CHALMERS
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HMI for Wireless Charging

A Development of a Human Machine Interface for the Alignment when Charging an Electric Car Wirelessly

Master's thesis in Product Development

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Department of Industrial and Materials Science
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2017

Master's thesis 2017:1

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Abstract

Wireless charging is an alternative to plug-in charging, where no cord is needed. The technology uses electromagnetic fields between a primary and a secondary coil to transfer power to the car. In order to initiate a high level of efficiency of the charging process, the car needs to be positioned so the coils are over each other. However, the critical part is to ensure a good positioning though the tolerances are low. To solve this, a good human-machine interface (HMI) is needed to inform the driver how to position the car and to make it as convenient as possible for the driver. This thesis is therefore aimed at developing a HMI for easier positioning of the car when parking for wireless charging.

The thesis project commenced with a market investigation to get an understanding of the technology and the stakeholders. Thereafter, an identification of user needs was carried out to understand why the alignment is a problem for the user and what is needed in order to help the driver. Concepts were further generated and evaluated until several functions were set to be the basis of the interface.

The final design for the interface is placed in the Driver Information Module (DIM) where a view of the car from behind is displayed in the middle with a pathway showing how to align the car. When turning the steering wheel, the user can see the exact direction displayed in front of the visualised car and indication of being right or wrong is visualised with colours. When driving closer to the charging pad, the perspective of the car changes to see the charging pad relative to the required position in order to start the charging process.

Keywords: electric car, wireless, charging, inductive, positioning, alignment, HMI, human machine interface

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We would like to extend our appreciations to the department of Electric Propulsion Systems at CEVT where everyone have been very curious about our work and helped us with contacts, ideas and expertise. A special thanks to our supervisor Alexander Berggren, who helped us with support and tips throughout the project, and our manager Johan Ekbäck, who inspired us to be creative in our process. We would also like to thank the HMI department at CEVT, especially Agnieszka Szymaszek and Josef Larsen who took their time to discuss our findings and contributed with feedback and inspiration.

We truly appreciate all the feedback we got from our test persons who helped us realise the issue with aligning the car as well as all the inspiration you gave us.

Last but not least, we want to thank our lovely classmates, you know how you are, that have been engaging in our project.

Lisa Magnusson & Frida Tjus, Gothenburg, June 2017

List of Abbreviations

AR - Augmented Reality

CSD - Centre Stack Display

DIM - Driver Information Model

EV - Electric Vehicle

FOD - Foreign Object Detection

GA - Ground Assembly

HEV - Hybrid Electric Vehicle

HMI - Human-Machine Interface

HUD - Head Up Display

LOP - Living Object Protection

LPE - Low Power Excitation

MV - Magnetic Vector

OEM - Original Equipment Manufacturer

VA - Vehicle Assembly

WPT - Wireless Power Transfer

Contents

List of Figures

List of Tables

1
Introduction

This master's thesis is a collaboration between the writers and China Euro Vehicle Technology AB with the aim to develop a human-machine interface (HMI) for aligning the car in order to charge the car wirelessly. This chapter includes the background of the project, purpose, aim, goal, scope, as well as an outline of the report.

1.1 Background

The market for electric vehicles (EV's) is emerging where the interest is higher than ever before (Office of Energy Efficiency & Renewable Energy, 2016). The global activity concerning EV's is increasing due to the strive of reducing greenhouse gases (NASA, 2016) as well as car batteries are getting more efficient than before (Harrop & Ghaffarzadeh, 2016). The EV's on the market are today charged with a cord that is plugged into the car. The negative aspects with the cord is that it reacts badly to altering weather and air temperatures, as well as if forgetting to plug-in; the car will be powerless. (Birrell et. al, 2015)

Wireless charging is an alternative to plug-in charging. The technology uses electromagnetic fields between a primary and a secondary coil to power the car. This is initiated by parking the car in a specific position (aligning the car coil above the ground coil). However, the critical part is to ensure good positioning of the primary and secondary coil. Since tolerances are narrow, it is hard to achieve the correct position when aligning the car. To solve this, a good HMI is needed to inform the driver how to position the car and make it as easy as possible for the driver.

