressed through UI improvements, which is the central focus of our study. Themes outside this scope, such as issues related to charging station infrastructure were excluded. From the remaining themes, we conducted a background review to identify which issues were already being addressed and which ones present an opportunity. Of the unresolved ones, we selected the three based on the highest number of notes and richness, indicating both frequency and significance in the data:

- **UI & InfoVis**
- **Charging capacity and power variability**
- **On-site charging Issues (subtheme: Charging Failures and Missing Error Info)**

7.3 Defining

The aim of this phase was to narrow down the scope of the study. Drawing on the data collected during the understanding phase, the focus was on identifying the key challenges taxi drivers face when charging EVs.

To implement a UCD approach, personas and journey maps were utilized. Furthermore, these artifacts helped to later derive a list of requirements to better outline the scope. The following sections describe the development process and results of each of these artifacts.

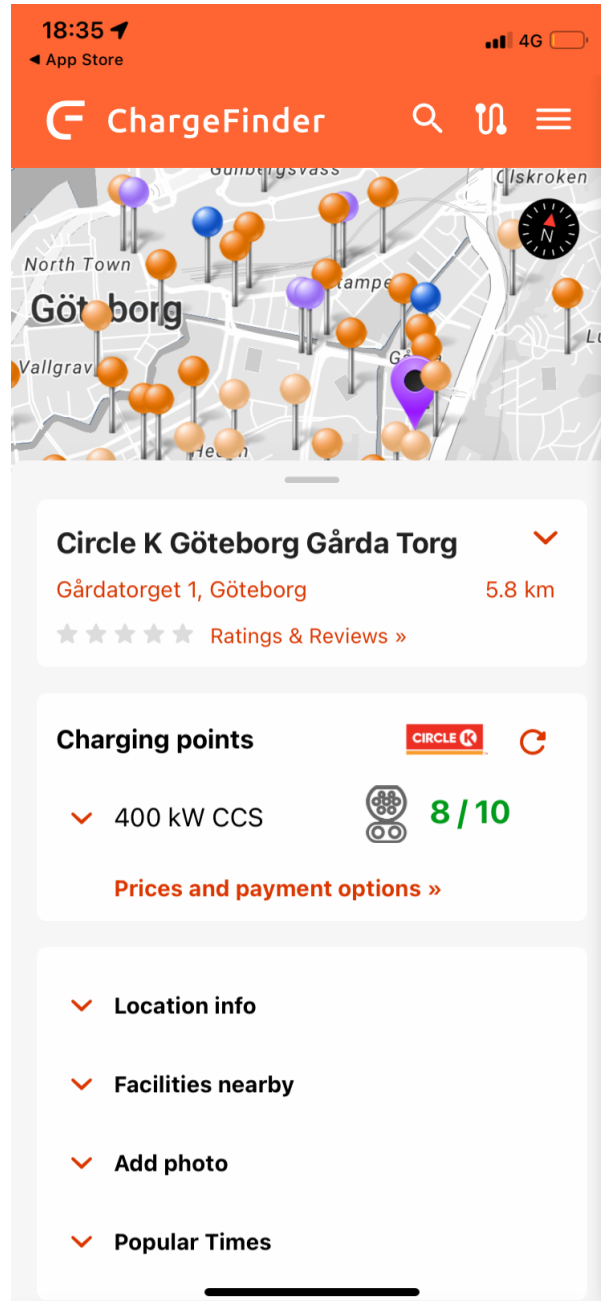


Figure 7.6: ChargeFinder UI

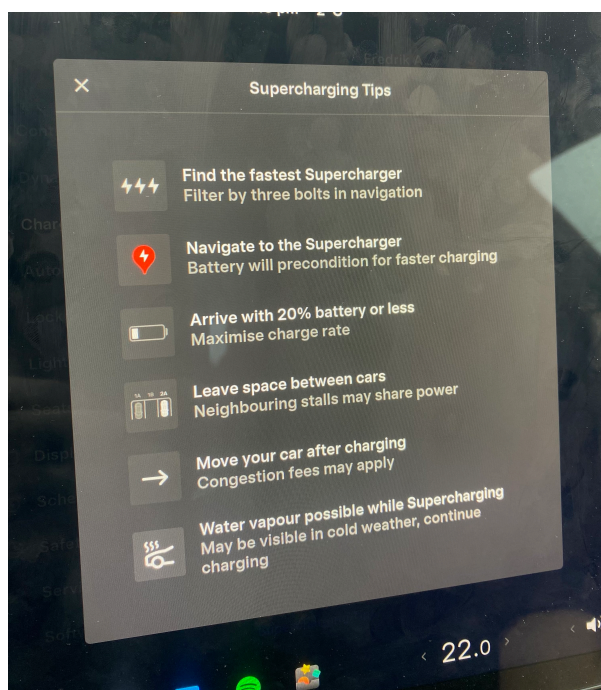


Figure 7.7: Tesla Supercharging Tips

7.3.1 Personas

Aim

The aim of creating personas was to support a UCD approach by ensuring that the design directly addresses the real needs of users. The personas served as reference points throughout the design and development stages, helping guide decisions to align with users' goals, behaviors, and pain points. By basing design choices in authentic user data, we ensured that our designs addressed the goals and needs of the intended user.

Execution and process

Based on the collected data from the interviews and demographic data, three personas were created. One persona represented the typical user and was constructed by combining insights from both quantitative and qualitative data. This included averaging numerical demographic variables (e.g., age, years of experience), identifying mode values in categorical variables (e.g., education level, car brand), and integrating dominant themes from the qualitative interview responses through the thematic analysis (e.g., themes that emerged from codes across many participants).

To capture variation and reflect the diversity within the dataset, participants were manually clustered based on similarities in their interview responses, with a focus on charging behavior, pain points, needs, and goals. Thematic codes, color-coded during analysis, were traced back to their respective interviews, from which the associated demographic data were extracted and summarized. For instance, the theme "Charging speed and station preference" included two sub-themes: "Acceptable charging time" and "Excessive charging time". The latter was significantly more commonly expressed and informed Persona 1, while the less common sub-theme helped shape Persona 2, whose demographic profile was based on the participants who expressed that the charging time was accept-

able.

This process resulted in three clusters. The largest group informed the typical user persona, while two smaller clusters became the basis of the remaining personas. Finally, we revisited our thematic analysis (7.2.1) to ensure alignment between the personas and key themes, highlighting both shared goals and distinct individual needs.

Results

The three personas are as follows:

Persona 1: Alex Klerk Alex is a 45-year-old taxi driver based in Gothenburg, operating a Tesla Model Y through a fleet service. With over a year of experience driving EVs, he is tech-savvy and relies heavily on apps like ChargeFinder and Google Maps to plan his routes and charging stops. His daily routine includes a mix of spontaneous and booked trips, often extending beyond the city, which increases his dependency on fast and reliable charging infrastructure. Alex starts his day with a high SOC and avoids letting the battery drop below 20% to minimize the risk of being unable to accept new rides.

His primary frustrations include limited access to high-capacity chargers, especially outside urban areas, slow charging above 80% SOC, and the fragmented nature of payment systems across charging providers. These challenges directly impact his income, as charging time is unpaid and often overlaps with peak demand hours. Despite having access to free Tesla charging, the lack of universal compatibility and reliable options forces him to take detours or spend time managing multiple apps. Alex desires more efficient infrastructure, streamlined payment systems, and smarter tools for real-time planning to reduce downtime and support a smoother workflow. See 7.8).

Persona 2: Kalle Schneidersen Kalle is a 70 year old retired engineer who now works part time as a taxi driver in Gothenburg to stay active and earn extra income. He has limited experience with EVs, having only used one for three months, and finds the charging infrastructure unfamiliar compared to traditional fuel stations. While he is optimistic and generally ok with the 30 minute charging time, he expressed frustration with the need for multiple apps, a lack of clear vehicle information, and inconsistent charging speeds. He is especially unsure about the technical aspects like battery preconditioning and would appreciate clearer, simpler guidance.

Unlike, full time drivers, Kalle sees charging breaks as a natural part of his workday and doesn't plan charging sessions in advance. He typically charges from 20-80% SOC without concern for optimization but is curious to understand why charging speed varies. His needs are less about performance and more about clarity, he wants better designed charging stations, simplified vehicle interfaces, and small tips or in-car information that explain what is happening during charging. See 7.9).

Persona 3: Jack Galore Jack is a 60-year-old full-time taxi driver in Gothenburg, operating a Volvo XC40 for airport and city rides. With only six months of EV experience, he finds charging to be a significant disruption in his daily workflow. Limited vehicle range forces him to charge to 100% SOC, often requiring two long, unpaid charging sessions per shift. He frequently encounters slow and inconsistent charging speeds, especially in colder weather, and feels the vehicle lacks helpful, personalized feedback to understand



Figure 7.8: Persona 1



Figure 7.9: Persona 2



Figure 7.10: Persona 3

or improve the situation. The inability to use Tesla Superchargers, which his peers rely on, adds to his frustration.

Jack relies on Google Maps to find nearby stations and prefers Circle K due to subscription access and high power charges. Although he is moderately tech-literate, he feels overwhelmed by the lack of clear guidance on how to optimize charging performance. His primary needs are faster, more predictable charging, access to more compatible stations, and vehicle support that explains why charging is slow and what, if anything, he can do about it. See 7.10).

7.3.2 User Journey Map

Aim

The aim of the user journey maps was to visualize charging scenarios based on the developed personas. From the mapped out journeys, the goal was to identify key pain points,

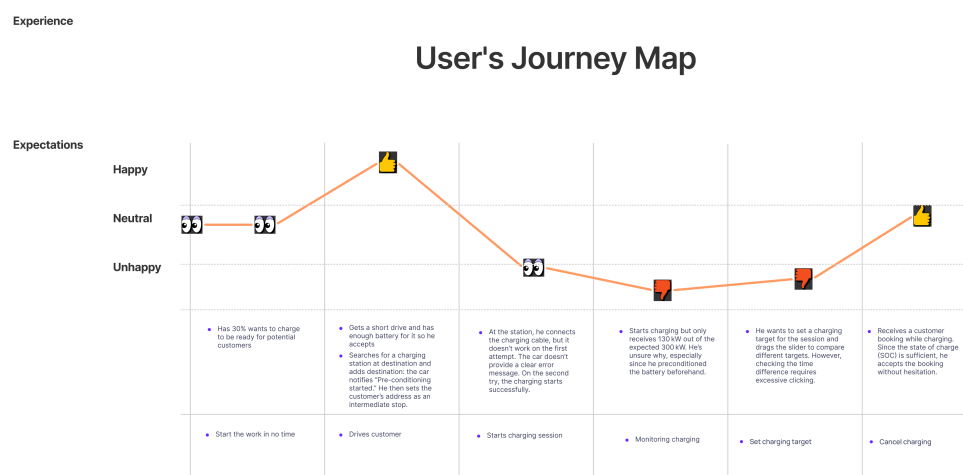


Figure 7.11: User journey map 1

emotional highs and lows, and contextual factors that influence the charging experience throughout a typical workday.

Process

Two journey maps were developed using a FigJam template and structured around three emotional categories: Happy, Neutral, and Unhappy. In order to develop realistic scenarios, insights were used from interviews with taxi drivers and personas were used with a focus on the selected themes from the thematic analysis. Emotional responses were then mapped to specific activities, providing a holistic view of the taxi driver experience and identifying key pain points.

Result

The journey map illustrates the drivers experience leading up to and during a charging session. It begins with a short trip and successful initiation of preconditioning, but issues arise at the charging station. The cable fails to connect on the first attempt without a clear error message. Once charging begins, the power received is significantly lower than expected, despite preconditioning. The driver is left guessing why, likely assuming it is due to battery level, but the lack of information causes uncertainty. Frustration continues when setting a charging target, as comparing options requires excessive clicking. The experience improves again when a new booking is accepted mid-charge with enough SOC. See (7.11).

The second journey map illustrates the drivers experience when planning and executing a charging session. The journey begins with frustration due to the cars navigation system lacking payment information, forcing the driver to use a third-party app. The experience improves once he gets a customer booking. He plans to charge after the customer drop-off by selecting a charging station near the customer's destination. He notices that preconditioning has started and then sets the customer destination as an intermediate stop. However, upon arriving at the charger, the speed is much lower than expected, despite a low SOC and preconditioning, and there is no explanation from the car. Charging speed later increases, easing the driver's concerns, but then drops again to 80 kW without clear reasoning. He assumes its due to a higher SOC but isnt sure. The session ends positively

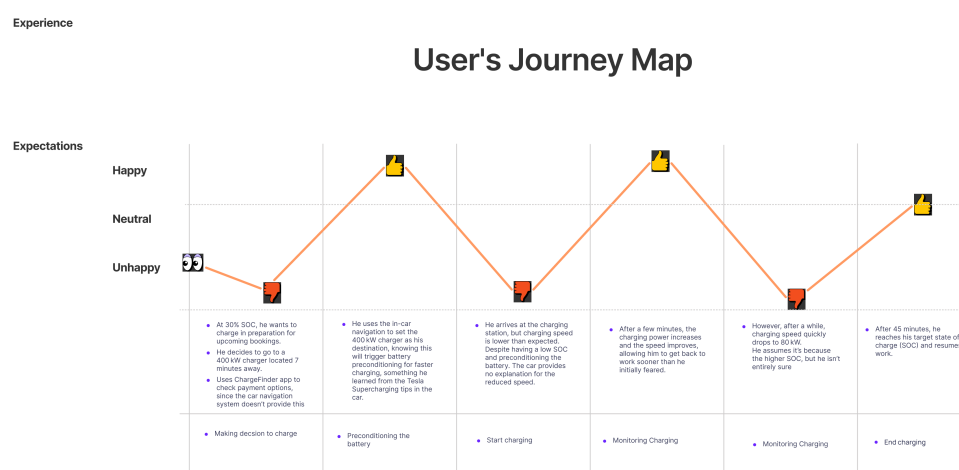


Figure 7.12: User journey map 2

when the target SOC is reached, and he resumes work (See 7.12).

7.3.3 Requirements

Aim

The aim was to develop a requirements list based on the collective findings from the research conducted so far, with a focus on the needs of taxi drivers. This list was intended to serve as a reference point to guide the development of the prototypes.

Process

In order to summarize the needs of the taxi-driver based on the selected themes from our thematic analysis, personas and journey maps, a list of user requirements was developed using User Stories, following the format: As [a user persona], I want [to perform this action] so that [I can accomplish this goal].

Result

In this section, a list of 10 user requirements are listed and described.

UR1: As a user, I want charging information to be intuitive so that I can take informed decisions that support more time-efficient charging

This theme derives from UI and InfoVis, and Charging capacity and power variability (See 7.2.1). Drivers expressed that the UI provided either insufficient information or unhelpful tips regarding how to charge more efficiently, pointing to a need for more intuitive and contextual information.

UR2: As a user, I want to see information on whether there is anything I can do to improve the condition of my car for charging so that the car can receive more power (kW)

Multiple taxi drivers expressed their dissatisfaction with the time it takes to charge their cars, saying it takes too long and it should be made shorter. Additionally, drivers expressed the desire for more kW because it leads to a faster charging time. This can be

seen in the theme Charging capacity and power variability (See 7.2.1). With P9 saying, "The time it takes (to charge) is annoying." Therefore, providing information on any actions the user can take could be beneficial.

UR3: As a user, I want to see the input kW (source power) so that I understand why the kW may be lower than expected (e.g. shared capacity at station or vehicle limitations)

Drivers expressed uncertainty about why the charging power (kW) varied, as reflected in the theme Charging capacity and power variability, as well as choosing stations with higher capacity than car can receive, possibly not knowing this reflected in the observations (See 7.2.1). Understanding whether the power source or the car is causing the limitation can therefore be important for building trust and clarity in the charging experience.

UR4: As a user, I want to see my car's predicted charging capacity so that I can make an informed decision about the station I choose (kW output) and when to charge

This requirement is derived from the themes Charging capacity and power variability and Charging speed and station preferences and the observations (See 7.2.1). Drivers will choose high-capacity chargers, sometimes taking detours to reach them. However, it is not always the case that their cars are capable of receiving the advertised capacities of stations. Providing users with a prediction of their cars expected charging capacity, based on current conditions or vehicle limitations, before they navigate to a station could help prevent unnecessary detours and enable improved understanding and decisions.

UR5: As a user, I want to be able to see how much extra time it takes to charge to a higher battery target than I initially set so that I can make an informed decision on whether to continue charging

For taxi drivers, they have to weigh out the option of denying a customer or choosing to continue to charge. Therefore, providing an intuitive way to compare the charging time may ease their cognitive load. This requirement derives from the theme Economic impact on charging and the observations noted during the taxi driver interviews (See 7.2.1).

UR6: As a user, I want to be able to see the payment alternatives at a station so that I can know that I am able to pay when I charge there

As discussed in the On-site charging issues theme (See 7.2.1), this requirement would allow drivers to see whether a station at their destination accepts their preferred payment method, as there are multiple subscriptions to different charging vendors.

UR7: As a user, I want to get more descriptive error messages when I encounter issues starting the charging session

As found in the On-site charging issues theme (See 7.2.1), users encountered at times issues starting a charging session, without a clear error message on what went wrong.

UR8: As a user, I want to be aware of the battery preconditioning function and see its current status

As found in the Navigation for preconditioning theme (See 7.2.1), there was a lack of awareness regarding the preconditioning feature, with uncertainty about its functionalities

occurring. Making preconditioning functionalities more visible and informative would help increase transparency.

UR9: As a user, I want the option to manually start preconditioning, so I can prepare my battery even when using external apps to find charging stations

While nobody explicitly requested a manual preconditioning button, this feature would eliminate the need to search for a charging station via the navigation just to start preconditioning, especially for users unaware of it, found in the Navigation for preconditioning theme. It would also support those who prefer using external apps for navigation as found in UI and InfoVis themes. This would eliminate the need to use in-car navigation when they prefer other apps. P18 note "I use charge finder, it is very smooth to find a charging station [...] the only thing needed is to connect the app to the car, so when I choose a station in the app, the battery should warm up". (See 7.2.1)

7.3.4 Volvo Survey

Aim

The aim of the survey was to verify whether the UI and InfoVis challenges identified in the taxi driver interviews, and further explored through the background review, are also applicable to Volvo BEVs. Due to the majority of taxi drivers interviewed primarily driving Teslas (see 7.4), and because this thesis is a collaboration with Volvo Cars, it was important to verify that these challenges extended to Volvo vehicles as well.

Ideally, we would have focused on taxi drivers using Volvo BEVs, as they represent primary users who would interact with the product frequently. However, this approach was deemed too resource-intensive and time-consuming within the scope of the thesis. Additionally, we believed that the challenges were not unique to taxi drivers but relevant to everyday BEV users who use fast charging. These users, considered secondary users, interact with the product occasionally due to less frequent fast-charging habits. To efficiently address these points, we conducted the survey.

Participants

A total of 54 participants answered the questionnaire, all based in Sweden. Most (87%) primarily drive a Volvo BEV, with 9% driving a Polestar BEV. BEV experience varied, with 50% reporting one year or less, 20% having 1-3 years, another 20% with 3-5 years, and 9% exceeding 5 years.

Process

We sent out an online survey made with Microsoft Forms on Viva Engage to the Volvo Cars Community aimed at experienced BEV drivers. The survey consisted of 18 questions (excluding demographic questions) that were based on the user requirements list. Since the goal was to confirm whether these needs exist, the questionnaire primarily consisted of yes/no closed-ended questions for clear and straightforward responses. Several contingency questions, also in yes/no format, were used to tailor the flow based on participants prior answers and gain further insight into their experiences. Additionally, one matrix captured ratings across related items, and two open-ended questions were added to capture deeper, qualitative feedback.

Analysis

The qualitative data was analyzed using affinity mapping and frequency analysis. For one question, an affinity map was created by transferring the answers onto digital post-it notes in FigJam. After which, they were grouped together according to similarity in order to identify patterns. For the other free-text question related to the use of external apps, we analyzed through a mixed-methods approach using frequency analysis and thematic analysis. Responses were also transferred to digital post-it notes in FigJam. The notes were initially grouped based on the specific app mentioned. Responses that mentioned multiple apps in the same answer were grouped separately. We then recorded the frequency with which each app was mentioned and extracted any stated reasons for its use. This information was summarized in a table to provide a clear overview of both the most commonly used external apps and the motivations behind their usage.

The quantitative data was automatically graphed by Microsoft Forms and, thus, we were able to use the graphs to examine the data. The quantitative data provided insight into whether the drivers shared the same needs.

Results

The results of the questionnaire were aligned with the issues found from the thematic analysis. For most questions, the majority of the participants confirmed they experienced the issue brought up for all of the themes selected.

Q1-2 On-site issues

81% of participants had experienced issues starting a charging session, requiring reconnecting the cable or switching to a different charging station, while 49% did not receive an error message and 49% received an error message which was not descriptive enough.

Q3 Fast charging tips

47% of participants disagreed or strongly disagreed that their car provides intuitive fast charging tips in the display, while 20.8% agreed or strongly agreed, and 32.1% were neutral.

Q4-9 Charging power expectations

87% of participants reported having received lower than expected kW capacity when starting a charging session. None of these (0%) recalled the vehicle providing an explanation for this. Additionally, 91% had experienced fluctuations in charging power during a charging session, with 96% reporting that the car does not inform why. A strong majority (93%) agreed it would be beneficial to visualize the factors affecting charging capacity (kW) while charging.

Q10-12 Interface Usability

Participants were split on whether it's easy to compare charging times for different battery levels without excessive interaction, 51% said it was easy, while 49% disagreed. Meanwhile, 92% stated that there is no intuitive way to understand how different factors (e.g. SOC, kW) affect charging time, and 90% expressed interest in having such a feature.

Q11-13 Navigation

39% of participant said that they do not receive enough information in the UI to choose the best charging station for their car and needs, while 31% said it does, and 30% said occasionally. When asked if any important information is missing and what, 22 participants

answered. The patterns found when mapping out the answers were:

- Charging station discovery and selection
 - Improve cars system for recommending charging stations
 - * Users want a smarter, more reliable charging station recommendation system. There is frustration with the car often selecting the latest possible station, which risks it being full upon arrival. Request for real-time occupancy data, dynamic rerouting, and the ability to prioritize cheaper stations with adequate charging speed. Additionally, there is a need for preferences for specific networks (like Tesla) to be respected and request more flexibility in suggested charging durations, such as allowing for longer breaks.
 - Charging station filter options
 - * Users want more control over how charging stations are selected and displayed. They ask for filters based on price (SEK/kWh), charging subscriptions (e.g. Volvo Public Charging, Ionia Passport), and preferred networks (e.g. Tesla, InCharge, Ionia, Mer). There is a need for better map interfaces to prioritize stations by cost, availability, amenities (like nearby food or rest areas), and charging speed. Users also want the ability to force routing through specific providers and improve UI for easier station selection, especially on longer trips.
 - Additional information on charging station
 - * Users want precise and practical details for each charging station, beyond vague categories like "fast" or "superfast." They request exact charging speeds in kW, real-time occupancy status, and nearby amenities such as food, stores, and their opening hours. This additional context helps users make informed decisions when choosing where to charge, especially on longer journeys.
- Payment and price for charging
 - Users want clear, upfront information about charging costs and payment methods. They are frustrated by the lack of visible pricing (e.g. cost per kWh) and unclear or overly complex payment processes, often requiring multiple apps. There is a desire for standardized, accessible details like actual kWh rates, total cost estimates, and available payment options at each station to simplify and plan charging more effectively.
- Transparency for preconditioning
 - Users want clearer information and control over battery preconditioning. They find it difficult to understand when and how preheating is activated, and want the ability to manually start preconditioning, especially when planning a charging stop manually. There is also a need for more transparent feedback on battery status, including whether it is ready for fast charging and how temperature or SOC affects max charging speed.

Additionally when asked if they use external apps or tools to help them choose a charging station and which ones and what kind of information they provide, 42 participants answered. 18 different apps were mentioned, with the most common being InCharge and ABRP, and the reasons mentioned where i.e. information about different pay options and easy to select preferred charging stations (see 7.13).

Q14-16 Preconditioning

62% answered that they use the car's navigation to precondition the battery before charging at a station, while 28% did occasionally. From these, 39% have at sometimes needed to add intermediate stops before reaching the charging station, however 97% answered that the car does not inform how it handles preconditioning in this case.

7.3.5 Main Findings

Through the personas, user journey maps, requirements list, and follow up survey with BEV drivers at Volvo, a clear set of challenges were identified and defined. It is highlighted that taxi drivers face uncertainty and inefficiencies during charging due to a lack of clear, real-time information. Key pain points include unpredictable charging speeds, unclear preconditioning status, and limited system feedback, impacting both workflow and user confidence. To ensure focus and feasibility within the scope of the thesis, we chose to concentrate on one of the three themes chosen from the earlier thematic analysis: **Charging capacity and power variability**, leading to prioritizing the requirements related to this theme (UR2-UR5) and refining the RQs (See 1.3).

7.4 Concept Development

The aim of this phase was to develop a feasible and novel concept that addresses identified user needs and requirements and could serve as the foundation for the design process. The process began with a benchmarking analysis. Building on the insights from this analysis, a brainstorming session was held, followed by a feasibility assessment and the development of low-fidelity prototypes.

The values presented in the design prototypes are intended for visualization purposes only and do not reflect real-world values from any specific vehicle.

7.4.1 Benchmark

Aim

While some comparative observations were included in the background review to identify opportunities and gaps, the aim of this benchmark is to evaluate the UI specifically for fast charging across five different car models by checking for the presence and implementation of specific components related to the theme chosen to focus on. By identifying which elements are commonly included and how they are presented, this analysis would guide and inform our own UI design, helping ensure it meets user expectations, addresses gaps, and aligns with industry standards.

7. Process And Results

App name	Frequency	Stated Reason
Chargefinder	21	<ul style="list-style-type: none"> • Info about different pay options and charge levels • Where to find charge station • Charging prices • (almost) Live update of the number of free charging spots • More charging vendors • Easy to search for charging stations • See how fast they are • What stores and other restaurants are in the area and the distance to them • Good way to find destination chargers when travelling • Easy to filter on speed and show different costs depending on charging network providers • To manually plan the route
ABRP	13	<ul style="list-style-type: none"> • Support the pre-planning of charging with SOC • Easier to select preferred charging stations
Tesla	7	<ul style="list-style-type: none"> • Price • Number of available station • Information on if any station is broken • Waiting time if all are occupied
Volvo app	7	<ul style="list-style-type: none"> • To find charging station and price for VPCS public AC and DC stations
Ionity	7	<ul style="list-style-type: none"> • Shows available chargers and max kW • To manually plan the route
Google maps	5	-
InCharge	4	<ul style="list-style-type: none"> • To locate the ones that accept the tag • To manually plan the route
Circle K	2	<ul style="list-style-type: none"> • Easy to check the map in the app and find charging station
Vattenfall	2	<ul style="list-style-type: none"> • Check prices of their stations
Fortum	1	-
Chargepoint	1	-
OKQ8	1	<ul style="list-style-type: none"> • Easy to check the map in the app and find charging station
Chargespot	1	-
Charge map	1	-
Plugshare	1	<ul style="list-style-type: none"> • To manually plan the route
e.on	1	-
Mer	1	-
Recharge	1	-

Figure 7.13: Frequency analysis of external apps

Process

The benchmark included six different electric BEVs, selected based on data from an industry analysis for the year 2024 by the Swedish Taxi Association ([79]). The chosen vehicles represent the five most commonly used electric car manufacturers in the Swedish taxi sector, with the addition of Volvo, which ranked eighth place. For each manufacturer, the most recently released model was selected. If the latest model was unavailable, another newer release was chosen. This approach assured the vehicles did not have outdated software or UIs. This approach aimed to capture current solutions, as older models, although still in use by taxi drivers, may lack recent UI developments relevant to the chosen view.

As we had limited access to the vehicles, the benchmark was conducted online through research rather than a hands-on approach. This made it time- and resource efficient and allowed for wider sampling, basing the benchmark on multiple user reviews, videos, manuals, and forums. These sources also provided real-world insights from users, providing great feedback.

We analyzed how the different cars handle charging UIs, noting important features (yes/no), and using that to inform our own design.

Result

The benchmark analysis revealed that while all vehicles included an interactive charging target slider, not all offered real-time updates during user interaction. Tesla and Volvo required the user to release the slider for the estimated time and target SOC to update, whereas in Skoda, the target and time updated automatically during interaction. However, all cars indicated when charging would be complete, either by showing the remaining time (majority) or a specific timestamp (minority).

In terms of charging tips, all cars provided some form of static DC charging tips, as presets were included. For example, Volvo offered preset charging options like "Daily Drive" capped at 90% SOC. However, in most cases, these tips were limited to presets or minimal tips. Tesla was the exception, offering an explicit list of fast charging recommendations, including guidance on preconditioning and setting charging limits.

The type of charging (AC/DC) was explicitly shown only in the KIA EV9, which displayed "DC charger" above the current charging power (kW) in the main charging view. While other cars also displayed charging power, they did not clearly indicate whether it was AC or DC. Additionally, all cars explicitly displayed the current SOC.

None of the cars displayed the power capacity of the charging station they were connected to within the charging interface (excluding information available via the built-in navigation system). Battery temperature was also missing, while some cars had general indicators, none displayed the specific numerical value (e.g., 20°C). Additionally, none of the vehicles displayed predicted charging power (kW) during a session or provided real-time charging tips during the charging session.

Tesla and Volvo were the only cars to occasionally mention factors affecting charging speed like cold battery temperature, but the information was limited and lacked detail, e.g. Volvo provides a snowflake icon next to the SOC on the display, when battery is cold, however neither explained how these factors are affecting power or other important factors, e.g., if SOC was limiting power or speed.

Half of the cars, Skoda, Kia, and Volkswagen, featured a manual preconditioning button linked to the display of estimated charging power. This allowed drivers to initiate preconditioning when the charging capacity was noticeably lower than the maximum. However, without clearly explaining the reasons behind the reduced capacity. Finally, all cars maintained a consistent UI design, however, the quality of this consistency is a subjective measure based on design principles.

Car	Skoda Enyaq	Mercedes Benz EQS	Tesla Model Y	Volkswagen ID.7	KIA EV9	Volvo EX90
Real time kW	Yes	Yes	Yes	Yes	Yes	Yes
Possible kW from power source	No	No	No	No	No	No
What factors affecting kW	No	No	Yes	No	Yes	Yes
How these factors are affecting kW	No	No	Yes	No	No	No
Type of charging (AC/DC)	No	No	No	No	Yes	No
Battery temperature (value)	No	No	No	No	No	No
SOC level	Yes	Yes	Yes	Yes	Yes	Yes
Predicted kW during charging session	No	No	No	No	No	No
Interactiveness of charging target	Yes	Yes	Yes	Yes	Yes	Yes
Real time interactiveness (changes)	Yes	Yes	No	Yes	Yes	No
Static DC charging tips	Yes	Yes	Yes	Yes	Yes	Yes
Real time charging tips (during)	No	No	No	No	No	No
Charging time	Yes	Yes	Yes	Yes	Yes	Yes
Consistent design	Yes	Yes	Yes	Yes	Yes	Yes
Manual preconditioning button	Yes	No	No	Yes	Yes	No
Estimated charging capacity	Yes	No	No	Yes	Yes	No
Factor(s) affecting estimated capacity	No	No	No	No	No	No

7.4.2 Brainstorming

Aim

The aim of the brainstorming session was to promote creative thinking and collaborative exploration in order to generate a range of ideas that addressed the identified user needs and requirements. A further aim was to develop initial low-fidelity drafts of novel concepts with uncertain feasibility, allowing for early expert feedback as part of the feasibility assessment.

Process

To begin the brainstorming session, a review of the requirements was conducted to establish a clear and shared understanding of the design scope and to ensure the idea generation remained goal-oriented. Two structured brainstorming techniques were employed during this session, the Crazy 8s and a modified version of the 6-3-5 Brainwriting method.

In the Crazy 8s method, each participant was given one minute per sketch and generated a total of eight ideas. The 6-3-5 method typically involves 6 participants generating three ideas every five minutes, after which the ideas are passed along and are completed

by another participant. Given that only two participants were involved in this session, the structure was adjusted to accommodate for two. Following this, all the ideas were reviewed and, through discussion, the ideas that were best suited to the requirements were selected.

To begin conceptualizing the selected ideas, an initial draft of low-fidelity prototypes was created in Figma, building on existing components from Volvo's design system. The goal was to visualize how the concepts might be visualized on screen, however, the actual development of a low-fidelity prototyping would follow at a later stage. While the intention was to keep the prototypes as low-fidelity first drafts, the use of an existing design system components gave them a relatively high-fidelity appearance.

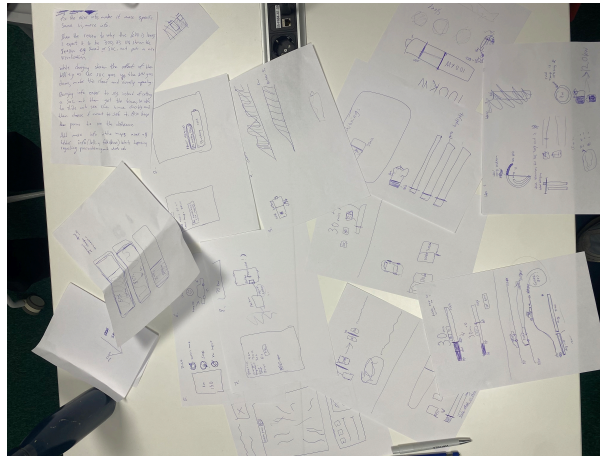


Figure 7.14: Brainstorming session

Result

The brainstorming session led to two initial design concepts: a charging curve visualization (see 7.15a) and a capacity page while charging (see 7.15). The charging curve aimed to visualize kW levels throughout a charging session, past, present, and projected future. The capacity page displayed the kW currently being received by the car, the power source (i.e., the charging station), an icon indicating whether the station was being shared, and vehicle-specific factors affecting the kW intake, namely, SOC, battery temperature, and energy consumption of the cabin climate.

7.4.3 Feasibility Assessment

Aim

The aim of the feasibility assessment was to get an early indication of the opportunities and challenges associated with implementing the features of the low-fidelity prototypes before further developing the ideas for evaluation.

Process

A semi-structured interview was conducted to investigate the technical feasibility of the features in the design concepts. Recruitment was conducted using purposive sampling by selecting a technical expert in vehicle energy management. The recruitment was carried

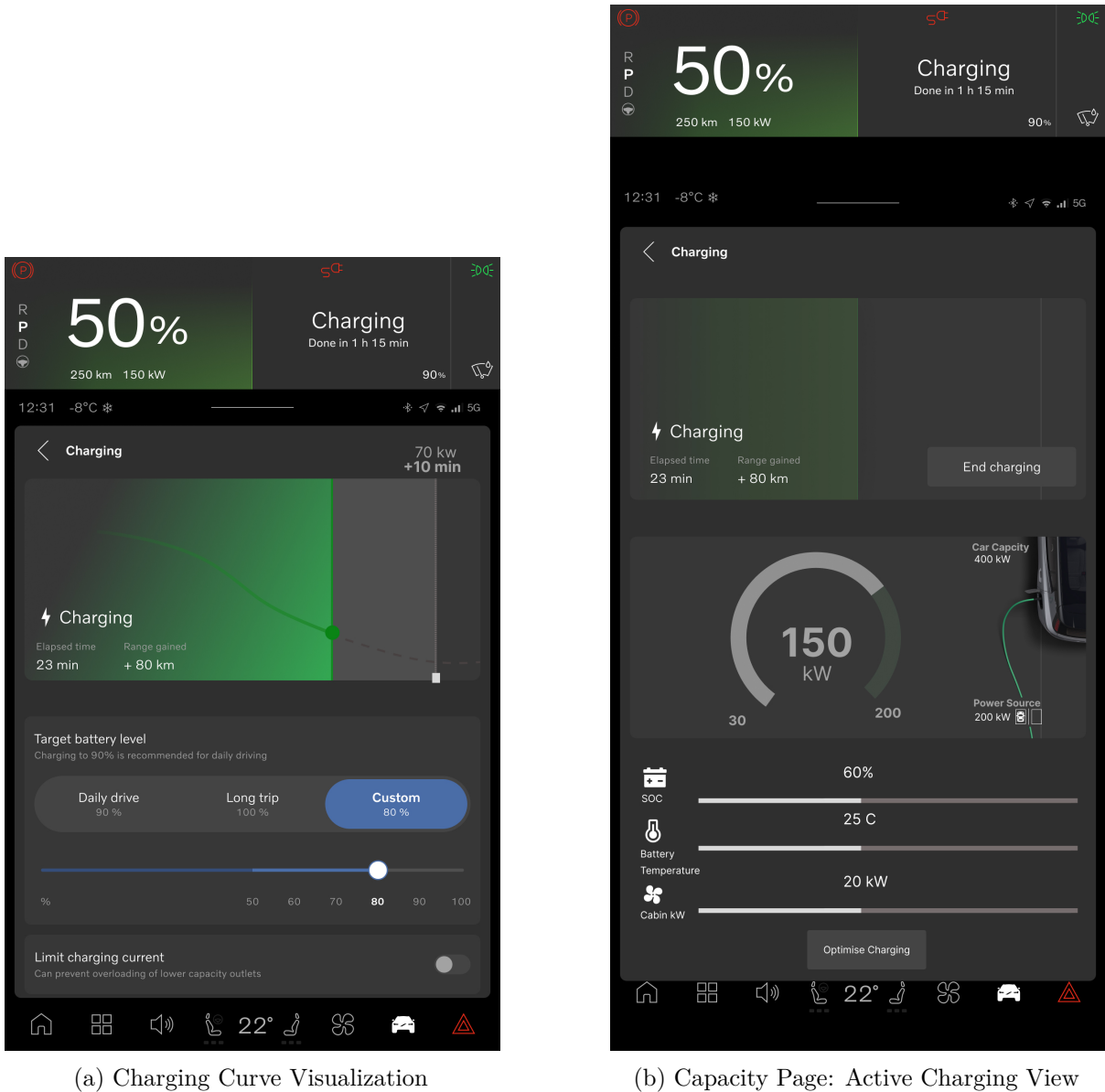


Figure 7.15: First draft of low-fidelity prototypes

out via Microsoft Teams, and the interview was held in a meeting room at the Volvo office in Gothenburg, Sweden. The session lasted approximately one hour and was audio recorded for analysis. Prior to the interview, the participant was briefed on the aim of the study and the interview. The interview followed a predefined set of questions but was carried out as an open dialogue, where some questions were answered naturally during the conversation and others were asked at the appropriate time. Each design concept was presented with contextual information provided throughout the session.

Profession (Title)	Industry Sector	Years of EV Experience
Engineering Manager	Automotive	6

Table 7.25: Demographic table of feasibility expert

Analysis

For the analysis of the interview, the audio recording was transcribed using Microsoft Word Transcriber. Thereafter, the transcription was reviewed while simultaneously listening to the audio recording. Statements regarding feasibility, challenges, and opportunities were highlighted. To ensure no critical points were overlooked, each researcher independently reviewed the transcript, highlighted significant segments. Thereafter, a discussion took place to identify areas of overlap in their highlights, and debated the reliability and significance of statements highlighted individually to reduce bias, if both researchers agreed on their reliance and significance, those statements were included. The highlighted statements were then synthesized as key takeaways so changes to the prototype could be made accordingly.

Result

It was expressed that the degree to which different factors affect the charging power can vary throughout the charging session. It was suggested by the participant that the interface could indicate what is currently limiting the charging power the most, which would help users understand the process and support learning over time, saying *"It could be that when you start charging, the battery is almost empty and the temperature is low - then it's the temperature that lowers your charging power. But then, as you charge and the battery gets warmer and you approach a full battery, the battery might be warm, but then its the SOC that limits how fast it can charge. These two could show what it is that's holding back the charging power, it becomes a kind of learning for the customer to understand."* and *"Yes, it needs to be pedagogical in some way for the user, showing which factor is affecting or limiting the charging power."*. Thus, implying that there is an opportunity for improvement in how the vehicle communicates the factors affecting charging power, which could support better user understanding and transparency of the cars behavior.

From the interview, it was found that the energy consumption of the cabin climate does not significantly reduce the charging time, the participant expressed *"It depends on how cold it is outside. If the weather is pleasant, like 15/20 degrees, then it probably only takes, we're talking maybe max 1 kW or so. Thats quite a small difference. But if it's minus 15 degrees outside, then you need a few kilowatts for heating the cabin climate. I dont know, maybe three kilowatts or something, three, four, somewhere around three. Overall, its not that many kilowatts when you're talking several hundred kW from the charger."*. Based on this insight, information about cabin energy consumption and the option to turn off the cabin climate through the "Optimize" button was removed. This decision was made to avoid frustrating users, since the effect would often be minimal, pressing "Optimize" might appear to do nothing, leading to confusion or lack of perceived value.

One of the features that was eventually removed, was a visualization that informed users when the charging station was being shared with another vehicle, resulting in reduced charging power. This was excluded due to the technical challenge of reliably determining whether the decrease in charging power was caused by charger sharing. Since the vehicle cannot directly detect whether another car is connected to the same charger, it cannot distinguish between power reduction caused by charger sharing or other external factors. The participant noted, *"The car finds out the power that the charger can provide, that Im pretty sure of. But the charger probably wont say how it is with other cars. Not all*

chargers necessarily need to split the power either. It can probably vary a bit depending on how the chargers are" and "It could also be other reasons than a new car arriving".

However, an opportunity was pointed out by the participant saying *"The general idea is that the user should be able to see if at 150 kW, it is the power source, or the car's capacity, to understand which of the two is the limiting factor. That should be visible".* This implies that there should be a clear visualization of whether the charging power is being limited by the charging station (regardless of whether its shared or not) or by the cars capacity. Our prototype displays the cars peak charging capacity, the current charging power, and the power source output. However, it does not explicitly indicate which of these is the limiting factor.

The forecasted data of the charging curve was considered feasible, however, the accuracy of the curve data would be difficult to but a generalization was possible, as noted by the participant *"its not unfeasible to have a curve like that, its something we should be able to develop. Its hard to define it exactly, because it also depends quite a lot on other things in the battery, I think. But some kind of curve should be possible to have. So yes, it is feasible."* This insight resulted in the charging curve being kept as part of the prototype.

An opportunity for improvement was identified in the InfoVis of the charging curve, suggesting using color channels to coach users on optimal charging with the participant saying, *"Theres definitely an opportunity to do something pretty cool here, like marking where in the zone you get the best charging, so to speak" and "The green field could be color-coded in some way to show where charging is fastest, and in that way, it could coach the user. I think this is also important because many customers might not understand that they have really good charging power at the beginning when they plug in, if the battery is warm. Otherwise, it takes a little while before the battery warms up."*

Another opportunity that was pointed out in regards to the the entirety of our concepts was related to the context of use and the different needs of individual users, saying *"abstract it on multiple levels, so that someone who just wants to glance at it, without having to read too much into the graph or understand all the connections, can still get a sense of why charging has gone quickly so far, or why it hasnt gone quickly yet."*

7.4.4 Low-Fidelity Prototyping

Aim

The aim of the low-fidelity prototyping was to further develop initial concepts, with feasibility in mind, in order to effectively communicate the ideas for evaluation, while minimizing the time and resources spent.

Process

The ideas chosen during the brainstorming session were transformed into low-fidelity prototypes using Figma. To align with Volvo's design system, existing components within their systems were utilized. The interface's header, navbar, and font size were consistent with Volvo's design guidelines. Since the new design concepts were not improvements of existing car functionalities, they were created from scratch rather than adapted from existing components. As the prototypes were of low-fidelity, they were not interactive at this stage.

Result

In this section, the low-fidelity prototypes are presented. In total, there are four views that are completely new to the system.

Target page

To support more intuitive charging planning, a target setting and forecasting view was created to address user needs around understanding charging time, efficiency, and power delivery (See 7.16). This interface allows users to set a target SOC and immediately see the impact on estimated charging time, and power output throughout the session. By visually representing how charging power (kW) decreases as SOC increases, and providing real-time updates through an interactive SOC slider, the feature helps users make informed decisions about how much and when to charge. It reduces idle time, supports efficient station use, and solves usability issues such as the difficulty of comparing different charging targets without excessive interaction.

Charging Curve Visualization

At the top of the interface is a simplified graph that displays both historical and forecasted charging power (kW). The background resembles a horizontal battery metaphor, filled in green to encode the SOC level from 0% to 100%. A line graph overlays this battery, showing the current power (kW) being delivered, how it has changed since the start of charging, and how it is expected to decline over the remainder of the session.

Displaying this decline as a curve helps manage user expectations and reinforces the logic behind longer charge times at higher SOC levels in a simplified manner, addressing UR1 (see 7.3.3).

Charging Goal Setting

Under the charging curve, the user can select a target SOC using an interactive slider. The timeline is visually divided into four charging segments (0–25%, 25–50%, 50–75%, 75–100%), each represented as a box along the charging bar. The size of each box correlates with the time required to charge through that interval, longer boxes indicate slower charging (i.e., more time per SOC gain), due to the natural tapering of power as SOC increases, visualized in the charging curve.

Each box is annotated with the average charging power (in kW) achieved within that segment (e.g., 150kW from 25% to 50%), helping users understand efficiency across the charging curve. When a user adjusts the target SOC (e.g., increasing it from 50% to 80%), the estimated time is updated in real-time, with an additional time factor clearly shown (e.g., +10 min). This feedback supports decision-making about whether the extended charging time is justified based on convenience, addressing UR5 (see 7.3.3).

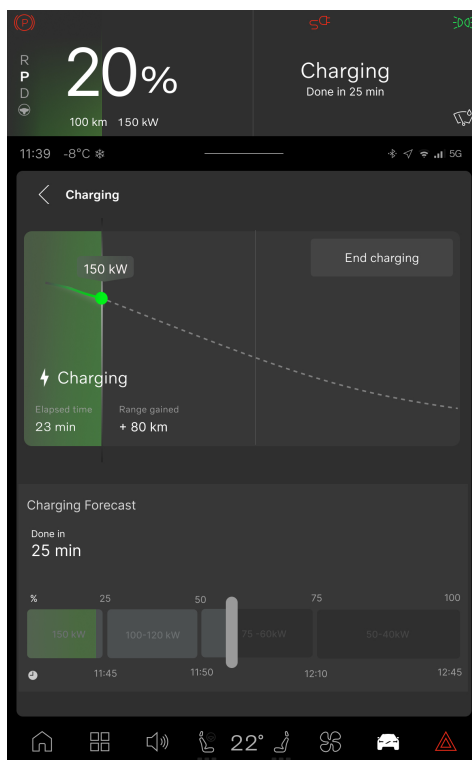


Figure 7.16: Target page

Capacity Page

To address user frustration with unexpectedly low charging power and the lack of feedback during charging sessions (7.2.1), a two-state charging power transparency view was developed. This interface includes a pre-charging estimation view and a real-time charging view, both designed to enhance clarity, control, and predictability in the charging process.

Estimated charging view

When the vehicle is not connected to a charger, the interface displays an estimated charging capability in kW based on current vehicle conditions, followed by the car's maximum capacity (kW). This is visualized through a horizontal bar graph where:

- The total bar represents the car's maximum DC charging capability (e.g., 300kW).
- The filled portion (e.g., 150kW) indicates the current estimated power the vehicle can receive from a charger.

If the current estimate is below the maximum potential, a reason is displayed in orange under the "Charging conditions" heading (e.g., "Charging speed may be slower due to cold battery temperature") with a circular indicator on the charging condition affecting. Below this, three circular gauges visualize:

- Battery Level (SOC)
- Battery Temperature
- Battery Health (SOH)

Each gauge is accompanied by exact numerical values (e.g., 30% SOC, -5 degrees C battery temperature).

To support user action, the view includes an option to manually prepare the battery for fast charging. A text description indicates the potential optimized charging power and the time it takes (e.g., "Optimization up to 250kW possible, 20min needed"), followed by an "Optimize" button. This enables the user to start battery preconditioning manually.

This view improves transparency before, helping users form realistic expectations and take proactive measures, addressing UR1, UR2, UR4, UR8 and UR9 (7.3.3). It addresses frequent complaints about receiving lower than expected charging power and being unaware of the causes (7.2.1). By offering insight into limiting factors and actionable controls such as manual preconditioning, the interface supports better station selection and trip planning, e.g., avoiding unnecessary detours to high-power stations if the car cannot utilize that capacity. Lastly, it supports trust and control in the charging process. See image to the left in 7.17.

Active charging View

Once charging has started, the interface adapts to display the current charging power being received, maintaining the same bar graph (See center and right image 7.17):

- The filled portion (e.g., 83 or 200kW) represents the actual power being delivered
- If the charging station (power source) provides less power than the car's maximum, there is a vertical line on the bar representing the charging station power:
 - If the power source is a limiting factor (e.g., provides only 200kW), a message highlighted in orange above the bar indicates this constraint. Additionally, the vertical line representing the power source becomes orange.
 - A patterned overlay portion visualizes what the car is capable of receiving (the car's current maximum DC charging capability under the given conditions (e.g., 250kW)) when the station is limiting.

As in the estimation view, the same three gauges remain visible and updated in real time. If any factor (such as high SOC or low temperature) is restricting charging speed, an explanatory message is highlighted in orange. Textual data also shows:

- Power source output (e.g., "Power Source: 200kW")
- What the car is currently capable of receiving (e.g., "Current DC Charging Capability: 250kW")

This view ensures transparency by showing both the charging station's output and the vehicle's maximum charging capability, which can help users understand why their charging speed may be slower than expected, addressing UR3 and UR7 (7.3.3). The inclusion of real-time updates for temperature and SOC allows users to track and address any factors that may be limiting charging speed, thus meeting the need for an efficient and predictable charging process.

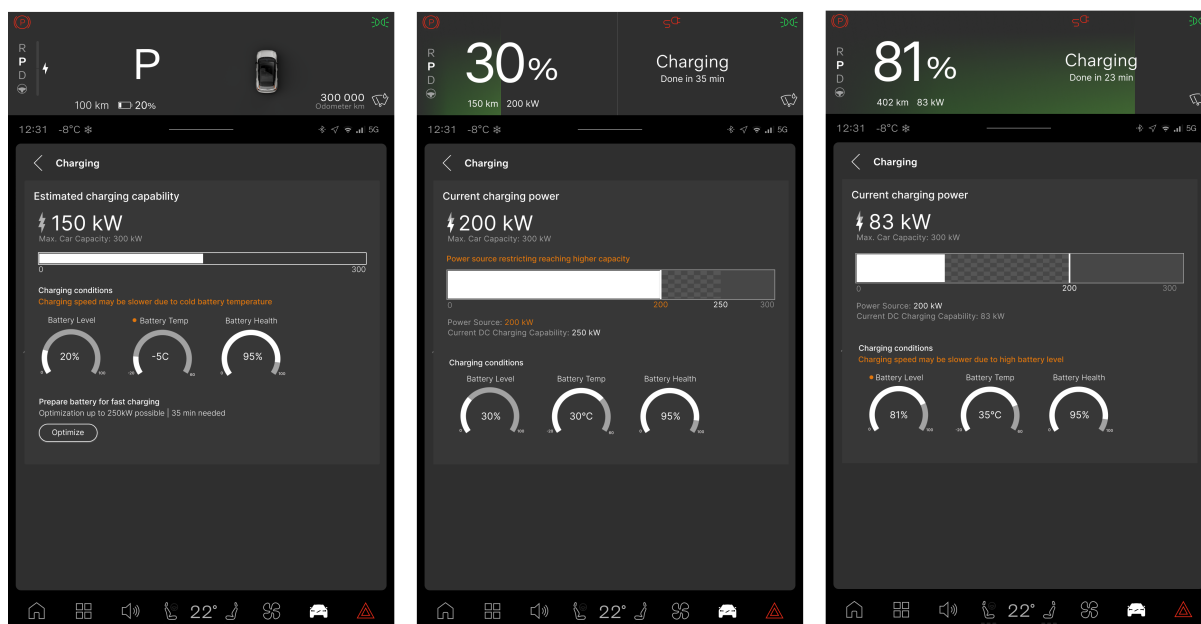


Figure 7.17: Capacity pages

Detailed Graph View

This graph view was created in response to user feedback about the lack of transparency, control, and predictability during charging. User expressed frustration with the lack of clarity about how charging power and SOC interact, especially in the context where the charging power fluctuates. It addresses these issues by clearly illustrating the relationship between SOC and charging power. By allowing users to set a target SOC and instantly see how it affects charging time and power delivery, the interface supports informed decision making and helps users weigh trade-offs between time and energy gain. Predictive insights, including dynamic updates and visual differentiation between real-time and forecast data, enhance user confidence and understanding of the charging process.

The graph employs a dual Y-axis configuration:

- The left Y-axis represents the SOC in percentage.
- The right Y-axis displays the charging power in kW.
- The X-axis denotes the time elapsed since the beginning of the charging session.

In order to distinguish the difference between the historical and forecasted data, visual encoding is utilized through saturation, hue and line types as channels. The vertical reference line indicates the current point in time within the charging session. The section to the left of the reference line uses hue and saturation in order to highlight the recorded trajectory of SOC and charging power being presented, while the right uses desaturated gray tones and a dotted line for SOC, showcasing the expected trajectory of SOC and charging power if charging continues under current conditions. This feature addresses UR1 and UR5 (7.3.3). See image 7.18.

Users can set a target SOC (e.g., 80%), which is visually indicated on the forecast curve. When adjusting this target, the system dynamically updates several key indicators in real

time, including:

- Estimated time required to reach the selected target
- Projected SOC, charging power (kW), and battery temperature at the time the target is reached

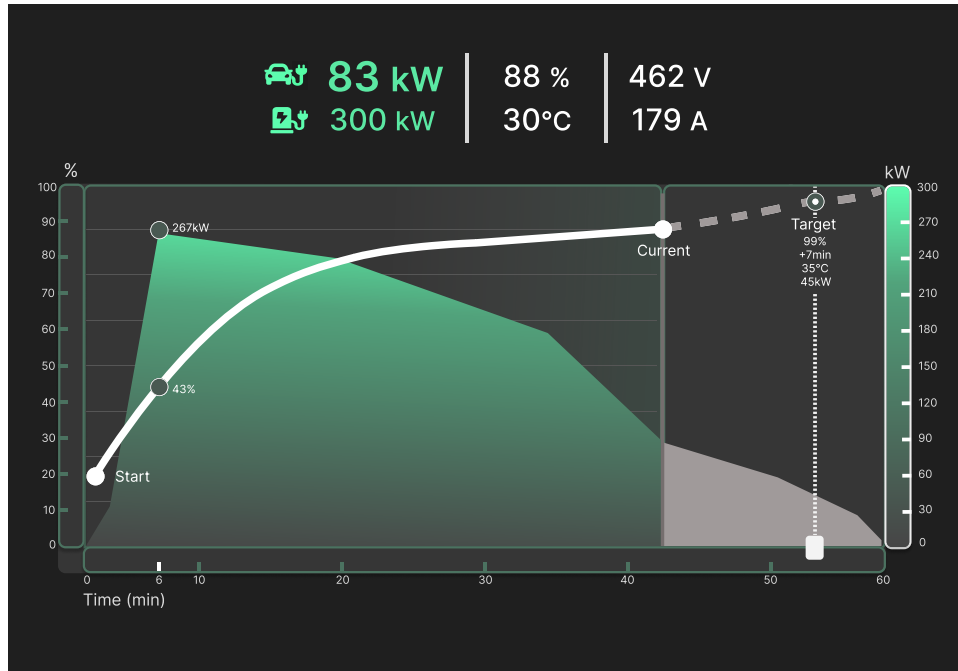


Figure 7.18: Graph of charging session

7.4.5 Main Findings

The benchmarking results supported the brainstorming session by providing an overview of key features that should be present in the charging interfaces, while also revealing opportunities for improvement. The initial drafts of the concepts developed during the brainstorming session effectively conveyed the ideas for the feasibility assessment, as reflected in the rich feedback received. The results from the feasibility assessment highlighted both limitations and new opportunities, which in turn guided the development of the low-fidelity prototypes ready for evaluation.

7.5 Design Iteration 1

The aim of this design iteration was to evaluate the low-fidelity prototypes and make refinements accordingly. The process followed a focus group evaluation, data analysis and a design refinement. Refinements were considered based on the frequency of feedback, how well aligned the feedback was with the findings from the interviews and background research.

7.5.1 Evaluation With Focus Groups

Aim

The aim of this evaluation was to assess the components and get feedback on potential challenges and improvements.

Participants

Thirteen participants (7 female, 6 male) aged between 25 and 59 years (avg. 34) took part in the study. Most had university education (10 out of 13), while the remaining three had completed high school. Participants' professions varied and included engineers, managers, and students. Experience with BEVs ranged from less than one year up to 10 years, with most having between 1 and 5 years of driving experience. Fast charging frequency varied, four participants regularly or occasionally used fast charging, five rarely used it, and four never used fast charging (3 of whom were students). The most commonly driven BEVs were Volvo models (see 7.26).

Process

We chose focus groups for the first evaluation iteration because we aimed to gather detailed feedback. By conducting longer sessions (1 hour), we were able to facilitate in-depth discussion among participants. Holding individual one-hour sessions would have been too time-consuming given our constraints, thus a focus group offered a more efficient way to collect rich, qualitative insights early in the design process. We contacted multiple taxi fleets in Gothenburg running BEVs over email, for recruiting taxi drivers to participate in the focus groups, offering incentives. After multiple failed recruitment attempts and the given time constraints, taxi drivers were not included in this evaluation iteration. However, the Volvo survey (7.3.4) confirmed that the fast charging issues affecting taxi drivers are applicable to regular BEV users, and therefore ordinary BEV drivers could be included in the evaluation phase, since they shared similar needs regarding the issues identified. The participants for this evaluation phase were recruited within the Volvo network.

In order to collect qualitative data, five focus groups were conducted. All participants were required to have prior experience in driving and fast charging a BEV, except for four IxD students who had experience driving BEVs but were not required to have fast charging experience. One non-student participant reported never using fast charging, as revealed during demographic analysis. The students were included to contribute with a design perspective and inform feature development. The evaluations aimed at assessing usability and identifying potential improvements of five features: charging forecast, target SOC slider, predicted car capacity view, current car capacity view and a detailed charging forecast graph.

Prior to each evaluation, the participants were briefed on the aim of the study and the evaluation session, given a consent form to sign, and a demographics survey to fill in. The evaluations were 1-hour sessions and recorded with an audio recorder to later be used for transcription. Participants introduced themselves at the beginning of the session to help create a comfortable atmosphere and encourage open, honest discussions. For each feature, the participants were given a few minutes to first view a printout

Participant ID	Age	Gender	Education Level	Years Driving BEV	Fast Charging Frequency	Car Model (BEV)	Profession
1	46	Female	University	3	Rarely	Tesla Model Y	Software Developer
2	29	Female	University	>1	Never	Volvo EX40	Student
3	27	Female	University	>1	Never	Volvo XC70 and Tesla Model 2	Student
4	34	Female	University	4	Occasionally	Volvo EC40	Design Engineer
5	38	Male	University	5	Rarely	Volvo XC60 and Volvo XC40	Engineering Manager
6	58	Male	High School	3	Occasionally	Volvo EX30	Test Engineer
7	27	Female	University	1	Never	MG Volvo and Volvo EX40 and Volvo EC40	Student
8	25	Female	University	>1	Never	Volvo XC60	Student
9	59	Male	High School	10	Regularly	Volvo EC40 and VolvoEX30	Quality Leader
10	33	Male	University	>1	Never	A3 Audi	DevOps Engineer
11	26	Female	University	1	Rarely	EX30	System Engineer
12	-	Male	University	1	Occasionally	XC40	Engineer
13	33	Male	University	2	Occasionally	EX40 Recharge	Project Manager Engineering

Table 7.26: Focus group participant demographics

of the feature and briefly discuss their first impressions. Thereafter, the participants were asked to complete the corresponding task and fill in a SEQ (Single Ease Question) questionnaire. The first questionnaire question asked participants whether the feature met their requirements as a user and the second one asked to rate how easy the feature was to use. Both questions were answered on a 7-point Likert scale from 1 (Strongly Disagree) to 7 (Strongly Agree)

Each task included a scenario that provided context for the view and a set of questions. Tasks were completed individually to minimize bias and ensure independent responses. After completing the task and filling in the SEQ questionnaire, participants were instructed to compare answers, and if any discrepancies occurred, they were encouraged to discuss the reasoning behind them. After discussing the answers, the participants were asked to have an open discussion on their opinions of the feature. Follow-up questions were asked when further elaboration was needed. For each focus group session, the tasks were administered in a random order in order to reduce sequence bias. Image 7.19 is taken from one of the sessions.



Figure 7.19: Focus group session

Analysis

A deductive thematic analysis was conducted to interpret the qualitative data collected from the focus group sessions. The analysis was structured around six predefined themes: Usability, InfoVis, Accessibility, Affordance, Context of Use, and Aesthetics. These themes were selected based on principles from HCI and UCD. They also reflect core aspects of interface evaluation highlighted in usability heuristics (e.g., Niensens Heuristics),

such as visibility of system status, match between system and real world, and aesthetic and minimalist design.

Together, the themes provided a balanced framework because they captured both practical aspects, such as the usability of the features, clarity of information, and component affordance, and experiential dimensions, such as contextual relevance and visual appeal. This combination allowed the analysis to address not only system functionality, but also how it is perceived and experienced by users.

The audio recordings from each session were transcribed using Microsoft Word AI Transcriber. After which, both researchers listened to audio recordings of each session while reviewing the transcriptions. Key statements and insights were annotated on post-it notes in a shared FigJam board. Once all the sessions were processed, the notes were collaboratively grouped into the predefined themes through discussion and consensus. Within each theme, the annotations were assigned code labels and annotations with the same or similar code labels were grouped together.

In addition to the thematic analysis, quantitative data from the SEQ (Single Ease Question) questionnaires and task success rates were analyzed. SEQ scores were averaged across participants to evaluate perceived ease of use and requirement satisfaction for each feature. The success rate for each task was calculated. Tasks or features with low success rates or low SEQ scores were noted for potential redesign or refinement.

Finally, insights from both qualitative and quantitative sources were synthesized to inform the next design iteration. Features that aligned across the thematic analysis, SEQ scores, and task completion data were prioritized in the refinement process.

Results

The results of the thematic analysis are presented first, followed by findings from the SEQ questionnaires and task success rates. The results of the evaluation are presented according to the predefined themes used in the deductive thematic analysis: Usability, Affordance, InfoVis, Context of use, Accessibility, and Aesthetics. Each view is discussed separately. When feedback from one view was clarified or confirmed in another, this is noted, particularly between view 2 and 3, which share functional and visual similarities.

Target Page

Usability: In general, participants found this view easy to comprehend. It was found that participants appreciated the timestamps, finding it helpful. Displaying the time remaining and 'done in X minutes' was also found to be informative. On the other hand, some participants found the set charging target feature less intuitive, preferring the charging curve component. It was noted that the graph component provided valuable information on kW, showing where it is best to stop charging.

P11: "I like the idea of putting the timestamp, because if you just show it's 25 minutes left and you might want to leave your car, then you have to check your watch [...] to do that calculation yourself or we can just display to you and they can be like, 'oh, okay, at 12:15, my car is going to be done "

InfoVis: Participants emphasized that the misalignment between the header bar, charging forecaster, and timeline slider caused confusion and should be corrected for easier

comprehension. They also found the timeline unclear, noting that the boxes were not proportional and it was difficult to determine which unit they represented, whether it was kW, time, or percentage. Some participants noted that kW could be removed from the timeline as it is already shown in the forecaster. Additionally, participants expressed that the target SOC needs to be displayed at all times, not only when setting the target.

P10: "You can also see that the values (kW) are quite high and then they decrease, but the boxes get bigger. Yeah, so you kind of have to choose which one you want to look at here to understand."

P7: "They (components) should align. If you have 50 % here, then it should be 50 up there as well same line, because it's the same on those two"

Accessibility: The font size of units on the timeline was considered too small and could be increased for better readability. In addition, the participants expressed that the low contrast between gray text and black background made it difficult to read, suggesting that improving the color contrast would enhance accessibility.

P1: "There are a lot of numbers, many small numbers that are hard to see because they're almost grey and almost black. It was really hard to read."

Capacity Page: Estimated Charging View

Usability: Participants appreciated the actionable option and found the interface easy to understand and provided valuable information prior to a charging session. Some participants suggested prompting the optimization action earlier and displaying the optimization button only when necessary to avoid unnecessary energy consumption. It was also pointed out that the user should be guided to use the navigation system to precondition as it is more energy efficient.

P6: "It's good [...] because when you're driving in everyday life, you might not always have a destination entered, that's you can still find it (precondition action)."

P9: "Yeah, then I'd want to have that button earlier. [...] And then maybe I could choose a later charging station with higher power? And press this button then, because this does consume a bit of energy."

P4: "I would've wanted it to take me to the navigation, to prompt me to use navigation [...] you really want to do it through navigation to get the best possible (optimization)."

InfoVis: Participants found the bar easy to comprehend and appreciated the minimal use of color. However, some found terms like capacity, capability, and charging speed confusing and inconsistent. It was also expressed that the optimization feature needed better visibility and clearer explanation.

P9: "There are many different definitions here, charging capability, car capacity, and charging speed that, in many ways, seem similar. We're talking about charging capability and car capacity, these are terms I'm not familiar with, and they make me start wondering, what is it? What do they actually mean here?"

Affordance: Participants noted that the placement and design of the optimize button could be improved to make it more visible and suggest interaction.

P3: "I kind of missed that you could optimize, [...] perhaps it should be a bit more

highlighted or have some small color indicator to show it."

Context of Use: It was noted that the view may vary between cars, since different models will have different min and max unit thresholds due to the chemistry of the battery, which is something that should be considered in the design.

Capacity Page: Active Charging View

Usability: Participants found this view easy to understand, pointing out that the charging conditions were informative. However, some participants felt that the complexity of the bar and supporting text and numbers caused cognitive load.

P13: "But okay, then the max charge capacity becomes very misleading."

InfoVis: Participants appreciated the color coding used between the bar and supporting text as well as the color choice. The graphical visualization (bar) improved understanding, however, it was found that the wording of the terms used to describe the values on the bar needed to be made clearer. It was also found that it was perceived to be an overload of numbers. Lastly, the color of the warning messages should not be too alarming and should be presented hierarchically.

P4: "I think the wording is important, how you say it, because its also like this, if you think about it, sometimes when writing, you have to write not just what you mean, but what the car means, or like, that you write 'the current charging capability of the car' or say what you're referring to, [...] that youre really overly clear."

Accessibility: The majority of participants did not mention anything related to accessibility. However, one participant expressed a need for a larger font size for the kW value to improve visibility and reduce the effort required to interpret the number from the bar.

P8: "Im almost a bit like Id rather have a bigger number here than to be able to see exactly (on the bar) where it is."

Detailed Graph View Usability: Some participants found this view to be intuitive and understandable, however, it was noted required more cognitive effort to understand, while others struggled to interpret it completely. It was still noted that the graph provided valuable information for charging. Information on volt and ampere units were considered not useful and could be removed.

P4: "Graphs are always generally kind of hard to take in [...]there wasnt any unnecessary information. There wasnt anything extra or anything. I still thought it was quite easy to read."

Affordance: It was noted that the round radius of the different sections of the graph made them appear separate from each other rather than a single entity.

P3: ".Because this box is kind of curved a bit, and it looks like it's set in place. If it had only been the color that changed, I think I wouldve understood more that this is a prediction. But now it looks like theyre statically divided like this."

InfoVis: The use of color coding for the axes and bars was found to be effective in helping users interpret the graph. Additionally, displaying the values above the graph reduced cognitive load, as users could easily map the values to specific points on the graph.

However, some participants were unsure about what the values referred to, indicating a need for clearer labeling.

P11: "Because I guess. It's battery temperature.." P12: "Yeah. That is, if you assume, yeah."

Accessibility: Overall, few participants commented on accessibility; however, one noted that increasing the font size of the target text would improve readability.

P5: "I was looking at what the selected charge level was and... yeah. In a way, I thought it was a bit hard because there were four things in a row there."

Context of Use: Participants expressed that the graph should be available for those who actively seek it, but it should not be prominently or easily accessible within the system.

P6: "It's the same as with the driving information you can bring up, like power consumption from the last drive and so on and in the (car) settings, it's pretty deep in the menus, so we never look at it."

Aesthetics: Overall, not many participants mentioned the aesthetics of the graph, however, one participant noted that the graph did not align with Volvo's design aesthetic as well as the other views. P1: "This looks like something that doesn't come from Volvo, so then it suddenly feels much more difficult to me."

SEQ Results

Mode values for SEQ1 and SEQ2 are presented in the table 7.27. For SEQ1, the highest rating was observed for Task 2 (mode = 7), while the lowest was for Task 4 (mode = 5). For SEQ2, Task 1.1 received the highest rating (mode = 7), and Task 4 again received the lowest (mode = 4), indicating it may benefit from further refinement or support.

Task	SEQ1 (Mode)	SEQ2 (Mode)
Task 1	6	6
Task 1.1	6.5	7
Task 2	7	6
Task 3	6	6
Task 4	5	4

Table 7.27: Mode values for SEQ1 and SEQ2

Task Success Rate

Task success rates ranged from 38% to 100%. The table below 7.28 presents the success rate for each task question in percent (rounded to whole numbers). Task 1.1 consisted of 3 questions, while the rest of the tasks consisted of 5. The highest success rates were observed in Task 1.1 (Q1 and Q2), Task 2 (Q1, Q2, and Q4), and Task 3 (Q5). In contrast, the lowest success rates were found in Task 1 (Q1), which aligns with thematic findings suggesting that the SOC value on the current target should be clearly visible. Task 3 (Q2 and Q3) also had low success, reflecting issues identified in the thematic analysis related to inconsistent and confusing terminology. Additionally, Task 4 (Q1) had a low success rate, consistent with findings that the graph required greater cognitive effort to interpret.

Task	Q1 (%)	Q2 (%)	Q3 (%)	Q4 (%)	Q5 (%)
Task 1	38	92	100	92	92
Task 1.1	100	100	92	–	–
Task 2	100	100	92	100	92
Task 3	92	46	85	46	100
Task 4	54	69	77	92	85

Table 7.28: Task success rates for each question (in percent)

7.5.2 Iteration Results

Semi-Functional Prototyping

The key takeaways from the evaluation of the low-fidelity prototype was reviewed and from those, semi-functional prototypes were developed using Figma (see 7.24). This iteration included improving the components based on feedback, adding interaction and integrating the stand-alone components into Volvo’s vehicle UI. To enable interactivity, the prototype was displayed through an iPad Pro, which could also mimic the CSD found in the vehicles.

Target Page

- Component sizes adjusted for better alignment
- Length of boxes on the timeline changed to be mapped to percentage instead of time.
- kW values removed from the boxes
- Color of unit text changed to white to increase contrast
- Target SOC made to be visible at all times
- ‘Range gained’ added as a metric

See 7.20a.

Capacity Page: Estimated Charging View

- Wording of terms improved for better clarity, for example, the title Estimated charging capability was changed to Predicted charging power
- Max capacity number under the kW number removed to reduce information overload
- Bar was divided into 100 kW segments to improve readability
- Text indicator on energy consumption added above the optimization button to address concerns about energy consumption during preconditioning
- The warning message color adjusted to a more neutral tone, reducing the intensity.
- Google Maps icon button added to guide users toward this method preconditioning via navigation for better efficiency
- The font size and size of the components increased for better accessibility.

See 7.20b.

Capacity Page: Active Charging View

- Wording of terms improved for better clarity, for example, the title "Power source" was changed to "Charging station" and "Current DC charging capability" to "Car can receive".
- Term 'Max Capacity' was removed to prevent confusion
- Text indicating why the car is not at max capacity added
- All transferable changes from the unplugged version of the capacity page were added to this view (e.g size, color)

See 7.20c

Detailed Graph View

- Interaction removed to reduce complexity
- Volt and ampere values removed
- Text section above graph rearranged, and labels added for better understandability
- The border radius of the sections was removed to increase coherency

See 7.20d

7.6 Design Iteration 2

7.6.1 Individual Evaluation

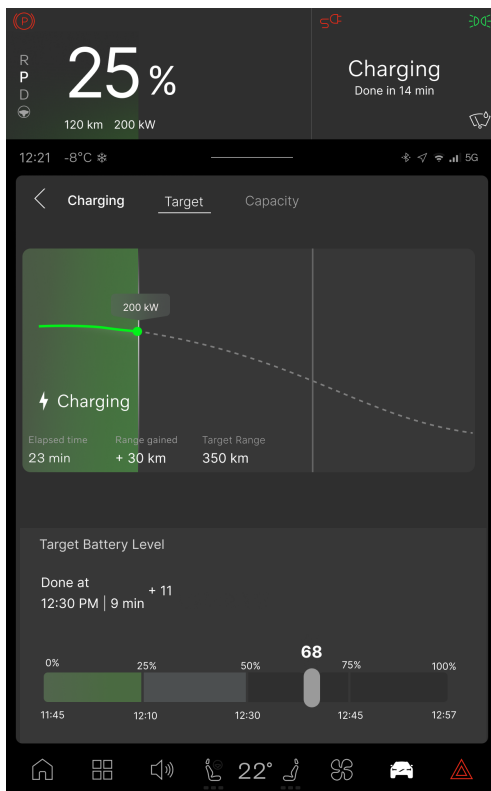
Aim

The aim of the evaluation was to assess the usability of key interactions, the findability of components, and whether the implemented changes adequately addressed the user needs.

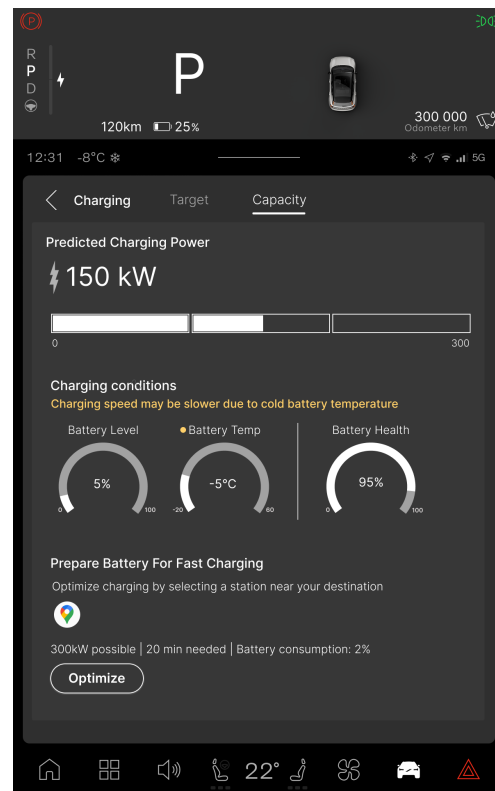
Participants

Ten participants (9 male, 1 female) aged between 33 and 63 years (average age 47) took part in the study. Most held a university degree (8 out of 10), while 2 had completed high school. 4 of the participants were taxi drivers, while the rest worked in engineering roles such as system architect, product performance engineer, and system design engineer. Experience with BEVs ranged from one week to over 10 years, with most participants having between 1 and 4 years of experience. Fast charging habits varied, 4 participants (40%), the e-taxi drivers, always used fast charging, another 4 (40%) used it occasionally or rarely, 1 participant (10%) used it frequently, and 1 (10%) had minimal exposure. Volvo was the most commonly owned brand (5 participants), followed by Tesla models (3 participants), with others owning a Toyota BZ4X, BMW 330i, and Polestar 2. This group reflected a diverse mix of BEV experience, usage patterns, and professional backgrounds. See 7.29.

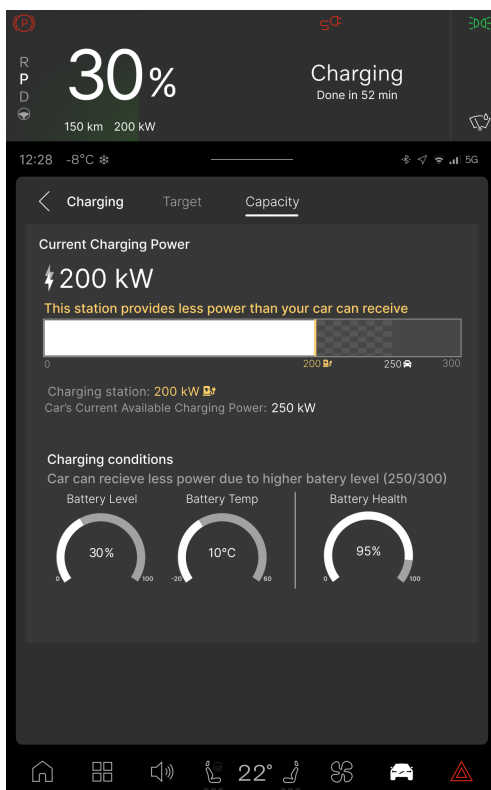
7. Process And Results



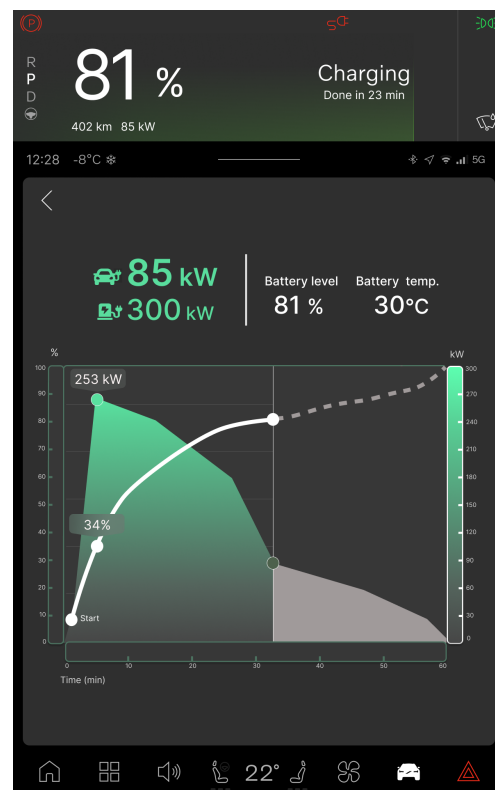
(a) Target Page



(b) Capacity Page: Estimated View



(c) Capacity Page: Active Charging View



(d) Graph View

Figure 7.20: Applied changes to prototypes

Participant ID	Age	Gender	Education Level	Years Driving BEV	Fast Charging Frequency	Car Model (BEV)	Profession
1	45	Male	University	1.5	Occasionally	Volvo XC40 SELR	System Architect
2	53	Male	University	7	Occasionally	Volvo EX40	Engineer
3	57	Female	University	10 years	Frequently	S60/V60	Product Performance Engineer
4	34	Male	University	2	Occasionally	BMW 330i / Volvo EX40	Engineer
5	49	Male	University	1	Rarely	Volvo C40 / Volvo EX30	Engineer
6	43	Male	High School	2	Always	Toyota BZ4X	Taxi Driver
7	56	Male	High School	1.5	Always	Tesla Model i	Taxi Driver
8	63	Male	University	1 week	Always	Tesla Model Y	Taxi Driver
9	36	Male	University	4	Always	Tesla Model Y	Taxi Driver
10	33	Male	University	1.5	Occasionally	Polestar 2 (2022)	System Design Engineer

Table 7.29: Participant demographics for individual evaluation

Process

Individual evaluations were chosen for this iteration, as this would make it possible to include taxi drivers in the evaluation. This approach allowed evaluations to be conducted on-site at charging stations, making participation more accessible for taxi drivers. Previous attempts to recruit taxi drivers for focus group evaluations at the office or university, even with incentives, had proven challenging. These environmental and experiential settings of the evaluations with taxi drivers resulted in tasks being orally administered.

The semi-functional prototype was evaluated by an individual task-based 20-30 min usability test, where participants were encouraged to think-aloud. There was a total of ten participants, including six regular BEV drivers, recruited within the Volvo network and four taxi drivers, recruited on-site at two different charging stations in the Gothenburg area. The structure of the evaluation was fairly similar to the first, where the participant was given six tasks to complete, and each task was followed by a SEQ questionnaire. Additionally, participants were asked follow-up questions if needed, to get clarification on their thought process, as well as one pre-defined question for each view. The first two SEQs (SEQ1 & SEQ2) were the same as the previous evaluation (7.5.1), while a third SEQ (SEQ3) was added regarding each task: "The task was easy to complete". Prior to the evaluation, participants were briefed on the aim of our study, given a consent form and demographics survey to fill in.

During the evaluation sessions, the participants were recorded using an audio recording device, and the task completion time was recorded in minutes using a timer that started when the participant began their task (after reading the task to ensure reading time was not included) and ended when they completed the task. The number of interactions to complete the task was counted manually. However, the evaluations were also screen recorded on the iPad in case an interaction was missed.

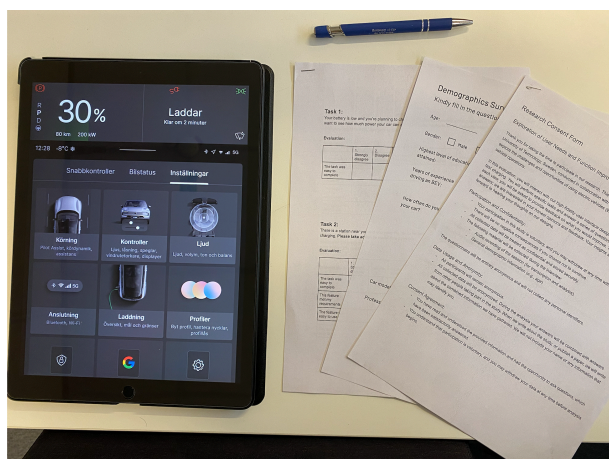


Figure 7.21: Individual evaluation setup

Analysis

A deductive thematic analysis was conducted using the same predefined themes and structure as described in 7.5.1. Similarly, quantitative data from the SEQ questionnaire and task success rates were analyzed following the same structure in 7.5.1.

Additionally, the SEQ1 and SEQ2 results from this iteration were compared to the results from iteration 1 (7.27), as these were the same questions. The SEQ results for taxi participants were also analyzed individually and compared to both the overall participant group in this iteration and the results from iteration 1. Task success rate could not be compared with iteration 1, as the tasks were different between the two evaluations.

Additional quantitative data, time on task (TOT) and number of interaction (clicks/taps), was analyzed to assess efficiency and intuitiveness. We calculated the average TOT and number of interactions per task across all participants. The average number of interaction was compared to the expected number (interactions needed) to evaluate navigation efficiency and detect any friction from excessive clicking.

TOT data was compared to that of an experienced user (a member of the design team). While this "best case" performance may not reflect typical user performance due to familiarity and knowledge of the prototype, it served as a useful benchmark. This comparison helped avoid misleading interpretation that could arise when comparing average times across inherently different tasks, and allowed us to better assess potential inefficiencies or usability friction. We also considered variance in both time and number of interactions.

A table was created to include the number of interactions, TOT, and SEQ3 ratings. This provided a holistic overview of each task and helped identify performance patterns. These patterns, along with the results from the thematic analysis, were synthesized into key findings to inform design refinement.

In this iteration, we excluded positive feedback that had already been identified in the previous iteration. However, positive feedback was included regardless of whether it recurred, if it diverged, or contrasted with the constructive feedback, to help inform design refinements.

Results

As in the previous design iteration, the results are presented according to the predefined themes used in the deductive thematic analysis. Each view is discussed separately, and instances where feedback from one view was clarified or confirmed in another are explicitly noted.

Target Page

Usability: The granularity of the charging target slider was perceived as unnecessarily fine. In the forecast graph, the absence of a visible power (kW) scale and lack of interaction options limited understanding.

P1: "You don't need this super precise resolution on this (target slider) [...] It's easier to just do like dom dom dom and have it jump 5% or a few percentage points."

Affordance: The visual design of the charging curve visualization suggested it was interactive, leading to attempts to drag or adjust the target directly on it. Additionally, there was no clear indication that tapping the graph would open a more detailed view (view 4), suggesting the visual design could better communicate the correct interaction zones. Additionally, the End Charging button blended in with surrounding elements, making it difficult to recognize as a separate interactive control.

P10: "It ("End charging") didn't feel like a separate button, but it feels like it was a part of this (Charging curve visualization)"

InfoVis: In the charging target slider, it was expected to see the current time displayed alongside the target time to make it easier to compare the two. Showing the forecast time only after the slider is released was seen as a good way to reduce visual clutter, but it still lacked enough time context around the target. The visualization of the charging curve could also be simplified for easier interpretation.

P6: "It (charging curve visualization) was actually clear, but it could be a bit simpler"

Capacity Page: Estimated Charging View

Usability: The structure and visibility of the preconditioning function was unclear. In some cases, users pressed the navigation button before noticing the Optimize button, whose placement and design did not clearly indicate it as the primary action. The energy consumption associated with preconditioning, such as a 5% battery loss, was not made visible enough, and the importance of optimization actions was not effectively shown. Presenting the battery consumption for preheating only as a percentage was considered inadequate for cost planning, however the majority preferred it as a percentage. There was also a preference for the ability to switch between units.

P10: "My immediate option would be to check if there's a better solution available or a more optimized one. So, I'd prefer to have it here (manual optimize button before navigation button). Once I've reviewed both and know which one is best, then I can proceed with the maps."

Affordance: The Google Maps icon could be misunderstood as the control for starting preconditioning, and in one case, the user expected preconditioning to begin automatically when navigation was started. This button was not clearly indicated as a button either.

P4: "I would have pressed the Google button, but intending to actually start the preconditioning, not intending to go to Google maps."

InfoVis: Visual cues indicating the preconditioning state were minimal. The blue progress line on the Optimize button was easily missed, and users found it hard to detect changes after activation. There was a desire for more contextual information, such as the optimal range for battery conditions to indicate whether the current values were within that range. The inclusion of the SOH data raised questions about its relevance in this view, with a preference for making such information optional rather than always visible. Additionally, some textual elements needed clearer wording or were seen as too detailed or unnecessary, increasing cognitive load.

P9: "Yes, it is hard to see (blue progress line on "Optimize button")"

P5: "Maybe I would've imagined having something like a target temperature, that would've been interesting, some kind of checked pattern, something to understand what's optimal for each (charging) condition"

Context of Use: The Location of this view and the optimize button, several steps into the interface, was considered acceptable in stationary use but suboptimal when driving.

P3: "It was not so hard to find, it was like three clicks. Yes, three clicks, but it is ok when you are standing still, but meanwhile I'm driving it is too much."

P1: "The preconditioning button, I don't want to have to go into plenty of settings to find it, I want to be able to access it fast and easy while driving [...] otherwise you have to sit like that (excessive clicking) as a taxi driver and that's not great"

Accessibility: Information text and warnings were reported as difficult to read due to small font sizes. key messages, including battery consumption and charging limitations, were not visually prominent.

P3: "I want to have bigger (font size)"

Capacity Page: Active Charging View

Since View 3 closely mirrors View 2 in layout and structure, several observations were repeated in both. To avoid redundancy, feedback that was identical to both views (e.g., requests for larger font size) is only reported once, under View 2. Only new or view-specific insights are highlighted in this section.

Usability: Redundant kW values were displayed without clear differentiation and inconsistency in capitalized headings was noted. Additionally, the lack of feedback when cars' available charging power fell below the maximum available (e.g., 250 kW instead of 300 kW) created uncertainty.

P2: "Yes, it says the car's current available charging power, so it shows that the car can't handle more than 250 (kW). But specifically why, when I pressed optimize for 300, that's not explained."

Detailed Graph View

Usability: Comprehension of the graph was hindered by the use of dual Y-axes. This representation was difficult to interpret, particularly in terms of understanding which line

corresponded to which scale, however it was deemed important especially for taxi drivers, but time might be needed to get used to it.

P1: "This took a bit of time to understand the double y-axis', what related to what."

P6: "Yes (meets my requirements) because time and power are very important for us, especially us taxi drivers, because we struggle with time, so yes."

P7: "These new things, you have to be able to work with them for a period, maybe one month, to really understand everything properly, because they're new and advanced features."

Affordance: It was not apparent that the graph in View 2 could be tapped to access this more detailed view. The lack of indicators or explicit controls meant that access to this information relied on prior knowledge or external instruction. Interactivity of this graph was not either adequately communicated.

P6: "There should be more color (to show it is interactive) [...], There are some features on phones or in apps, you know, you can't tap on them because they have less color or faint color"

P7: "It could be easier (to find the graph), I think", "Something here, a button or a description somewhere (to show the graph is interactive)"

InfoVis: The visual mapping of lines to their respective axes lacked clarity. Labels or color coding between axes and data lines were either insufficient or missing. Separate graphs or more clearly linked axes and lines were preferred. Supporting parameters, such as charger limitations, or elapsed time, were absent. The view was expected to support diagnostic messages shown in other views. A desire was expressed to manually inspect past moments (e.g., point of time) by dragging the current point in the graph.

P5: "What I think is hard to see is which line belongs to which axis [...] if this (SOC axis) would have been white or something, so you'd know the white axis belongs to the white curve and the green to the green curve, right now its not completely clear" "

Aesthetics: Visual consistency was lacking between this graph and the rest of the interface. The graph's style was more technical and did not match the broader design system, which reduced the overall cohesion of the UX.

P10: "See how it looks here (target page), it looks very homogeneous, but when I go to this graph, it looks quite different from the design of the previous page."

SEQ Results

	SEQ1	SEQ2
Target Page	6	6.5
Capacity Page: Esitimated View	5.5	5.5
Capacity Page: Active Charging View	5.5	5.5
Graph View	5.5	5

Table 7.30: Mode values for SEQ1 and SEQ2 in evaluation 2 for all participants

Comparing the SEQ results across the evaluations in iterations 1 and 2 reveals both consistency and divergence in participants' perception of how well the features meet their

	SEQ1	SEQ2
Target Page	6.5	6.5
Capacity Page: Esitimated iew	6.5	6
Capacity Page: Active Charging View	6	6.5
Graph View	5.5	5.5

Table 7.31: Mode values for SEQ1 and SEQ2 in evaluation 2 for taxi participants

needs (SEQ1) and their usability (SEQ2). In iteration 1, mode values for SEQ1 ranged from 5 to 7, and SEQ2 from 4 to 7. The highest ratings were for the charging forecast (Task 1) and subview (Task 1.1), with mode values of 7 (SEQ1) and 6.5 (SEQ2), indicating a strong alignment with user expectations and perceived ease of use. Contrary, Task 4 received the lowest ratings (SEQ1: 5, SEQ2: 4), suggesting room for improvement (see 7.27).

Iteration 2, which included a more diverse user sample including four taxi drivers alongside six regular BEV drivers, showed generally lower ratings across all participants compared to iteration 1. For all participants, SEQ1 values ranged from 5.5 to 6, while SEQ2 ranged from 5 to 6.5. View 1 performed best in both SEQ1 and SEQ2, with modes of 6 and 6.5, while View 4 had the lowest ease-of-use rating (SEQ2: 5) (see 7.27), similar to the pattern observed in the first iteration, implying it could be easier to use, aligning with thematic findings e.g., visual mapping of lines to axes lacked clarity and interactivity not adequately communicated (7.6.1).

However, when isolating taxi drivers, SEQ scores were slightly higher (e.g. SEQ1 modes of 6.5 for views 1 and 2, SEQ2 modes around 6-6.5), suggesting taxi drivers have greater needs for the designs or different usability expectations compared to regular drivers. Nevertheless, view 4 remained the lowest rated view among taxi drivers as well, however higher than in iteration 1. See 7.31.

Task Results

SEQ3	Avg. time	Time benchmark	Succes	Avg. Interactions	interactions bennchmark	Task
1	5.5	00:26	00:06	100%	2.5	2
2	6	00:22	00:03	100%	2	1
3	6.5	00:47	00:07	100%	3	2
4	6.5	00:22	00:06	90%	1	1
5	5.5	00:28	00:05	90%	3	2
6	5.5	00:38	00:03	100%	4	1

Table 7.32: Task data

The average task completion times ranged from 22 to 47 seconds, which is notably longer than best-case performances. Average interaction counts varied between 1 and 4 clicks, indicating moderate engagement with the interface. Success rates were high overall, with five out of six tasks achieving 100% success and only Tasks 1 and 5 slightly lower at 90%.

Task ease ratings (SEQ3) ranged from 5.5 to 6.5 on a 7-point scale, with Tasks 3 and 4 perceived as easiest to complete (SEQ3 = 6.5), while Tasks 1, 5, and 6 received slightly lower ease ratings (SEQ3 = 5.5). These perceptions align with thematic findings: Capacity page required improvements to the accessibility of it (Task 1), the simple graph lacked clear affordances for accessing the detailed graph (Task 5), which in turn had unclear interactivity (Task 6).

Participants consistently took longer to complete each task compared to the best-case benchmark, conducted by a design team member familiar with the prototype. This discrepancy was particularly evident in Task 6, with the average completion time of 38 seconds versus just 3 seconds in the benchmark. This supports thematic findings that the graph interactive elements were not effectively communicated.

While participants generally followed the expected navigation flow, they made slightly more interactions than the optimal path required. Task 6 again showed the largest deviation with an average of 4 interactions compared to the ideal 1. In contrast, Task 4 was completed with just one interaction, matching the optimal number, due to its similarity in structure to Task 1. However, TOT was still longer, due to the need to interpret warning information on the Capacity page, supporting thematic findings that the text size was insufficient and the warning message lacked visual emphasis.

Individual variation also revealed areas of confusion. One participant required 4 interactions for task 5, which ideally needed only 2. This reinforces the thematic findings of a need for improved visual cues and interaction affordances around accessing the detailed graph view.

Lastly, Taxi participants generally took significantly longer to complete tasks but required fewer interactions on average. This difference may reflect a more exploratory approach under less familiar or more distracting real-world conditions, which is further discussed in the discussion.

7.6.2 Iteration Results

Refining The Semi-Functional Prototype

Based on the gathered insights, this refinement involved improving interactions and affordances, as users struggled to identify actionable components. Navigation and discoverability were improved using clearer visual cues. Terminology and consistency were also improved. Additionally, one new feature was introduced, resulting in a new page being added to the prototype (7.23).

Refinements were considered based on frequency of feedback, impact on UX, contextual relevance (feedback that aligned with the goals of the design), potential for improvement with minimal effort, and their potential to improve clarity, reduce cognitive load, and enhance task efficiency. While some changes were based on the input of a single participant, they were still deemed valuable if the feedback was thoughtful and addressed clear usability concerns. Feedback that previously in iteration 1 seemed insufficiently grounded to act on was prioritized in this iteration after recurring across users.

Target Page

- SOC target slider adjusted to 5 step (5%) granularity to simplify the interaction while still providing enough control.
- Allow users to tap directly on bar to set target to enhance the interface's ease of use.
- Adding a clearly marked button to make navigation to detailed graph clear.
- Reducing affordability of the simple graph to make clear not interactive.

- Adding color to "End charging" button to increase affordance and removing it outside the graph component to increase accessibility.

See 7.22a.

Capacity Page: Estimated Charging View

- Made optimize button more accessible by popping up as a notification when the car reaches a low SOC level - resulting in a new component (7.23).
- Replaced the Google Maps icon with a more button-like element to improve affordance for navigating to the precondition.
- Adding a clearly marked button to make navigation to the detailed graph clear.
- Remove option to optimize when the car has low SOC or high kW capacity for feasibility (also informed by expert interviews)
- Visualization for optimal range of charging conditions added for improved clarity.
- Font size increased to make energy consumption of optimization, warning message and other components to enhance readability and accessibility.
- Color change of bar graph to enhance visualization of active preconditioning and improve action-related feedback.
- Reordered the 'Optimize' and 'Navigation' buttons to match user expectations and improve flow and clarity of the primary action.

See 7.22b.

Capacity Page: Active Charging View

- Made text elements more standardized removing inconsistencies in capitalization.
- Message added explaining why car's current capacity is less than max, when the station is limiting for improved clarification.
- Clearer language was used to describe the cars current capacity and charging station capacity in a simpler manner.
- All transferable changes from the estimated view of the capacity page was added to this view (e.g size, optimal range visualization)

See 7.22c.

Detailed Graph View

- Clear color coding used to clarify how the y-axes map to the respective lines on the graph.
- Current values made consistently visible for better affordance and interactivity, indicating that the user could now draw the current point for historic details.
- Ensured current values remain consistently visible to enhance interactivity, allowing users to draw the current point for historic data.
- Added warning messages and history of error messages for better understanding of past charging issues and comprehension of the graph.

- Design of graph made consistent with other views to ensure cohesive UX.

See 7.22d

7.7 Design Iteration 3

7.7.1 Expert Evaluation

Aim

The aim was to evaluate the functional accuracy of the UI, confirm whether the UI effectively supports the systems intended workflows, identify misalignments between UI design and underlying system logic, and enhance usability by aligning the design with user goals and expectations.

Process

The final evaluation of the semi-functional prototype was conducted with two experts, both function owners responsible for specific features within a vehicle. One of the experts was included in the first evaluation iteration (7.5), being already familiar with the concepts. These individuals have deep knowledge of system functionality and intended workflows, making them suitable for this stage of evaluation. Each expert provided informed consent before participating in separate one-hour sessions.

Using an iPad, the experts engaged in semi-structured sessions where they completed user tasks to assess how intuitively the interface supported critical workflows, while thinking aloud and offering real-time feedback as seen in 7.21. The evaluation methodology combined open-ended exploration with structured assessment principles, particularly drawing from cognitive walkthrough.

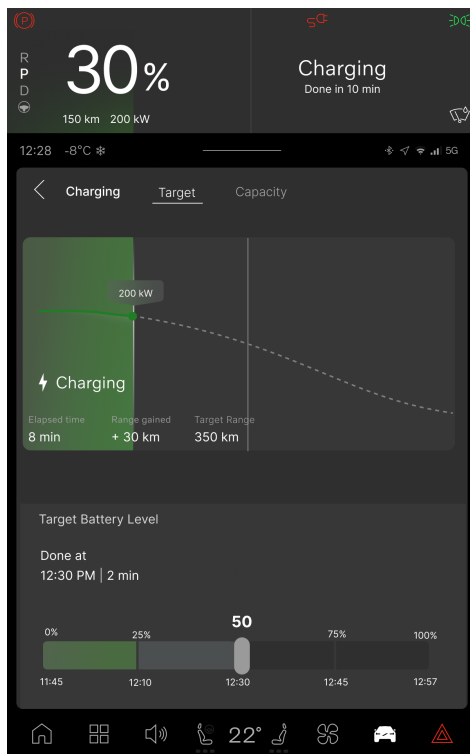
To guide the evaluation and ensure comprehensive usability coverage, we prepared a few questions per interface view based on Niensens 10 usability heuristics [70]. While many heuristics were naturally addressed during think-aloud feedback, prepared questions were introduced when specific issues were not spontaneously raised. Follow-up questions were also used to clarify or deepen understanding, and design suggestions were encouraged to gain constructive input for refinement.

Given the specialized nature of the system and limited availability of qualified function owners, two experts were selected. Despite the small sample, the depth of their knowledge ensured qualitative feedback. Expert evaluations with a small number of knowledgeable participants can reveal majority of usability issues, particularly when guided by structured heuristics ([80]). These experts were chosen to assess both usability and functional alignment.

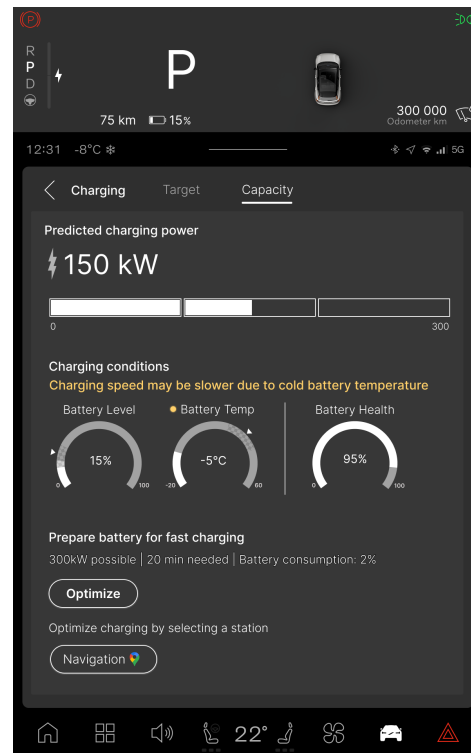
Analysis

The evaluation data were analyzed using heuristic evaluation principles, with the feedback mapped against Niensens 10 usability heuristics [70]. This allowed for a structured assessment of usability strengths and weaknesses based on these established guidelines for UI design. Task success, measured by whether the experts could efficiently and accurately complete tasks, provided an additional metric for evaluating the interface effectiveness.

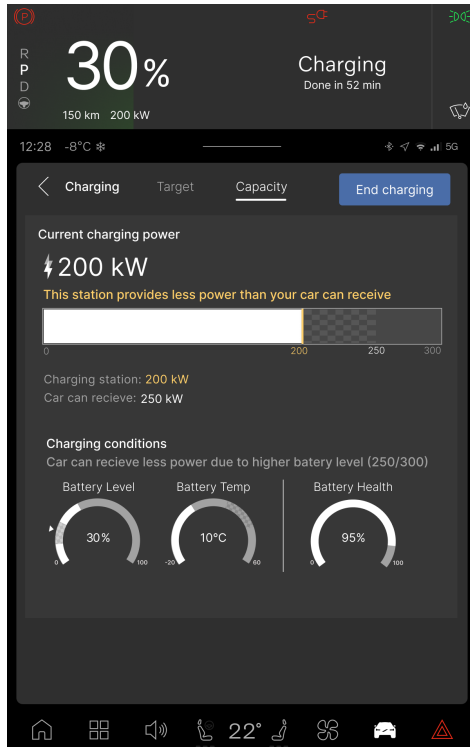
7. Process And Results



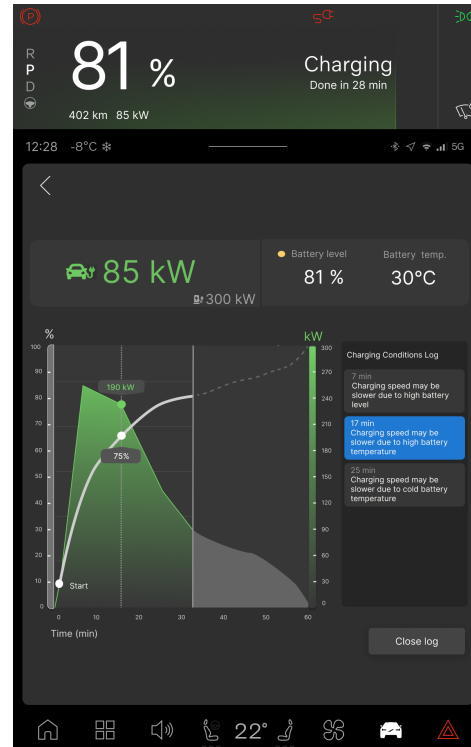
(a) Target Page



(b) Capacity Page: Estimated Charging View



(c) Capacity Page: Active Charging View



(d) Detailed Graph View

Figure 7.22: Overview of the refined interface views

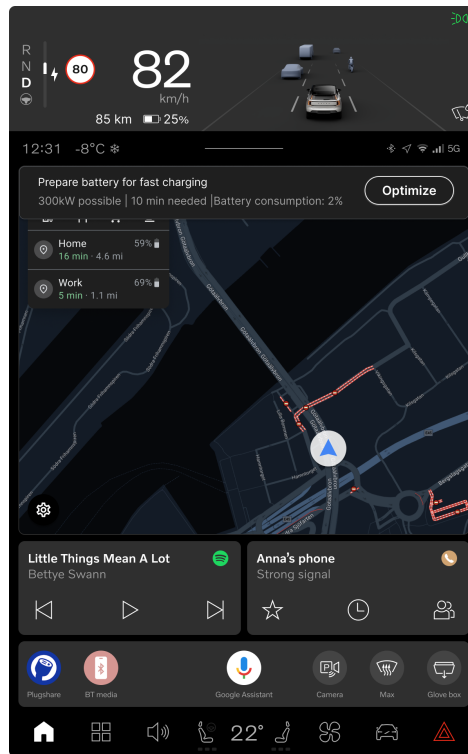


Figure 7.23: Preconditioning Notification View

The evaluation sessions were first transcribed, and then reviewed by listening to the recordings while reading the transcripts. During this review, relevant insights were identified and directly coded onto color-coded post-it notes, each color representing one expert. These post-its captured observations, issues, or suggestions raised during the sessions. The notes were then thematically grouped to identify areas of convergence, revealing consistent challenges or suggestions related to Nielsens heuristics, such as navigation difficulties, lack of immediate feedback after user actions, and misalignments between UI elements and the systems underlying logic.

Divergent feedback was also taken into consideration, where the experts offered contradicting or isolated observations. These discrepancies were categorized as potential usability gaps, which would require further investigation.

Results

Target Page

Time animation: The experts diverged in their opinions on usability issues from different angles. It was noted that the animation showing the time increasing while dragging the target slider felt detached from the interaction itself. Additionally, it was mentioned that users might miss the animation initially: *"maybe you dont have time to notice those extra minutes [...] while you're doing it the first time, you might not have thought about it."* - P2 Addressed design heuristics include: (H1, H4, H6)

End charging button: The experts diverged in opinions on this component where P1 disliked the navigation bar placement saying *"the location of end charging button bit strange to me because I mean I just see this more like a switchable tabs for different*

information pages" while P2 liked it saying "I can understand it, or I mean, I like that you separate them." Addressed design heuristics include: (H4, H6, H8)

Timestamps: One expert suggested removing historic timestamps: *I don't think the historic times are really useful, so maybe they can just be removed, I would say"* - P1. Addressed design heuristics include: (H1, H8)

Capacity Page: Estimated Charging View

Warning message: Both experts noted that the warning message should not be yellow after the user optimizes. P2 saying "it would tie together the idea that youre indicating change with color.". Addressed design heuristics include: (H1, H4, H9).

Bar numbering: Both experts expressed that to improve readability, numbers on spaces of the bar should be added: "It took some cognitive load to understand this bar, so probably I would be happy to have this numbering here as well" - P1. Addressed design heuristics include: (H2, H6).

Bar color: Experts diverged on opinions, P1 preferred less color and adding an blinking animation saying "The bar is progressing, but it is not very clear [...] maybe like make it more blinking or some motion" while the P2 thought the colors were adequate and users might overlook an animation when quickly viewing the screen saying "The thing with blinking is that its an action that can be visually distracting. At the same time, if you just quickly open and close the screen, you might not see the blinking.". Addressed design heuristics include: (H1, H8).

kW number: One expert expressed that the kW unit should be colored or highlighted like the error message to not remove the focus from it: "Since everything is white, I read this first (the coloured warning message) [...] I started reading this, and then I went back here. So, probably, either both can have the same color, or this one could be a little highlighted" - P1. Addressed design heuristics include: (H1, H8).

Optimization energy consumption: P1 expressed it was beneficial to inform the user on the energy consumption of preconditioning, however, was unsure about in which unit it should be expressed, saying "As a regular user, I'm happy to see this. What unit? I don't know. If it's 2% or in a kilowatt hour or in range, that may be different question, but I like this feedback". Addressed design heuristics include: (H2, H6).

Charging conditions: Experts diverged on whether to always have the charging conditions visible or to have them as drop-downs or remove them. P1 stated "I would prefer it in a very different way, or just don't tell me about this here" further stating "here there's not much happening, it's really slow, so I think I would like that (dropdown to toggle conditions). However P2 stated "personally, I think it is nice to always have them (charging conditions) visible, so you can get a quick overview at glance". Addressed design heuristics include: (H1 (expert 2), H3 (expert 1), H8 (Expert 1)).

Optimal charging condition indicator: Both participants did not understand the optimal range indication very clearly, and it was noted an info box would help, with P2 saying "Maybe there should have been another sentence or some kind of indication here, maybe you press something (to get more information)". Addressed design heuristics include: (H2, H10).

SOH: Experts diverged on whether to show SOH as a condition. P2 stated "I think its

appropriate, because this is very much about the battery you're charging, and everything else like temperature is already included. As you mentioned, most of the tips you get aren't really about DC charging or how to DC charge to maintain good battery health, so I think it belongs here. And it's really nice that you've separated it like that." further emphasizing "When else would you go into battery health, It's not like you actively check it, so it's quite nice to have an overview - to keep it in mind - every time I've checked, it's always been at 95(%), I think there's value in getting that update.". However, P1 stated "Battery health isn't something that changes on a daily or weekly basis, it's going to take a long time to change. So, do I really want to see it every day? Maybe, because I might be happy to see that after using it for one year, it's still above 90(%) - good. But then maybe it's like a repetitive value". Addressed design heuristics include: (H1 (Expert 1), H3 (Expert 2)).

Overview on target page: P2 expressed that it would be beneficial to have an overview of key information (including kW capacity) on the target page saying "I would've maybe wanted a more detailed overview, like the first page shows: Okay, this is how much I can charge, this is how much percentage I have, this is my target setting, but also this is my capacity. Like, some kind of overview on the first page. I think we have quite a large screen that could've been split to show both of those, so you'd have capacity as well.". Addressed design heuristics include: (H1, H2, H8).

Optimise on target page): One expert (P1) expressed that "If I'm coming to this app the first time, I'd be searching for that feature (the optimize button) here (on the target page). Intuitively, I wouldn't go to the capacity page, because to me, any settings I use would be here. [...] So first, I'd be looking for something on this first page". Addressed design heuristics include: (H3, H7).

Capacity Page: Active Charging View

Warning message when capacity is less than maximum: One expert suggested the message be placed under the textual data about car capacity saying "I think 250 and 300 are really battery power rate, but it is kept next to battery level, so maybe this has to be kept here (under the bar)". It was alternatively suggested by P2 to rephrase the message to give it more context and keep the placement saying "I would probably have wanted to add some kind of time-based element, either 'now' or, well, with current conditions". Addressed design heuristics include: (H1, H2, H4).

Icons: One expert (P1) emphasized that the icons should align more closely with Volvo standards, given that the study is Volvo focused. "Will you study be more Volvo focused or in general?", "Then we do have a blinking pattern (referring to flash icon) on the CSD, so it's over here. So both of these should be aligned. Maybe this one is pulsating [...] I want to see the same thing over here as well. It's more natural to have aligned behavior: same shape, sign, color, frequency". Addressed design heuristics include: (H4, H6).

Bar: P1 suggested to keep the bar dimensions consistent as in the Estimated View state, to minimize potential confusion saying "I did not like the fact that like this screen is very dynamic [...] like now it's totally different one. So in general, I think for Volvo when we don't like really want to change so many things because we want to keep it very simple language. So in that sense. I think the basic blocks shall remain the same." Addressed design heuristics include: (H1, H4, H8).

Bar textual data: One expert (P1) found the textual data on the bar unclear: "I got

the information by reading this (referring to description of textual data on bar), and not only by looking at this first (textual data on bar) [...] I read this (textual data on bar) and was trying to figure out what it was", when asked whether something like an icon alongside the textual data might help, the expert responded: "That could be a solution, yes". Addressed design heuristics include: (H1, H6, H8).

Charging condition title: Charging condition title may not be need as expressed by P2, *"Maybe you dont even need a title, maybe its enough to just write 'current charging power,' 'charging station,' 'car,' and so on, and then you get the rest if you need it."* Addressed design heuristics include: (H2, H8).

Detailed Graph View

Forecast prediction: Both experts noted on the accuracy of the forecasted kW, however they diverged. P1 questioned the feasibility of such predictions: *"How will you get this plot, have you thought about the estimated charging powe?r" "I know it's not possible (to get predicted charging curve (kW)) [...] for the future of Volvo cars, you can just make a fluffy graph [...] like you can just extrapolate of course, but it's not exactly possible to have it like this (accurate) because we don't know the reason, we are very dynamic" "It's very adaptive, for the (charging) conditions and scenario" "fluffy (forecast) wouldn't really help because then we are giving a false promise".* In contrast, P2 was more positive about showing a forecasted curve, while still acknowledging its limitation: *"It is always hard to be accurate, but I think generally it's very, very similar. Once you have driven the car for a while, there's some data to go on. And when we have connected the charger, we get the technical part, like a prediction of how long time it will take, and so on. So that data exists. How accurate is it? Sure, that's always difficult. But, I don't think that, as a customer, if this curve was a bit lower or higher, I don't know if I would (mind)".* Addressed design heuristics include: (H1, H2, H7).

Warning message log : P1 expressed that the formatting of the warning messages is misleading and can worry the users, and to use fewer words to reduce information overload, saying *" People are like not still confident about the EV cars, right? So when you read something like high battery temperature. Like they'll be concerned."* Addressed design heuristics include: (H1, H2, H8).

Graph: P2 expressed the time stamps on the warning messages were unclear and a yellow error dot on the x-axis or line graph would solve the uncertainty: *"Something that I think would be nice is to have the yellow dot also appear on the time (x-axis), because my first question was whether it was 7 minutes ago or 7 minutes into the charging session. So it would be good to map the time aspect".* Addressed design heuristics include: (H1, H6).

Preconditioning notification

Notification navigation P2 noted it would improve navigation to click on the notification and come to the optimize page saying, *" When you now have this up here with 'stop,' that you could also click on it and get to an overview":* Addressed design heuristics include: (H3, H6).

Notification context: P1 mentioned that the preconditioning notification *"It should have some logic behind it"* explaining that it should not pop up when the user is not going to charge: *"I do not want this to happen at a time when I'm not going to charge. For example, if I'm heading home, I don't want to heat up the battery because the car will*

be at home overnight". Addressed design heuristics include: (*H3*, *H7*).

All views Navigation: P1 noted that it would be useful to have "*a quick launcher for charging from the main page or from the home page*" to easily access the charging settings. Addressed design heuristics include: (*H3*, *H7*).

7.7.2 Iteration Results

Final Refinement

Based on expert feedback, we improved the interaction of the prototype and refined specific components and user flows. The common themes identified in the analysis of the function owner evaluations led to informed design refinements. Although time constraints limited follow-up evaluation for the divergent feedback, these issues were reviewed in the context of previous evaluations and established design principles to make informed refinement decisions.

Target Page

- Increase font of added time (e.g., +15) for better visibility
- Removed timestamps when historic to remove invaluable info reducing clutter

See 7.24a

Capacity Page: Estimated Charging View

- Change color of warning message to gray when the user optimizes to give feedback of the action
- Add numbers for each section of the kW bar for easier readability
- Add drop-down boxes to toggle charging conditions, but have them open as default
- Add a blinking icon to indicate the progress of the precondition more clearly
- Add information box with explanation for optimal charging conditions
- Increase size of the estimated kW number to highlight it more
- Add option to toggle between kw/h and % for battery consumption of preconditioning
- Better wording to indicate optimization through navigation is more optimal
- Add estimated kW on the target page for a better overview

See 7.24b

Capacity Page: Active Charging View

- Rephrased the warning message so that it's better anchored to the context
- Made icons more standardized (e.g., size, color) and aligned with Volvo's design language

- Added icons to the charging station capacity and the car's current capacity values on the bar to improve immediate understanding and reduce reliance on explanatory text

See 7.24c

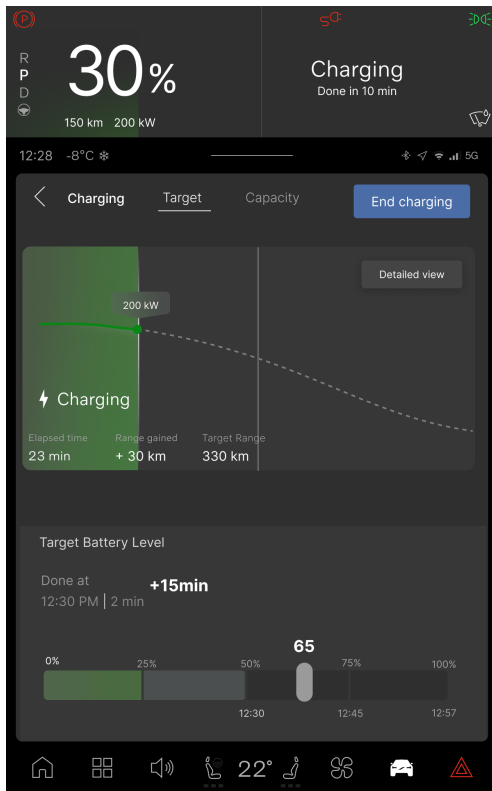
Detailed Graph View

- When predicted power changes significantly and updates, include a message in the warning charging log for transparency and clarity
- Added indicators on the graph to mark where warning messages occurred, improving transparency and user understanding

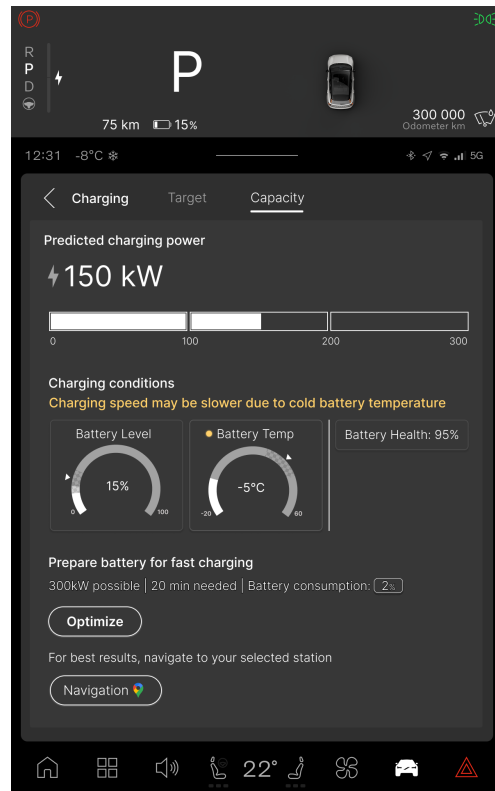
See 7.24d

Preconditioning Notification

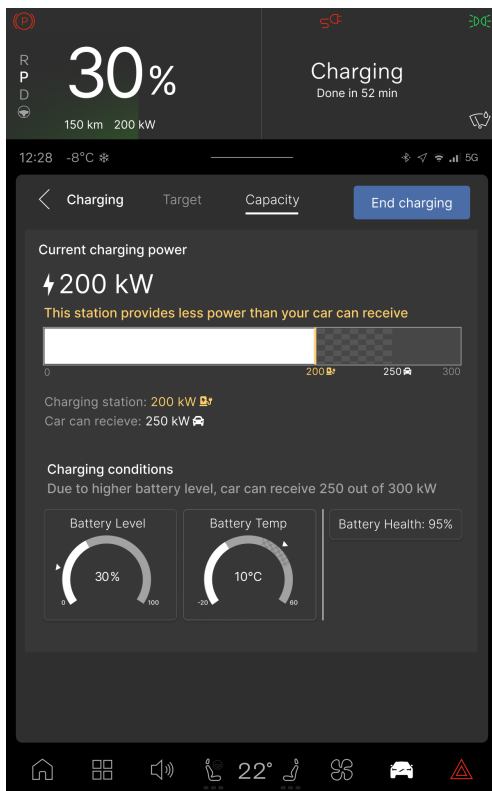
- Allow users to navigate to the capacity page: estimated view, by clicking on the preconditioning notification



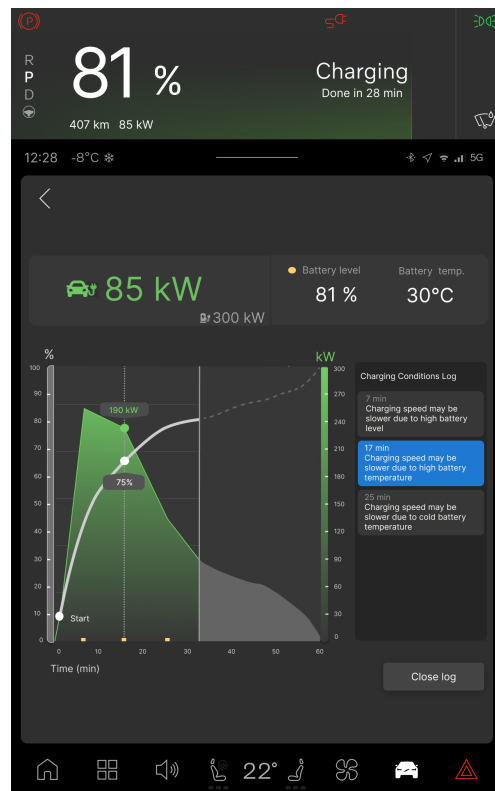
(a) Target Page



(b) Capacity Page: Estimated View



(c) Capacity Page: Active Charging View



(d) Graph View

Figure 7.24: Final changes to prototypes

8

Design Recommendations

Eight actionable design recommendations were created. The aim of these is to translate the empirical findings from the study into concrete, actionable guidelines. These recommendations are intended to inform and support the development of user interfaces for BEV charging, particularly for e-taxi drivers.

ID	Design Recommendation	Description	
R1	Provide transparent, contextual messaging to explain charging behavior	Clarifies variations in charging performance, aiding user understanding and trust.	7.3.3, 7.3.3, 7.3.3 , 7.5.1, , 7.2.3, 7.1.2.2
R2	Frame charging as a dynamic process	Helps users interpret variations as normal results of SOC, temperature, and station conditions.	7.3.3, 7.3.3, 7.3.3 7.2.1, 7.2.1, 7.2.3
R3	Prioritize key charging metrics	Reduces cognitive load with simplified, structured data presentation.	7.2.1, 7.7.1, 7.7.1
R4	Give clear feedback on user actions	Reinforces learning and supports informed experimentation.	7.3.3, 7.3.3, 7.2.1, 7.2.1, 7.3.4, 7.6.1, 7.7.1, 7.7.1
R5	Use standardized icons and metrics	Reduces ambiguity, frustration, and improves consistency across systems.	7.5.1, 7.6.1, 7.5.1, 7.2.3, 7.4.1
R6	Include historic, real-time, and forecasted data	Provides temporal context to help users understand charging trends.	7.3.3, 7.27, 7.5.1
R7	Allow flexible data access	Supports different user needs and contexts through toggles or layered data views.	7.3.3, 7.27,7.31,
R8	The interface should provide flexibility and information access	Allows users to tailor the interface to their needs by toggling between basic and detailed information.	7.5.1, 7.5.1, 7.7.1

R1: Provide transparent, contextual messaging to explain charging behavior. This recommendation is supported by UR2-UR4 (7.3.3, 7.3.3, 7.3.3), requirements, which point to the need for more contextual information, together with feedback from evaluations in iteration 1 and 2 (7.5.1, 7.6.1) highlighting the need for clear and consistent

terminology and labeling in the UI. Aligning with the findings of the technical interviews, under the theme '*UI and Communication*' (7.2.3) where it is reflected that there is a need for standardized and well-defined metrics. Similarly, the findings from the expert interview from the pre-study (7.1.2.2) pointed out that providing transparent information in the UI can reduce time anxiety.

R2: Frame charging as a dynamic condition-based process. Primarily mapped to requirements UR1, UR2 and U4 (7.3.3, 7.3.3, 7.3.3), re-framing helps users interpret variations in charging as normal and impacted by various factors such as SOC, temperature, and car/station capacity. Awareness of these factors, and how they impact charging time, may not be apparent even to experienced drivers, as reflected in the themes "*Charging Capacity and Power Variability*"(7.2.1) and "*Range Limitations and Performance*"(7.2.1), where experienced users expressed feelings of uncertainty and unreliability with their car's behavior. Aligning with the findings of the technical interviews, under the theme '*UI and Communication*' (7.2.3) , where it was noted that there was a lack of guidance for the user.

R3: Reduce cognitive load by unifying and prioritizing key charging metrics. The need is highlighted in the theme "*UI and InfoVis*" (7.2.1) where taxi drivers consistently monitor the vehicles status, primarily focusing on the SOC or remaining range. While the infotainment system provides a range of information, there is a hierarchy what users consider most valuable. Therefore, it is important to ensure that this key information is both easily accessible and understandable. Feedback from experts in evaluation 3 reinforced this by emphasizing the need for a clear overview of key metrics (7.7.1) and easier access to primary actions (7.7.1), also highlighted in evaluation 1. Suggestions included making the preconditioning button visible within the first views, to support quick decision-making. By prioritizing and clearly presenting key metrics, users can develop a holistic understanding of the charging process without becoming overwhelmed by unnecessary detail.

R4: Ensure continuous and clear feedback about system status and user actions. This recommendation is supported by UR2 and UR4 (7.3.3, 7.3.3), which highlight the need to provide user action and feedback on the system's status. Additionally supported in the theme *Navigation for Preconditioning* (7.2.1), it was found the status on the of preconditioning process was unclear at times. Similarly, in *Charging Capacity and Power Variability* (7.2.1), the factors affecting the status of the car's capacity is not conveyed. Results from the Volvo survey (7.3.4) further revealed user frustration with the lack of feedback when errors occurred. In evaluations 2 and 3, participants also emphasized the need for clearer visual indicators that the preconditioning of the battery was ongoing after pressing the optimize button (7.6.1, 7.7.1), as well as using color as visual encoding to indicate the status of the system has changed (7.7.1). Together, these findings highlight the importance of providing real-time and understandable feedback, not only in response to user actions, but also to maintain visibility of system status. In doing so, users will have an improved UX, as it may reduce confusion.

R5: Use standardized icons and well-defined metrics in the UI. As reflected in the findings across all evaluations, users expressed the need for consistency in labeling (7.5.1, 7.6.1), icons (7.7.1), and design aesthetics (7.5.1). Supporting this, are findings of the technical interviews, under the theme '*UI and Communication*' (7.2.3), where a need for standardized and well defined metrics is emphasized. Additionally, the benchmark

results (7.4.1) showed that all reviewed vehicles featured a consistent UI design, further reinforcing the importance of visual coherence and standardization.

R6: Have historic, momentary and predicted charging data. To support users in learning how charging speed behaves over time, it is important to provide historic, momentary, and predicted charging data. This gives context to the current behavior, helping users interpret discrepancies as part of a larger trend rather than as unexplainable deviations. This recommendation is supported by UR1 (7.3.3), which emphasizes the need for an intuitive understanding of charging behavior. Additionally, the SEQ results from iteration 1 (7.27) related to the task related to the charging curve prediction, which visualized past, present, and future data, received the highest rating among all features. This was also reflected in usability theme, where participants expressed they the contextual charging information was valuable (7.5.1).

R7: Presenting key data in a clear and simplified format improves user understanding. There is a lot of complexity regarding the vehicle's condition, which is knowledge that may not be easily acquired and should therefore be communicated in a simplified way to reduce learning barriers. The charging curve, a simplified version of the graph shown in the Graph View, received higher ratings in the SEQ results from both Evaluation 1 (7.27) and 2 (7.31) compared to the more complex graph. This suggests that the simplified version was easier to understand while still meeting users informational needs which also aligns with UR1 (7.3.3).

R8: & The interface should provide flexibility and information access As reflected in the evaluations in design iteration 1, users appreciated timestamps indicating when charging would be completed (7.5.1), highlighting the need for varied metrics. Additionally, found in the theme 'context of use' 7.5.1, accessibility to more complex features could be made more difficult for those who seek it out. During discussions on preconditioning energy consumption, there participants reflected on which unit the preconditioning energy consumption should be shown in, either percentage or kWh (7.6.1, 7.7.1), indicating the importance of a flexible interface tailored to user needs.

9

Discussion

The purpose of this study was to explore how in-car infotainment systems can better support E-taxis in understanding and managing the charging process. Unlike private EV users, taxi drivers operate under demanding conditions that require frequent and efficient charging. Despite the environmental and economic viability of e-taxis, limited battery range and prolonged charging times continue to pose significant challenges. While previous research has largely focused on infrastructure-level solutions, this study narrowed its focus to the driver experience, specifically, how interface design can reduce uncertainty, enhance understanding, and support more informed decision-making. The findings informed the development of a novel solution that addresses user needs through improved InfoVis and UI design.

To guide the research, the following RQs were formulated:

- **RQ1:** What barriers prevent electric taxi drivers from fully understanding the charging journey?
 - **SRQ1:** How do these barriers affect decision-making before and during charging?
- **RQ2:** What design improvements and recommendations to the infotainment system can enhance drivers' understanding of the charging process?

9.0.1 Interpretation of findings in relation to the RQs

To answer RQ1 and SRQ1, the research first set out to capture the challenges e-taxi drivers face through user interviews:

The study showed that there is a lack of wide implementation of optimal charging tips across different EV manufacturers. Tesla stands out as an exception, providing some fast charging tips, as highlighted in the taxi driver interviews (e.g., P8 (7.9)). This was further confirmed by the benchmark analysis, which showed that Tesla offered the most sufficient fast charging tips, whereas several other vehicles lacked similar guidance (7.4.1). Supporting this, the Volvo survey revealed that close to half the participants disagreed that their car provided intuitive fast charging tips (7.3.4).

While, Tesla was the brand to provide the most sufficient tips among the benchmarked vehicles, these were not always considered genuinely helpful (e.g., P10 (7.9)). This implies that there is a lack in the infotainment system, where the presence of information does not guarantee its usefulness.

A related theme emerging from the thematic analysis (7.2.1) revealed that many drivers were aware that SOC and battery temperature impact charging speed (e.g., P15 (7.14)), therefore taking measures like preconditioning (e.g., P6 (7.11)). However, a lack of clear information was identified, possibly resulting in gaps in understanding (e.g., P5 (7.11)). In the absence of informative system feedback, drivers might rely on peer advice (e.g., P7 (7.9)) or trial-and-error learning (e.g., P8 (7.18)). This dependence on informal knowledge might contribute to fragmented understanding and inconsistent charging behavior. This suggested a need for greater transparency and clarity within vehicle interfaces.

The need for improved communication was particularly evident in the charging capacity and variability theme (7.2.1), which identified two major issues related to the infotainment system: discrepancies between advertised charging power and actual power received, and fluctuating kW output during charging sessions.

While many taxi drivers were aware of factors affecting the charging capacity, the level of understanding varied. Some participants recognized that charging power depends on factors like SOC and shared use of chargers (e.g., P11, P18 (7.15)). However, there remained considerable uncertainty regarding discrepancies and fluctuations in received power (e.g., P12 (7.15)), especially when these could not be attributed to known causes (e.g., P10 (7.15)). These concerns were validated by the Volvo Survey (7.3.4), which also confirmed a demand for more explanatory infotainment systems regarding capacity discrepancies and fluctuations. This issue could be further found in the observations, revealing a consistent pattern where drivers frequently charged at stations with output capacities exceeding their vehicles maximum charging capacity (7.2.1). While driver had knowledge about kW affecting charging speed found in the theme 7.2.1 (e.g., P15 (7.15)), the observations indicate there is a knowledge gap, where drivers often assume that higher station kW ratings directly translate into faster charging, without fully considering their car's limitations (e.g., P14 (7.15), P18 (7.2.1)). This mismatch between perceived and actual charging benefits can lead to poorly informed decisions, such as unnecessary detours to higher capacity stations (e.g., P14 (7.2.1)) and potential frustration when charging speed don't meet expectations (?? (7.15)).

Such behavior highlights the limitations of current infotainment systems, which often fail to clearly communicate the user's vehicle charging capability in relation to charger capacity and real-time conditions affecting it. This is further confirmed by the benchmark analysis, where only half the vehicles displayed an estimated charging capacity (kW) before charging. Additionally, only two vehicles showed real-time charging conditions during the session, although these indicators were still insufficient (7.4.1).

The comparison between Tesla and Volvo drivers also illustrates the role of design in shaping behavior. Tesla's system provided guidance such as charging until 80% (e.g., P8 (7.9)), enabling making more informed decisions (e.g., P6 (7.12)). Preconditioning advice further supported drivers in optimizing efficiency (e.g., P7 (7.11)). In contrast, Volvo did not offer such sufficient tips, found in the benchmark (7.4.1). Neither of the two interviewed Volvo taxi drivers mentioned using preconditioning, unlike most Tesla drivers, despite the functionality being available. While the small sample size limits conclusions, this may reflect differences in the information provided, possibly resulting in reduced understanding of the charging process (e.g., P12 (7.8)).

Additional, infotainment limitations were identified in the On-site theme (7.2.1). Partici-

pants reported problems initiating charging sessions, sometimes requiring them to switch chargers or restart the process, without the infotainment system providing any sufficient explanation for the failure (e.g., P8, P10 (7.18)). This challenge was also reflected in the Volvo survey, where the majority of respondents reported having experienced issues starting a charging session without receiving any, or descriptive enough, information to understand what went wrong (7.3.4). These findings further emphasize the need for clearer guidance and greater transparency within the infotainment interface to help drivers understand potential errors, learn from them, and mitigate them. Supporting this, a theme emerged in the technical expert interviews (7.2.3), which was the need for greater transparency and communication regarding the vehicle's charging process (P2 (7.21)).

Furthermore, limitations were not confined to the charging interface alone. The built-in navigation system was also found to be insufficient. Several participants reported relying on external apps to plan charging due to missing or outdated information in the car navigation system, such as the lack of payment option details (e.g., P8 (7.9)) or delayed updates in the built-in navigation (e.g., P10 (7.9)). This pattern of using third-party apps due to gaps in the in-vehicle navigation system was also found in the Volvo survey. Respondents cited reasons such as payment options and route planning for preferring external tools (7.3.4). For taxi drivers, effective charging planning was critical to maintaining efficient operations, yet it was also perceived as challenging due to the dynamic and time-sensitive nature of their work (e.g., P9, P16 (7.5)). The limitations of the built-in navigation system, particularly for charging planning, may contribute to these difficulties.

Ultimately, the SEQ questionnaire (7.31) from the second evaluation iteration confirmed the need for a well-designed infotainment system to overcome the barriers preventing e-taxi drivers from fully understanding the charging journey. On average, taxi drivers agreed that the proposed system design met their requirements, reinforcing the importance of implementing such solutions in production vehicles.

To answer Q2, a set of user centered design recommendations were developed based on the results derived from the research conducted:

- R1.** Provide transparent, contextual messaging to explain charging behavior
- R2.** Frame charging as a dynamic, condition-based process
- R3.** Reduce cognitive load by unifying and prioritizing key charging metrics
- R4.** Ensure continuous and clear feedback about system status and user actions
- R5.** Use standardized icons and well-defined metrics in the UI
- R6.** Have historic, momentary, and predicted charging data
- R7.** Present key data in a clear and simplified format
- R8.** Provide interface flexibility and tailored access to information

9.0.2 Broader reflection

9.0.2.1 User sample

The benchmark study revealed that few car UIs displayed the estimated charging capacity of the vehicle, suggesting that this feature is still in the early phases of adoption. As highlighted in the theme "*Charging Capacity and Power Variability*" (7.2.1) taxi drivers frequently expressed feelings of uncertainty about their car's charging capacity. Most participants drove Teslas (7.3), which at the time of the study did not display an estimated charging capacity, possibly contributing to this uncertainty.

9.0.2.2 Alternative solution

The resulting design solution aims to alleviate the uncertainties surrounding charging power discrepancies and to guide users toward achieving optimal charging speeds, thereby reducing downtime through both system transparency and user learning (e.g., preconditioning). However, this addresses only a subset of the broader challenges identified in the study (7.2.1).

Taxi drivers often need to charge during work shifts, which directly impacts their operational efficiency and revenue. This frequent charging amplifies barriers related not only to time loss but also to the complexity of planning charging sessions, navigating suboptimal UI and infotainment systems, selecting suitable charging stations, and coping with inconsistent charging performance.

These challenges point to systemic usability issues that may hinder wider EV adoption, particularly in commercial use cases. A more holistic solution may involve reducing the need for frequent charging altogether, through increased vehicle range, or minimizing the time impact of charging by enabling significantly faster charging technology, ideally approaching the speed of conventional refueling.

9.0.2.3 Cross-User Validation of Infotainment System Issues

The Volvo Cars survey (7.3.4) revealed that several of the issues addressed by the prototype were relevant to all BEV drivers, not just taxis. This suggests that the pain points were systemic, likely rooted in limitation in the infotainment system, particularly transparency, rather than being specific to commercial drivers. However, while the types of issues may be shared across user groups, the impact and frequency of those problems likely vary. For instance, E-taxis typically fast charge on a daily basis, whereas normal BEV users tend to charge less frequently (??). This means usability issues in the charging interface are more disruptive to e-taxis, whose work depends on frequent DC charging (7.3). As a result, improvements to the DC charging experience may offer more immediate and tangible value to e-taxi drivers compared to normal BEV users.

This is reflected in the results of the SEQ questionnaire (7.6.1), where e-taxis rated the design prototype higher than normal users. This difference could also be attributed to the design process itself, which was primarily informed by user research conducted with e-taxi drivers (7.2.1). Their specific workflows, pain points, and expectations likely had a direct influence on the resulting prototype. As a result, the solution may have been naturally more aligned with their needs.

9.0.2.4 Charging target component

Observations during the taxi driver interviews (7.2.1) indicated a usability issue with the target setting feature. However, findings from the Volvo survey showed that a slight majority (51%) of regular BEV users found it easy to compare charging times for different battery levels without excessive interaction (7.3.4). The taxi drivers observed were using Teslas, which as found in the benchmark study (7.4.1), require users to drag a slider and release it to set the new charging target, only then updating the charging time. Volvo vehicles use a similar mechanism. This could be seen as contradicting the observation, given that a slight majority of Volvo users reported ease of use. However, a notable mention is that taxi work is time-sensitive where this interaction may become more common.

However, since it was only a slight majority and given the nature of taxi drivers' time-sensitivity, where this interaction may become more common, it can be argued that a significant portion of users still experience usability issues, potentially validating the original observation. Supporting this, results from the SEQ questionnaire during the first evaluation, which included participants from the same user group as the Volvo survey, showed a high satisfaction rating for the target-setting feature, with a mode of 6 out of 7 (7.27).

This suggests that, although the issue was initially observed in a small sample of taxi drivers, and only partially reflected in the survey data, the changes made in response were positively received and aligned with user needs. While the feature was intended to reduce excessive interaction and cognitive recall by displaying added charging time in real time as the target goal is adjusted, user feedback indicated particular appreciation for the timestamps mapped to battery percentages (7.5.1). This implies that the high SEQ score may be more attributable to the timestamps than to the resolution of the originally observed problem.

9.0.2.5 Charging Speed Inefficient

Although DC fast charging is considerably faster than AC charging, both taxi drivers and technical experts noted that charging from a low SOC (e.g., 10-20%) up to 80% typically is fast (e.g., P15 (7.22)). This aligns with background findings showing that a vehicle with a relatively small 36kWh battery can be recharged in approximately 20 minutes using a fast charger (2.1.2).

Despite this performance, the charging time is still substantially longer than the time required to refuel a conventional ICEV. As a result, many taxi drivers perceived even fast charging as excessively time-consuming, particularly in the context of their work, which often involves time pressure and quick turnaround between trips (e.g., P7(7.13)). While several participants compared charging duration to that of refueling petrol or diesel cars, one notably expressed a desire for charging times that more closely resemble the speed of conventional refueling (P18 (7.14)).

9.0.2.6 Pre study

In the taxi survey, only one recorded comment explicitly mentioned the insufficient range of BEVs, which was not sufficient to form a theme on its own and was therefore excluded. However, concerns related to limited range were implicitly reflected in other themes,

particularly the need for frequent charging, suggesting that range limitations may have been an underlying issue, even if not directly articulated by participants or possibly articulated but not captured in the recorded notes.

9.0.2.7 Iteration 2 evaluations

In evaluation 2, the results of the TOT and number of interactions, it was shown that taxi participants generally took longer to complete tasks but used slightly fewer interactions, on average (7.6.1). This could be due to environmental and experiential factors. Some participants were Volvo employees familiar with Volvos design, and completed their evaluations in a quiet, controlled office setting. In contrast, taxi drivers were non-Volvo users and completed the evaluation on-site at charging stations, either outdoors or inside their vehicles (7.29). These less controlled environments lead to potential distractions and discomfort, which likely affected time performance.

Additional, the fact that tasks were orally administered to taxi driver due environmental constraints could might have influenced, this might have affected performance. Receiving instructions verbally could require additional time to mentally process the information before acting.

However, the reduced number of average interactions among taxi participants may reflect a more cautious exploration of the interface. Instead of rapidly trying different actions, these users were observed to have engaged in more observational behavior before interacting, possibly to avoid making mistakes in this unfamiliar system.

Furthermore, the TOT for participants overall were excessive compared to the benchmark time (7.6.1). A key reason for these extended times is the introduction of many entirely new components and views within the prototype. Regardless of prior Volvo experience, all participants were effectively encountering these feature, more or less, for the first time. This unfamiliarity might have led to increased exploration and decision-making time as users attempted to interpret new visual structures and functionality. Task 4 illustrates this well, which required users to navigate to the Capacity page, a navigation path already completed in Task 1. One interaction was required for users, matching the optimal number. This suggests users were able to learn from experience, retaining navigation knowledge when tasks followed familiar structures. Additionally, Task 4 received one of the highest ease ratings (7.6.1), enforcing the idea that consistency and experience contribute to improved perceived usability.

9.0.3 Work Process Discussion

The process began with the initial RQs, "*What are the barriers that limit e-taxi drivers from reaching optimal conditions for time-efficient direct (DC) charging?*" and "*What features in the energy management interfaces can be implemented to overcome the barrier and promote time-efficient DC fast charging?*". Although the questions concerned a specific domain, namely charging, from the interviews with the taxi drivers a wide range of themes emerged indicating that the scope of charging was broader than initially anticipated. In order to reduce the scope, the focus was narrowed down to address one theme resulting in refinement of the RQs. By reducing the scope, the depth and quality of the design development and evaluations could be ensured. However, this narrowing of focus came with trade-offs. Some important issues such as infrastructure availability

were excluded, as they fell outside the scope of what could be meaningfully addressed through in-car infotainment interfaces. Further narrowing led to the exclusion of insights from the design scope, such as those related to the UI of the in-car navigation interface. While these insights were recognized as relevant, they were not addressed in the design phase, as they were outside the interaction scope defined for this study.

Throughout the process of this study, a rewarding framework followed was RtD. The findings from the interviews guided the development of the prototypes, which were then evaluated and iterated. The insights gained from the iterations served to generate new knowledge in guidance of the development of the design recommendations. This framework was advantageous in including users through out the design process, ensuring user-centered designs. However, since RtD is generative rather than falsifiable [40], the design outcomes should be understood not as objective facts, but as informed recommendations based on contextual insights.

The user group for this study was e-taxi drivers, who are considered expert users due their extensive, daily use of BEVs. Unlike typical private BEV users, taxi drivers interact with charging systems far more frequently (7.29) and under tighter time constraints (e.g., P1 7.14), making their insights particularly valuable. However, this group is also notable difficult to recruit. The most effective method for approaching participants was on-site recruitment at charging stations, as this coincided with their downtime (7.2.1). Still, interviews had to be short and conducted within the limited charging window, since this time was often unpaid time and thus associated with revenue loss (7.2.1). Additionally, the unpredictable nature of taxi operations posed further challenges, even having 3 interviews cut short due to incoming customer bookings during the interviews. This reinforces findings from the theme: **customer constraints**, where charging disruptions due to customer bookings was identified. Although more in-depth interviews, such as those with technical experts, were preferred to collect deeper insights, attempts to recruit taxi drivers for such sessions failed. Nevertheless, the conducted methods enabled us to get a larger sample and achieve data saturation, as it was found during the data analysis that redundancies occurred.

Furthermore, while the evaluation phase was designed to consistently involve taxi drivers, given that they represent the target user group, in practice, recruitment challenges led to delays and inconsistent involvement throughout the design iteration. This may have influenced the evolution of the prototype. Nonetheless, the core functionalities implemented in the design concepts were grounded in insights from initial interviews with taxi drivers and were later validated during the second evaluation phase (see 7.6.1).

9.0.4 Limitations

The taxi driver interviews were conducted during daytime hours, and it is likely that most participants worked day shifts. However, the needs, behaviors, and charging patterns of night-shift drivers may differ, which were not captured in this study. Additionally, the relatively small sample of taxi drivers included in the evaluation phases limits the generalization of the findings, even though expert users. All participants were operated in the same city, meaning the results may also reflect location specific factors such as charging infrastructure, driving regulations, or cultural practices. As a result, the findings cannot be generalized to taxi drivers in other regions or working conditions.

The majority of participants, 14 out of 18, were Tesla drivers. This limited the diversity of the sample, introduced a potential bias in the findings. As a result, any correlations related to vehicle brand or interface features should be interpreted with caution. These insights cannot be generalized without further investigation involving a more balanced demographic group or cross-validation with other sources, such as benchmark analysis. Another limitation is the complete lack of gender diversity, as all participants were male. This restricts the study's ability to capture potentially different perspectives that female e-taxi drivers might have. While the Swedish taxi market is male-dominated, with over 90% of drivers reported to be men in 2024 ([79]), the findings may not be generalizable to regions where taxi operations are more gender-balanced or female-dominated.

The study is limited to the constrained testing environments since the evaluations did not take place with real-life fast charging environments. Thus, results may differ when the design solution is implemented in the real world situation. External factors that were not accounted for in this study, which could affect the results of this study.

The validity of the benchmark conducted in this study is limited. Without testing the systems hands on, important details on interactions may have been missed. Additionally, the systems from the user reviews and videos may have been altered to custom settings, which may not reflect the standard experience. Because of this, some features or issues could have been misunderstood or overlooked. To strengthen the validity of the benchmark, future benchmarking should involve hands-on interaction with the systems in vehicles to capture interactions.

In the evaluations including a iPad, two device related limitations influenced performance during the evaluation. First, participants occasionally experienced delays in interaction and system response on the iPad, which likely increased the TOT, and number of interactions, especially when users misinterpreted the delays as an unregistered interaction and attempted repeated taps. Secondly, several views in the prototype were not adjusted accurately to the dimensions of the iPad screen and required vertical scrolling. Although this was explained to participants when relevant, it's likely that some components were missed or initially overlooked. This probably contributed to the excessive time taken to complete Task 3, where the change target slider was not fully visible without scrolling. To address this, the additional interaction due to delays or need of scrolling were not registered. However, these factors might have influenced the lower SEQ ratings compared to iteration 1, where an iPad was not utilized. These limitations should be addressed in future design iterations to ensure responsiveness and fully content visibility.

In the pre-study, limitations arose due to the oral administration of the survey with taxi drivers. This format led some participants to provide additional verbal comments that were not always possible to fully capture and document in real time. Only the comments that were successfully noted down and confirmed by the participants were included in the thematic analysis. As, a result, there is a risk that valuable insights may have been missed. Additionally, the sample size was limited (n=5), especially for a survey context, limiting the ability to identify representative themes. However, this size was sufficient for a pre-study, as supported by relevant literature. key patterns identified in the survey were also later confirmed during follow up interviews with taxi drivers, strengthening confidence in the findings.

Similarly, a limitation of evaluation iteration 3 is the validity of its findings, as it was

conducted with only two participants, due to time constraints. Although both were function owners with expert insights, there remains a risk that some usability issues were overlooked. Similarly, in evaluation iteration 1, two focus group sessions were scheduled with three participants each, however, one participant was unable to attend at the last minute in both sessions, leaving only two participants per session. The small group size limited the usual interaction and diversity in perspective found in larger groups, potentially affecting data richness and variety. Nevertheless, continuing with two participants was necessary due to scheduling constraints. Despite the limited size, the sessions lasted one hour and useful, detailed insights were collected. Furthermore, these focus groups were part of a broader mixed-methods approach, mitigating the impact of the limited group size on the overall findings.

Usability expert Jacob Nielsen has argued that the first few participants are also those who tend to uncover the majority of key insights, with diminishing returns for each additional user [80]. This principle supports the use of small, focused samples. In both the pre-study and evaluations in iteration 3, the participants, e-taxi drivers, and function owners, respectively, represented relatively homogeneous expert groups. Although Nielsen's principle was originally rooted in usability (as was evaluation 3), the oral survey format additionally provided richer qualitative insights, beyond what a typical survey would.

9.0.5 Ethical consideration

The increase in vehicle status information provided by the infotainment system may induce additional cognitive load and stress. As identified in our interviews, this already affects taxi drivers due to the demands of their work operations (7.2.1). To avoid this, it is important that the system does not alarm the user unnecessarily and that the information is presented in a way that supports decision-making without adding pressure (7.7.1).

A core goal of our design is to empower e-taxi drivers to make informed and time-efficient charging decisions. However, this objective introduces an ethical dilemma. While fast charging is critical to meet immediate operational demands, frequent use of fast charging can accelerate battery degradation, which in turn leads to increased environmental costs due to battery replacement and resource consumption. This tension creates a responsibility to balance encouraging efficient charging behavior with fostering sustainable practices that support the long-term health of batteries.

This ethical balance is reflected in design decisions around features such as manual preconditioning. While some users expressed a desire for more control through manual options (7.5.1), it's generally more energy efficient to use navigation-based preconditioning (7.5.1). Manual preconditioning can lead to higher energy consumption, if not used correctly (7.23). In order to reduce unnecessary energy use, it is important to only make manual preconditioning available when it is appropriate, such as at low battery temperatures or low SOC. It is also important that users understand that preconditioning consumes energy (7.23).

9.0.6 Future Work

While this thesis identified key information gaps and usability issues in EV charging interfaces, future work should explore how these solutions perform over time in real-world

charging scenarios, how effectively they address the needs of taxi drivers, and whether they can be adapted for other user groups.

Our evaluations were limited to short, task-based sessions, which do not capture the full situational complexity of a typical fast-charging session. For instance, the frequency and timing of system feedback, such as warning messages, may vary depending on environmental or vehicle-specific conditions. Furthermore, the projected data on the charging curve is just an estimation, as these projections are difficult to calculate precisely and can change dynamically. For example, if another vehicle connects to the same charging station, the available power may drop, altering the curve mid-session. It remains unclear how often these significant changes occur in real-life, users' reaction to changes, and how it can affect trust and perceived system reliability. Rather than evaluating isolated interactions, future studies should investigate how users make sense of evolving system states, and whether increased transparency continues to support, or begins to overwhelm users as conditions change.

Although the design solution was based on insights from taxi drivers, this study does not provide sufficient evidence to determine the extent to which it improves their real-world experience. Future work should involve testing the solution in practice with taxi drivers during actual charging sessions to assess its impact. Additionally, it would be valuable to explore how the solution performs with taxi drivers in other countries, where differences in climate, infrastructure, and operational context may influence usability and relevance. Demographics may also differ significantly. While the profession in Sweden is predominantly male, other regions may have more gender balance or female dominated e-taxi driver population. Future research should therefore aim for a more inclusive and diverse participant sample to account for potential differences related to gender, vehicle brand, and regional context. This would help ensure that the solution and the underlying findings remain relevant across a broader range of contexts.

Future work should also aim to validate whether the findings and proposed solutions are applicable across different driver groups. While normal BEV drivers were included in the evaluation phase, the core design decisions were grounded in the needs of e-taxi drivers, whose usage patterns and charging frequency differ significantly. Feedback from private BEV users indicated that they found value in the proposed features. However, to ensure the broader relevance of these design recommendations, further user interviews with private BEV drivers should be conducted. This would help develop a more in-depth understanding of their specific needs, behaviors, and expectations when it comes to managing EV charging.

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Conclusion

This thesis aimed to gain a comprehensive understanding of the barriers taxi drivers face in preventing efficient fast charging, to develop a design solution that addresses the identified barriers through user interface design, and to formulate a set of design recommendations to guide future development. The study was guided by the following research questions:

RQ1: What barriers prevent electric taxi drivers from fully understanding the charging journey?

- **SRQ1:** How do these barriers affect decision-making before and during charging?

RQ2: What design improvements and recommendations to the infotainment system can enhance drivers understanding of the charging process?

To answer these questions, a user-centered and iterative approach was employed. Data was collected through user interviews with taxi drivers, benchmark studies, surveys, and technical expert interviews. Insights from this research guided the design of low-fidelity prototypes, which were evaluated and refined through multiple iterations. Building on the results of these evaluations, a set of eight design recommendations was formulated.

With the adoption of EVs continuing to rise, it is increasingly important to ensure a high-quality user experience that accommodates the diverse needs of different drivers. The findings from this thesis are highly relevant for designers and researchers working with EV user interfaces and charging. The identified challenges, such as lack of feedback and transparency around charging, are not limited to taxi drivers and reflect broader usability issues.

Future work should focus on real-world testing of these recommendations, and further explore of how they apply across different driver groups and environments. This thesis contributes to the understanding of how interface design can guide BEV drivers to manage and get a deeper understanding of charging.

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A

Pre-study Survey: Electric Taxi Driver Needs (Original Language)

Hej!

Vi genomför denna enkät som en del av en förstudie till vårt examensarbete. Syftet är att samla in data för att bättre förstå pålitligheten av räckviddsestimation i elbilar som används som taxi av flera förare.

Important Information:

Ditt deltagande är helt frivilligt. Denna enkät är anonym och vi samlar inte in någon personlig eller identifierande information. Dina svar kommer endast att användas i forskningssyfte och presenteras i sammanställd form i examensarbetet. Du kan när som helst avbryta ditt deltagande genom att stänga formuläret. Genom att klicka på "Jag samtycker" nedan samtycker du till att delta i denna enkät. Tack för din medverkan!

1. Jag samtycker till att delta i enkäten

Svarsalternativ: Jag samtycker

2. Delar du taxin med andra taxichaufförer?

Svarsalternativ: Ja / Nej

3. Hur många år erfarenhet har du som taxichaufför med elbil?

Skrivsvar: _____

4. Hur tillförlitlig tycker du att den beräknade räckvidden är? (1-5)

Svarsalternativ:

- 1 Inte alls tillförlitlig
- 2 Lite tillförlitlig
- 3 Något tillförlitlig
- 4 Ganska tillförlitlig
- 5 Mycket tillförlitlig

5. Hur ofta upplever du att den faktiska räckvidden avviker från den beräknade? (1-5)

Svarsalternativ:

- 1 Aldrig
- 2 Sällan

- 3 Ibland
- 4 Ofta
- 5 Alltid

6. **Har du märkt att den beräknade räckvidden påverkas när någon annan har kört bilen innan dig? (1-5)**

Svarsalternativ: Som ovan

7. **Hur ofta är den beräknade räckvidden applicerbar på dig när du börjar köra efter en annan förare? (1-5 + Vet ej)**

Svarsalternativ:

- 1 Aldrig
- 2 Sällan
- 3 Ibland
- 4 Ofta
- 5 Världigt ofta
- Vet ej

8. **Hur påverkar detta din tillit till den beräknade räckvidden? (1-5)**

Svarsalternativ:

- 1 Inte alls
- 2 Lite
- 3 Något
- 4 Ganska mycket
- 5 Mycket

9. **Övriga kommentarer:**

Skribsvar: _____

A.1 Pre-study Survey: Electric Taxi Driver Needs (English Translation)

Important Information: Your participation is entirely voluntary. This survey is anonymous and does not collect any personal data. Your responses will be used exclusively for research purposes and summarized in the thesis. You may withdraw at any time by closing the form. By clicking "Yes, I consent" below, you agree to participate. Thank you for your participation!

1. I consent to participate in this survey
Answer: I consent
2. Do you share the taxi with other drivers?
Answer options: Yes / No

3. How many years of experience do you have driving an electric taxi?
Short text
4. How reliable do you find the estimated range? (1–5)
 - 1 – Not at all reliable
 - 2 – Slightly reliable
 - 3 – Somewhat reliable
 - 4 – Fairly reliable
 - 5 – Very reliable
5. How often does the actual range differ from the estimated range? (1–5)
 - 1 – Never
 - 2 – Rarely
 - 3 – Sometimes
 - 4 – Often
 - 5 – Always
6. Have you noticed the estimated range is affected when someone else has driven the car before you? (1–5)
7. How often is the estimated range relevant to you when you begin driving after another driver? (1–5 + Don't know)
 - 1 – Never
 - 2 – Rarely
 - 3 – Sometimes
 - 4 – Often
 - 5 – Very often
 - Don't know
8. How does this affect your trust in the estimated range? (1–5)
 - 1 – Not at all
 - 2 – Slightly
 - 3 – Somewhat
 - 4 – Quite a bit
 - 5 – Very much
9. Additional comments:
Short text

B

Pre-study Expert Interview

Exploration of User Needs and Function Improvements for Non-personal Electric Vehicles

Purpose of Interview

This interview was conducted as part of a master's thesis at Chalmers University of Technology, Sweden, in collaboration with Volvo Cars AB. The thesis, commissioned by Volvo Cars AB, explores user needs and function improvements for non-personal vehicles.

The final thesis will be publicly published by Chalmers, with plans to refine and submit the work to a journal (journal to be determined). The research is carried out by Adam El Jabaoui (jabaoui@chalmers.se) and Sofia Sjöblad (sofiasjo@chalmers.se).

This is considered an expert interview conducted as part of the pre-study. Its purpose is to gain insights, validate the scope of the research question, and refine it if necessary.

Interview Questions

1. How many years of experience do you have with EVs (Electric Vehicles)?
2. Can you give us an overview of the current state of electric vehicles in the market?
3. What are the biggest hurdles to the adoption of EVs?
4. What are the main advantages and disadvantages of EVs compared to internal combustion engine (ICE) vehicles?
5. What are the key differences in maintenance needs between EVs and traditional vehicles?
6. How has the UI/UX in EVs evolved in recent years, and what major developments are on the horizon?
7. How well do EVs fit into work environments where multiple drivers share the same vehicle (e.g., taxis, delivery services, company fleets)?
8. What are the most common challenges faced when multiple drivers share an EV?
9. Are there any specific issues that might arise for EVs used for work purposes (e.g., taxi, delivery, fleet services)?

10. Are there any specific features that EVs should have to better suit work environments?
11. What are the main issues with range estimation in EVs?
12. Previous personal consumption is taken into account when the range is being calculated - how does this affect cars with multiple users?
13. How quickly does a car adapt to the current driver after a change of drivers?
14. What are the main issues with EVs for experienced drivers?
15. Are there issues related to battery degradation when EVs are used extensively in work environments?
16. What approaches can be taken to alleviate range anxiety among EV drivers?
17. Is range anxiety more common for specific demographics?
18. Without changing the calculations for the range estimation and other displayed info, can range anxiety and time-related anxiety be alleviated in other ways (e.g. through UI)?

C

E-taxi Driver Interview questions (Swedish version)

1. Vad tycker du om tiden det tar att ladda din elbil, och varför?
2. Vad tror du påverkar hur snabbt din taxi laddas?
3. Har du märkt att laddningen ibland går snabbare eller långsammare (varierar)?
 - (a) Om ja, vad tror du orsakar det?
4. Finns det tillfällen då du är osäker på varför det laddar långsammare än förväntat?
5. Gör du något specifikt för att göra laddningen snabbare, som att ändra när, var eller hur du laddar?
 - (a) Om nej, toor du det finns något du kan göra för att få snabbare laddning? I så fall, vad?
6. Finns det information i bilen som hjälper dig att ladda så snabbt som möjligt?
7. Om din taxi kunde ge dig laddnings tips i realtid, vilken typ av råd skulle vara mest användbara?
8. Vilka är de största utmaningarna du stöter på när du laddar din taxi under ett arbetspass?
9. Finns det tillfällen då du vill ladda men inte kan?
 - (a) Om ja, vad hindrar dig?
10. Planerar du dina laddnings stopp i förväg, eller laddar du när det passar?
11. Är det svårt att planera laddning i förväg? Varför?
12. Finns det något som hindrar dig från att vänta tills batterinivån är lägre (2030%) innan du laddar?
13. Vilka faktorer påverkar när du väljer att ladda?
14. Hur vet du att det är dags att ladda (ex., kollar du på något i bilskärmen, vad)?
15. Hur påverkar laddningen din dagliga inkomst eller förmåga att ta körningar?
16. Är laddstationerna placerade på ett sätt som passar ditt arbetsschema och dina rutter?

17. Om du kunde ändra en sak med hur laddningen passar in i din arbetsdag, vad skulle det vara?
18. Ser du några negativa konsekvenser med dina laddnings vanor?

C.1 E-taxi Driver Interview questions (English version)

1. What do you think about the time it takes to charge your EV, and why?
2. What do you think affects how fast your taxi charges?
3. Have you noticed that charging speed is slower or faster at times (varies)?
 - (a) If yes, what do you think causes it?
4. Are there times when you're unsure why charging is slower than expected?
5. Do you take any steps to improve charging speed, like adjusting when, where, or how you charge?
 - (a) If not, do you think theres anything you could do to make charging faster? In that case, what?
6. Do you feel that your taxi provides enough information to help you charge as efficiently as possible?
7. If your taxi could give you charging tips in real-time, what kind of advice would be most useful?
8. What are the biggest challenges you face when charging your taxi during a shift?
9. Are there times when you want to charge but cant?
 - (a) If yes, what prevents you from charging?
10. Do you plan your charging stops in advance, or do you charge when its most convenient?
11. Is it difficult to plan charging stops in advance? Why?
12. Is there anything that prevents you from waiting until the battery is lower (ex. 10-20%) before charging?
13. What factors influence when you choose to charge?
14. How do you know it is time to charge (e.g. do you look at anything in the car screen, what)?
15. How does charging impact your daily earnings or ability to take rides?
16. Are charging station placed in a way that fits your work schedule and routes?
17. If you could change one thing about how charging fits into your workday, what would it be?
18. Do you see any negative consequences with you charging habits?

C.2 Demographic Questionnaire for E-taxi Drivers

Demographic Questionnaire

Please answer the following about yourself



Age: _____

Sex: Male Female Other

Highest completed education: Elementary School High School University

Ownership of car: Yes, I own the taxi-car No, I don't own the taxi-car

Do you always drive the same taxi: Yes, I always drive the same car No, I change car

How many years have you worked as a taxi driver: _____

How many years have you driven a taxi with an EV: _____

Electric car model you use/ have used as a taxi: _____

How many times do you charge per workshift: _____

What type of charging do you usually use during your shift: Fast Charging (DC) Normal (AC)

Figure C.1: Demographic Questionnaire E-taxi

D

Thematic Analysis

D.1 Themes and subthemes from taxi driver interview

Main Theme	Subthemes
Charging Planning and Timing	<ul style="list-style-type: none">• Charging During Downtime and Workload Management• Charge For Next Shift• Flexible Charging Based on Need• Cant plan charging without a fixed route• Need for Charging Planning• Difficulties planning charging during peak hours or long routes• Battery Monitoring and Charging Alerts• Navigation for planning charging
Customer Constraints	<ul style="list-style-type: none">• Minimize charging time with customer for better experience• Need to charge with customer• Charging disruption due to bookings
Range Limitations and Performance	<ul style="list-style-type: none">• Unreliable range estimation• Insufficient range for operations• Fast charging decreases range• Cold temperature decreases range
UI and InfoVis	<ul style="list-style-type: none">• Charging information and tools in the car• Use Of External Apps for lacking information• Charging Notifications and Alerts• Monitoring SOC and Range for Charging Decisions• Lack of Optimal Charging Information• Navigation for charging station information

Main Theme	Subthemes
Charging Station Accessibility and Efficiency	<ul style="list-style-type: none"> • Detours for charging • Limited spots at charging stations • Need for more and better placed charging stations • Need for charging at home
Navigation for Preconditioning	<ul style="list-style-type: none"> • Using Google Maps for Preconditioning • Preconditioning for Faster Charging • Lack of Awareness of preconditioning feature • Ease of Using Google Maps for Preconditioning
SOC-Based Charging Habits	<ul style="list-style-type: none"> • Charging Limits for Battery Health • SOC Charging Habits for time loss mitigation • Sufficient battery for operational readiness • Charging Threshold for SOC Level
Concerns and Barriers to EV Integration	<ul style="list-style-type: none"> • Uncertain about impact of DC fast charging • Expensive battery replacement concern • EV not suitable for taxi service
Charging Speed and Station Preferences	<ul style="list-style-type: none"> • Charging Station Preferences For Faster Charging • Cold Temperatures negatively impact Charging Speed/Frequency • Acceptable charging time • SOC Impact on Charging Speed • Excessive charging time • Charging Speed Differs by Car
Charging Capacity and Power Variability	<ul style="list-style-type: none"> • Charging station capacity sharing • Inconsistent kW output • Discrepancy in advertised charging power • Desire for high kW for faster charging • SOC-dependent charging power • kW affects charging speed
Driving Pattern/Style	<ul style="list-style-type: none"> • Highway driving drains battery faster • Range capacity for one charging session limited • City driving better for battery efficiency

Main Theme	Subthemes
Economic Impact on Charging	<ul style="list-style-type: none">• Choice of charging station dependent on price• Charging Time as Non-Paid• Time lost to charging• Charging disruptions affecting revenue
Cognitive Load	<ul style="list-style-type: none">• Reassurance from destination charging• Range anxiety• Cognitive load of charging management• Stress and Time Pressure from Charging
On-site Charging Issues	<ul style="list-style-type: none">• Charging Payment Challenges• Charging Start Issues and Lack of Error Information• Charging Station Malfunctions

E

Technical Expert Interviews

E.1 Expert 1 Interview Questions (Original Language)

1. Hur hade jag som elbilsanvändare kunnat optimera laddning för att den ska gå så snabbt som möjligt? Och vilka faktorer spelar störst roll?
2. Vilka typiska laddningsvanor finns det som försämrar batteriet och/eller påverkar tidseffektiviteten på laddningen?
3. Vilka är de största hindren som förhindrar förare från att ladda sina fordon tidseffektivt?
4. Hur påverkar laddningstekniken som används av BMS laddningstiden med snabbbladdning?
5. Vilka strategier har Volvo när det gäller laddningsteknik och vad är resonemanget kring dem?
6. Under vilka SOC-nivåer är det optimalt att ladda bilen med tanke på tidseffektivitet? Varför?
 - Är det realistiskt för en förare att alltid kunna ladda under dessa förhållanden, och varför eller varför inte?
7. Hur påverkar SOC-nivån vid start av en laddningssession tiden det tar att uppnå en optimal laddningsnivå?
8. Ger nuvarande energihanteringssystem för elbilar tillräcklig vägledning om SOC-optimering? Om inte, vad saknas?
9. Vilka är de bästa metoderna för att hantera SOC för att minimera den totala laddningstiden?
10. Vilken roll spelar batteriförkonditionering för att förbättra DC-snabbbladdningens effektivitet?
11. Är nuvarande funktioner för förkonditionering effektiva, eller behöver de förbättras?
12. Hur stor är påverkan av batteriförkonditionering på laddningshastigheten?
13. På vilka sätt påverkar externa faktorer som väder och laddinfrastruktur?
14. I nuvarande tillstånd finns det ingen notifikation som indikerar att förkonditionering har startat när man navigerar till en snabbbladdare. Finns det andra faktorer i bilen som kan indikera detta?

15. Hur informeras föraren om batteriförkonditioneringen och dess energiförbrukning? Finns system som justerar eller avbryter den automatiskt för att undvika onödig energiförlust?
16. Finns det system som tar hänsyn till flera faktorer, såsom körstil, omgivningstemperatur och SOC, för att beräkna och rekommendera en strategi till föraren för att minimera laddningstiden? Om inte, vad tycker du om möjligheten att utveckla ett sådant system?

E.2 Expert 1 Interview Questions (English Translation)

1. How could I, as an electric vehicle user, optimize charging to make it as fast as possible? And which factors matter the most?
2. What typical charging habits contribute to battery degradation and/or reduce time efficiency during charging?
3. What are the main obstacles that prevent drivers from charging their vehicles in a time-efficient manner?
4. How does the charging technique used by the Battery Management System (BMS) affect charging time during fast charging?
5. What strategies does Volvo have regarding charging technology, and what is the reasoning behind them?
6. At which State of Charge (SOC) levels is it optimal to charge the car in terms of time efficiency? Why?
 - Is it realistic for a driver to always be able to charge under these conditions, and why or why not?
7. How does the SOC level at the start of a charging session affect the time it takes to reach an optimal charge level?
8. Do current energy management systems for EVs provide sufficient guidance on SOC optimization? If not, what is missing?
9. What are the best practices for managing SOC in order to minimize total charging time?
10. What role does battery preconditioning play in improving the efficiency of DC fast charging?
11. Are current preconditioning functions effective, or do they need to be improved?
12. How significant is the impact of battery preconditioning on charging speed?
13. In what ways do external factors such as weather and charging infrastructure affect charging performance?
14. Currently, there is no notification indicating that preconditioning has started when navigating to a fast charger. Are there other indicators in the vehicle that can show

this?

15. How is the driver informed about battery preconditioning and its energy consumption? Are there systems that automatically adjust or cancel it to avoid unnecessary energy loss?
16. Are there systems that consider multiple factors such as driving style, ambient temperature, and SOC to calculate and recommend a strategy to the driver for minimizing charging time? If not, what is your opinion on the potential to develop such a system?

E.3 Expert 2 Interview Questions (Original Language)

1. Vad skulle vara ett optimalt sätt att planera laddning under en arbetsdag som yrkesförare?
2. Vilket är det optimala temperaturintervallet för batteriet vid snabbaddning?
 - Hur påverkar andra faktorer, (t.ex. kallt väder), batteriets förmåga att ladda snabbt?
3. Hur bestämmer eller begränsar BMS (Battery Management System) laddningshastigheten? Vilka nyckelparametrar övervakar det (t.ex. temperatur, spänning, SoC, intern resistans)?
 - Hur dynamiskt är BMS i att justera laddningskurvan baserat på realtidsförhållanden?
4. Skulle det vara möjligt att förutsäga det bästa laddningsfönstret eller den mest optimala laddningsstationen för en förare baserat på t.ex. SoC, batteritemperatur, stationens status eller andra faktorer? Och finns det redan ett sådant system?
5. Även om en laddstation annonserar en effekt på 150 kW eller 350 kW kan den faktiska effekten som levereras till fordonet vara mycket lägre. Vilka primära faktorer (t.ex. batteritemperatur, SoC, batteridesign) avgör hur mycket av den angivna effekten bilen faktiskt kan ta emot?
6. Finns det något föraren kan göra för att förbereda bilen eller påverka situationen så att den kan ta emot mer effekt?
7. Hur jämför sig delvis laddning (t.ex. från 30% till 60% flera gånger per dag) med en enstaka laddning från 10% till 80%? Är det praktiskt för föraren, och minskar det den totala laddningstiden? I så fall, med hur mycket?
8. Vilka är de största utmaningarna med förkonditionering (t.ex. tidsbegränsningar, yttre temperatur, ökad energiförbrukning)? Vilka risker eller aspekter bör beaktas om föraren ges möjlighet att manuellt aktivera förkonditioneringen?
 - Är nuvarande funktioner för förkonditionering effektiva, eller behöver de förbättras?
9. När en yrkesförare behöver ladda, vilka faktorer bör prioriteras för att minimera den totala laddningstiden förkonditionering, SoC, stationsbelastning eller något annat?

10. Vilka mätvärden (t.ex. kW, tillförda kilometer per minut, uppskattad tid till nästa 10%) ger den mest intuitiva återkopplingen så att förare kan avgöra om det är "värt" att vänta på mer laddning?
11. Vilka vanliga missuppfattningar har förare om elbilar och laddning?
12. Finns det något som är otydligt, missvisande eller inte visas explicit i hur elbilar presenterar batteristatus? Vilka ytterligare batteridata eller mätvärden skulle vara mest hjälpsamma för förare, men som dagens elbilsdisplayer kanske inte visar tydligt?
13. I vilken utsträckning kan extrautrustning i bilen, såsom GPS, kortläsare eller taxiväxel, påverka energiförbrukningen och öka behovet av laddning?
14. Hur mycket batterikapacitet förbrukas vid förkonditionering av batterierna?
15. Hur påverkar frekvent DC-laddning (t.ex. en gång per dag) batterihälsan, och finns det faktorer som kan förändra denna påverkan, såsom förkonditionering innan laddning eller vid vilken SoC-nivå laddningen sker?
16. Vilka tekniska utmaningar är de största hindren för att minska laddningstiderna för elbilar (ex. batteriets livslängd)?
17. Finns det specifika laddningsfunktioner som är utformade för att passa förare med höga körsträckor, såsom taxiförare?
18. Hur samlar och analyserar Volvo användardata för att förbättra laddningseffektivitet och batterihantering?

E.4 Expert 2 Interview Questions (English Translation)

1. What would be an optimal way to plan charging during a workday as a professional driver?
2. What is the optimal temperature range for the battery during fast charging?
 - How do other factors (e.g., cold weather) affect the battery's ability to charge quickly?
3. How does the BMS (Battery Management System) determine or limit the charging speed? What key parameters does it monitor (e.g., temperature, voltage, SoC, internal resistance)?
 - How dynamic is the BMS in adjusting the charging curve based on real-time conditions?
4. Would it be possible to predict the best charging window or the most optimal charging station for a driver based on, for example, SoC, battery temperature, station status, or other factors? And does such a system already exist?
5. Even if a charging station advertises a power output of 150 kW or 350 kW, the actual power delivered to the vehicle can be much lower. What are the primary

- factors (e.g., battery temperature, SoC, battery design) that determine how much of the advertised power the car can actually receive?
6. Is there anything the driver can do to prepare the car or influence the situation so that it can receive more power?
 7. How does partial charging (e.g., from 30% to 60% several times a day) compare to a single charge from 10% to 80%? Is it practical for the driver, and does it reduce the total charging time? If so, by how much?
 8. What are the biggest challenges with preconditioning (e.g., time constraints, external temperature, increased energy consumption)? What risks or aspects should be considered if the driver is given the option to manually activate preconditioning?
 - Are current preconditioning features effective, or do they need improvement?
 9. When a professional driver needs to charge, what factors should be prioritized to minimize total charging time preconditioning, SoC, station load, or something else?
 10. What metrics (e.g., kW, kilometers added per minute, estimated time to next 10%) provide the most intuitive feedback so that drivers can determine whether it is "worth" waiting for more charging?
 11. What common misconceptions do drivers have about electric vehicles and charging?
 12. Is there anything unclear, misleading, or not explicitly shown in how electric vehicles present battery status? What additional battery data or metrics would be most helpful for drivers but may not be clearly displayed on current EV dashboards?
 13. To what extent can additional equipment in the car, such as GPS, card readers, or taxi meters, affect energy consumption and increase the need for charging?
 14. How much battery capacity is consumed during battery preconditioning?
 15. How does frequent DC charging (e.g., once per day) affect battery health, and are there factors that can change this impact, such as preconditioning before charging or the SoC level at which charging occurs?
 16. What technical challenges are the biggest obstacles to reducing EV charging times (e.g., battery lifespan)?
 17. Are there specific charging features designed to suit high-mileage drivers, such as taxi drivers?
 18. How does Volvo collect and analyze user data to improve charging efficiency and battery management?

E.5 Demographic Survey Expert Interviews

Questionnaire



Please answer the following about yourself

Profession (Job Title): _____

Industry Sector: _____

Years of Experience with EVs: _____

Figure E.1: Demographic Survey used for the pre-study expert, the feasibility expert, and the two technical experts

F

Volvo User Interface for Fast Charging: Survey

As part of a masters thesis at Chalmers University of Technology, we are conducting a study to explore the user needs of drivers who use battery electric vehicles (BEVs). This research focuses specifically on aspects related to charging, with the goal of enhancing user experience and improving overall efficiency. The purpose of this survey is to validate the findings from interviews conducted earlier in the study.

1. Important Information:

Your participation is completely voluntary. This survey is anonymous, and we do not collect any personal or identifying information. Your responses will be used solely for research purposes and will be presented in a summarized form in the thesis. You may withdraw at any time by closing the form. By clicking Yes, I consent below, you agree to participate in this survey.

Answer (required): *Yes, I consent*

2. Do you drive a Battery Electric Vehicle (BEV)?

Type: Single choice

Options: Yes / No

3. What model of BEV do you drive (e.g., XC40)?

Type: Short text

Answer: _____

4. How many years of experience do you have driving a BEV?

Type: Short text

Answer: _____

5. Are you located in Sweden?

Type: Single choice

Options: Yes / No

6. Have you experienced issues starting a charging session, requiring you to reconnect the cable or switch station?

Type: Single choice

Options: Yes / No

7. If yes, did the car provide an error message and was it descriptive enough?

Type: Single choice

Options:

- Yes, error message was descriptive enough
- Yes, but not descriptive enough
- No error message

8. **How strongly do you agree with this statement?**

Type: Likert scale (1-5)

9. **Have you ever received less kW capacity than expected when starting a charging session?**

Type: Single choice

Options: Yes / No

10. **If yes, did the car inform you of the reason why?**

Type: Single choice

Options: Yes / No

11. **Have you noticed that capacity (kW) changes during charging?**

Type: Single choice

Options: Yes / No

12. **Does the car inform you why the capacity (kW) fluctuates?**

Type: Single choice

Options: Yes / No

13. **Would it be beneficial to visualize the factors affecting capacity (kW) while charging?**

Type: Single choice

Options: Yes / No

14. **Is it easy to compare the time it will take to charge to different battery levels without excessive interaction?**

Type: Single choice

Options: Yes / No

15. **Is there an intuitive way to see how different factors (SoC, kW, etc.) interact and affect charging time?**

Type: Single choice

Options: Yes / No

16. **If no, would it be beneficial to have such visualization?**

Type: Single choice

Options: Yes / No

17. **When navigating to a charging station, do you receive enough information in the UI to choose the best station for your needs?**

Type: Single choice

Options: Yes / No / Occasionally

18. **Is any important information missing? If yes, what?**

Type: Short text

Answer: _____

19. Do you use external apps or tools to help choose a charging station? If so, which ones and what information do they provide?

Type: Short text

Answer: _____

20. Do you use the cars navigation to precondition the battery before charging?

Type: Single choice

Options: Yes / No / Occasionally

21. Have you ever needed to add intermediate stops before reaching the charging station?

Type: Single choice

Options: Yes / No

22. If yes, does the car inform you how it handles preconditioning in this case?

Type: Single choice

Options: Yes / No

G

Feasibility Study: Interview Questions (Original Language)

- Är det tekniskt möjligt att förutsäga vilken kW-nivå som förväntas vid olika SOC-nivåer under en laddsession?
 - Till exempel för att hjälpa användaren förstå hur effekten kommer förändras över tid beroende på SOC.
 - Tror du att det här skulle kunna vara värdefullt för användaren?
 - Finns det något som känns svårt att genomföra tekniskt, eller något vi borde tänka extra på?
 - Är det något du saknar eller tycker vi borde lägga till?
- Vilka är de viktigaste faktorerna som påverkar hur hög laddeffekten blir under laddning?
 - Är SOC, batteritemperatur och kupétemperatur, och batterihälsa de mest avgörande?
 - Kan man se hur stor påverkan varje faktor har på kapacitet mottagande?
 - Exempelvis en bil kan ta emot 300kW och laddar på en station med 300kW, men får endast 150kW är det möjligt att se vilka av dessa faktorer påverkar detta och i vilken utsträckning?
- Kan bilen känna av om laddstationen delas med ett annat fordon, och därmed förstå att minskad effekt beror på delad kapacitet?
- Finns det något användaren direkt kan göra under laddningen, förutom att stänga av klimatanläggningen, för att uppnå snabbare laddning?
- Hur mycket påverkar det laddhastigheten att ha klimatanläggningen på under laddning?
- Kan bilen känna av vilken maxeffekt en laddstation har, även om den inte tar emot full kapacitet (t.ex. p.g.a. bilens egna begränsningar eller stationens tillfälliga begränsningar)?

G.1 Feasibility Study: Interview Questions (English Translation)

- Is it technically possible to predict the expected kW level at different SoC levels during a charging session?
 - For example, to help the user understand how the power will change over time depending on SoC.
 - Do you think this could be valuable for the user?
 - Is there anything that seems technically difficult to implement, or anything we should pay extra attention to?
 - Is there anything you feel is missing or that we should add?
- What are the most important factors that affect the charging power during charging?
 - Are SoC, battery temperature, cabin temperature, and battery health the most critical?
 - Can the impact of each factor on charging capacity be quantified?
 - For example, if a car can receive 300 kW and is charging at a 300 kW station but only receives 150 kW, is it possible to see which of these factors are affecting this and to what extent?
- Can the car detect if the charging station is shared with another vehicle, and thus understand that reduced power is due to shared capacity?
- Is there anything the user can do during charging, besides turning off the climate control, to achieve faster charging?
- How much does having the climate control on during charging affect the charging speed?
- Can the car detect the maximum power output of a charging station, even if it is not receiving full capacity (e.g., due to the cars own limitations or temporary station limitations)?

H

Evaluation 1

H.1 Set-up

- Introduction
 - Introduce ourselves and the study (aim and process)
 - Introduce the focus group set-up
 - Ask participants to read/sign consent form and demographic survey
 - Ask participants to introduce themselves to each-other, to build trust and more comfortable atmosphere
- First impressions and open-ended questions (discussion)
 - Give participants some time to look at the view and then discuss:
 - * What do you think this screen is showing you?
 - * What can you do on this screen, if anything?
- Give context and context specific questions
 - Briefly explain what the view is showing or encourage them to read the context written down and ask participants to quietly write down answers to the following questions and SEQs (see H.2 for task questions and SEQs).
- Compare answers and discuss
 - Ask participants to compare and discuss answers, as well as discussing the view
 - Ask following questions when needed:
 - * What led you to that answer?
 - * Did anyone interpret it differently?
- Ask reflection questions if needed
 - What part of this screen was most helpful?
 - What, if anything, was confusing or unclear?
 - Is there anything you would change or improve?
- Repeat for all views (components)

- Conclude session and thank participants

Tips for moderators

- Encourage quieter participants to share
- Dont explain or correct too early, let confusion surface first
- Take notes on where participants stumble or misinterpret

H.2 Tasks

Task 1 Charging Target Slider

You are charging your car and the target goal is set, but now you want to increase the target goal and understand how much more time it will take.

1. What percentage is the charging target currently set to?
2. How long will it take to reach that charging target?
3. How does the charging power (kW) change at different percentage levels?
4. If you wanted to adjust your charging target, what would you do?
5. If you increased your charging target to 70%, how would that affect the time?

	1 Strongly Disagree	2 Disagree	3 Somewhat Disagree	4 Neutral	5 Somewhat Agree	6 Agree	7 Strongly Agree
This feature met my requirements							
The feature was easy to use							

Task 1.1 Charging Curve Visualisation

You are charging your car and the target goal is set and you want to understand how the kW is changing while charging.

1. How much power is currently being delivered?
2. What happens to the kW over time?
3. What is the difference between the straight line and dotted line?

	1 Strongly Disagree	2 Disagree	3 Somewhat Disagree	4 Neutral	5 Somewhat Agree	6 Agree	7 Strongly Agree
This feature met my requirements							
The feature was easy to use							

Task 2 Charging Capability

You havent started charging yet. Youre comparing stations and want to know how much power your car can currently receive and what might limit or improve that.

1. How much power can your car receive right now?
2. What is your cars maximum charging capability?
3. Why is the power lower than the max?
4. If you wanted to charge faster, what would you do?
5. How much improvement can you expect if you optimize and how long time would it take?

	1 Strongly Disagree	2 Disagree	3 Somewhat Disagree	4 Neutral	5 Somewhat Agree	6 Agree	7 Strongly Agree
This feature met my requirements							
The feature was easy to use							

Task 3 Charging Capacity

You have started charging at a station and want to know how much power youre getting, whats affecting it, and whether it can be improved.

1. What is your car currently receiving from the charging station?
2. What is your car currently capable of receiving?
3. Why is the current charging power lower than the car's capability?
4. If you changed to a different charger, would the power increase? Why/why not?
5. Which condition (battery temp, SoC, battery health) is limiting charging now?

	1 Strongly Disagree	2 Disagree	3 Somewhat Disagree	4 Neutral	5 Somewhat Agree	6 Agree	7 Strongly Agree
This feature met my requirements							
The feature was easy to use							

Task 4 Graph

Youre looking at more detailed data during a session. You want to see how kW and battery % change over time to decide how long to charge and when to stop, as well as when it is best to start charging for future charging.

1. How much kW do you currently have?
2. How much will you receive when you reach your target?

H. Evaluation 1

3. If you wanted to adjust your charging target, what would you do?
4. How much more time would it take to reach the new set target?
5. What info can you see when choosing a specific point during the charging?

	1 Strongly Disagree	2 Disagree	3 Somewhat Disagree	4 Neutral	5 Somewhat Agree	6 Agree	7 Strongly Agree
This feature met my requirements							
The feature was easy to use							

I

Evaluation 2

I.1 Set-up

- Introduction
 - Introduce ourselves and the study (aim and process)
 - Introduce the evaluation session set-up
 - Ask participants to read/sign consent form and demographic survey
- Conduct tasks
 - Ask participants to read the description on the paper and complete the task on the iPad (see I.2 for tasks).
- Ask participant to describe the view:
 - Task 1 (describe what info is shown on the view):
 - * How much kw could you receive if you charge?
 - * What is restricting you from receiving more?
 - Task 2 (describe what is happening):
 - * Do you see any changes on this view?
 - * What does the blue line on the button represent?
 - Task 3 (describe what info is shown on the view and what happened when you changed the target):
 - * How much more time does it take to charge to 80% compared to 50%?
 - * How much kw are you currently receiving?
 - * At what time will the charging be done?
 - Task 4 (describe what info is shown on the view):
 - * How much are you receiving from the station?
 - * How much kw could your car be receiving?
 - * What is restricting you?
 - Task 5 (describe what info is shown on the view):

- * What does the white line represent?
- * What does the green filled line represent?
- * How much is your current kw?
- Task 6:
 - * What was the max kw?
 - * What % did you have during the max kw output?
- Ask reflection question if needed after each view:
 - What if anything would you change about this screen or improve?
- SEQ questionnaire (see I.2 for SEQ Questionnaire)
 - After each task ask participant to answer the task specific SEQ
 - After each view ask participants to answer the view specific SEQs
- Conclude session and thank participant

I.2 Tasks

Task 1

Scenario: Your battery is low and you're planning to charge soon. Before choosing a charging station, you want to see how much power your car can accept. Please navigate to the Capacity page.

Evaluation:

	1 Strongly Disagree	2 Disagree	3 Somewhat Disagree	4 Neutral	5 Somewhat Agree	6 Agree	7 Strongly Agree
This task was easy to complete							

Task 2

Scenario: There is a station near you and you want the car to be able to receive 300kW when you start charging. Please take action to make this possible.

Evaluation:

	1 Strongly Disagree	2 Disagree	3 Somewhat Disagree	4 Neutral	5 Somewhat Agree	6 Agree	7 Strongly Agree
This task was easy to complete							
This feature met my requirements							
The feature was easy to use							

Task 3

Scenario: Congrats! You drove to the charging station and started charging, however after some time charging, you remembered that your charging target was set to 50%. You want to change your charging target to 80%, navigate to the charging view and do this.

Evaluation:

	1 Strongly Disagree	2 Disagree	3 Somewhat Disagree	4 Neutral	5 Somewhat Agree	6 Agree	7 Strongly Agree
This task was easy to complete							
This feature met my requirements							
The feature was easy to use							

Task 4

Scenario: You see on the graph that you never received more than 200kW since the start of the session even though you optimized the battery to receive 300kW. Navigate to the Capacity page to see why.

Evaluation:

	1 Strongly Disagree	2 Disagree	3 Somewhat Disagree	4 Neutral	5 Somewhat Agree	6 Agree	7 Strongly Agree
This task was easy to complete							
This feature met my requirements							
The feature was easy to use							

Task 5

Scenario: You now know why and want to navigate back to the charging view with the graph. You look at the graph but you are not satisfied and want to see a more detailed version of the graph. Please navigate to the detailed graph view.

Evaluation:

	1 Strongly Disagree	2 Disagree	3 Somewhat Disagree	4 Neutral	5 Somewhat Agree	6 Agree	7 Strongly Agree
This task was easy to complete							

Task 6

Scenario: You want to know how much the max kW you received during this session was. Please take action to see this.

Evaluation: Evaluation:

I. Evaluation 2

	1 Strongly Disagree	2 Disagree	3 Somewhat Disagree	4 Neutral	5 Somewhat Agree	6 Agree	7 Strongly Agree
This task was easy to complete							
This feature met my requirements							
The feature was easy to use							

J

Demographic Questionnaire for Evaluation 1 and 2

Demographics Survey

Kindly fill in the questions



Age: _____

Gender: Male Female Other

Highest level of education attained: Elementary School HighSchool University

Years of experience driving an BEV: _____

How often do you fast charge your car?

- Never
- Rarely (a few times a year)
- Occasionally (once a month)
- Regularly (a few times a month)
- Frequently (once a week or more)
- Always (every time I charge)

Car model you currently drive: _____

Profession: _____

Figure J.1: Demographic Questionnaire Evaluations

K

Evaluation 3

Goal: Identify both constraints and opportunities from the charging function owner's perspective, focusing on the feasibility, usability, and alignment of the prototype with real-world systems and user workflows.

Explain the task and let experts provide real-time feedback (think-aloud); thereafter, if needed, ask heuristic questions and request additional suggestions.

Flow 1: Power Status and Optimization (View 1-2)

Task 1: Check how much power the car can receive

- **Visibility of System Status:** Is the power the car can receive (e.g., 150/300 kW) clearly visible?
- **Match Between System and the Real World:** Are the terms and units (e.g., kW, percentage) familiar to a BEV driver? Do the labels make sense in a real-world charging context?
- **Error Prevention:** Is there a mechanism that prevents the user from unknowingly entering a low-power situation?

Task 2: Optimize the power reception

- **User Control and Freedom:** Can you easily cancel the optimization or go back if you change your mind?
- **Consistency and Standards:** Does the design of the Optimize button follow common conventions in terms of appearance and behavior?
- **Error Prevention:** Is there any risk of making an accidental change when clicking the 'Optimize' button? Should there be any confirmation?
- **Visibility of System Status:** Once you click 'Optimize', does the UI provide clear feedback that the optimization has started? Is the system status communicated effectively?

Flow 2: Charging Target (View 3-4)

Task 3: Change the charging target from 50% to 80%

- **Match Between System and the Real World:** Is the language for setting the charging target clear and understandable? Does it align with user expectations?

- **Recognition Rather Than Recall:** Are all necessary details (current charge, target, etc.) visible on the page?
- **Flexibility and Efficiency of Use:** Can experienced users adjust the target quickly? Are there shortcuts or presets?
- **Aesthetic and Minimalist Design:** Is the screen simple, with no unnecessary elements? Is the process straightforward?

Task 4: Investigate why user is only receiving 200 kW

- **Help Users Recognize, Diagnose, and Recover from Errors:** Is it clear why the power is limited? Are there hints or guidance to resolve the issue?
- **Error Prevention:** Does the system offer warnings or preventative messages that help users avoid or resolve low power situations?

Flow 3: Detailed Graph (View 5)

Task 5: Navigate to the detailed graph

- **Visibility of System Status:** Is the graph easily accessible? Is it clear what the data represents?
- **Recognition Rather Than Recall:** Is the graph intuitive without relying on memory from earlier screens?

Task 6: Look for warning message on the graph

- **Help Users Recognize, Diagnose, and Recover from Errors:** Are warning/error messages clearly indicated and easy to understand?
- **Consistency and Standards:** Are warning/error messages formatted consistently across views?
- **Error Prevention:** Do error messages help prevent future mistakes?

Extra: Preconditioning Notification (View 6)

Task 7: Optimize and reopen notification to check status

- **General Feedback:** What are your thoughts on this new component?

Holistic Evaluation (After All Tasks - if needed and within time constraints)

- **Visibility of System Status:** Were you always informed about the systems state?
- **Match Between System and the Real World:** Did the terminology feel familiar and realistic?
- **User Control and Freedom:** Could you go back or change actions freely?
- **Consistency and Standards:** Was the design coherent throughout?

- **Help and Documentation:** Was there any help or explanations to understand specific features or behaviors when needed, and was this easy to find?