The thesis project is initiated by China Euro Vehicle Technology AB, CEVT, which is a development centre for future mobility of the Geely Group. CEVT covers all aspects of passenger car development – from the total architecture, powertrain and driveline components, to top hat engineering as well as the vehicle's exterior design.

1.2 Purpose and Aim

The purpose with this thesis project is to understand what usage needs that are necessary to be able to align a car in a specific position when parking manually, initiating charging of a car wirelessly. Relevant to the project is also to investigate how this task can be made convenient and with the aspect that *"It should be fun to charge your car"*.

The aim of this thesis project is to develop a human-machine interface (HMI) concept for easier positioning of the car when parking for wireless charging.

1.3 Goal

The goal with the thesis project is to use all gathered knowledge from the master's programme *Product Development* in a real environment. The final solution will be made in written descriptions and graphical visualisations, such as images and motion graphics.

1.4 Scope

The scope for the thesis sets the boundaries for the project and are stated below:

- The primary coil is placed above ground.
- The secondary coil is placed in the front part of the car.
- The solution should be integrated in the car.
- The solution should be focused on manual parking.
- Only the functions and graphics are considered in the solution.
- The project will take standard SAE J2954 into account
- The solution will not be designed for public suppliers

1.5 Report Outline

Chapter 1 - Introduction
The introduction to the report is presented with the background, purpose, aim and goal. The scope is also defined to set the framework for the project.

Chapter 2 - Wireless Charging
This chapter explains how wireless charging works and the most important aspects with the positioning. The technology systems regarding wireless charging are also presented.

Chapter 3 - Theoretical Framework
The theoretical search is focused on the definition of convenience. The framework also consists of cognitive ergonomics and what to consider when developing HMI for cars.

Chapter 4 - Process and Methods
The process for the project is described and applied methods are presented in this chapter, as well as how they have been interpreted.

Chapter 5 - Needs Identification
The overall needs are identified in this chapter through investigating how the surrounding elements affects the future solution and how the solution should affect the surroundings, as well as what the user values in a solution. The chapter covers a market investigation, technology and competitor analysis resulting in needs and an initial ideation.

Chapter 6 - Usage Design
The chapter involves the investigation of what needs there are for the user and the intended effects, and to examine the overall solutions that meet the usage needs. The chapter covers usability tests, observations and interviews to understand the usage needs.

Chapter 7 - Overall Design
Overall Design includes the investigation of which elements of the interface that gives a certain result and the investigation of how the interaction between human and machine should be designed. A large amount of concepts are here generated and evaluated.

Chapter 8 - Detailed Design
The chapter involves the stages to decide the final solution and how it should be visualised. The different visualisations are evaluated and a final decision is made. An error analysis is made to investigate necessary functions needed for the final design.

Chapter 9 - Final Results
The final design is presented in this chapter with all functions explained and visualised. A verification is included to see how the designs usability is performing.

Chapter 10 - Discussion
In this chapter, the project and the process are discussed with relevant topics. The final solution is discussed and recommendations for continuous work are stated.

Chapter 11 - Conclusions
The overall results and findings in the project are in this chapter concluded.

2

Wireless Charging

Wireless charging is a technology that uses electromagnetic fields to transfer the electricity from the power supply to the vehicle. The wireless power transfer (WPT) is feasible through a two-part gapped core transformer, consisting of a primary and a secondary coil that are separated from each other. Wireless charging is possible for electrical vehicles (EVs) and hybrid electric vehicle (PEVs) for a more convenient alternative compared to a plug-in cable charging. Figure 2.1 below illustrates the process of the WPT. The primary coil is installed in a ground assembly (GA) and the secondary coil is placed in a vehicle assembly (VA).

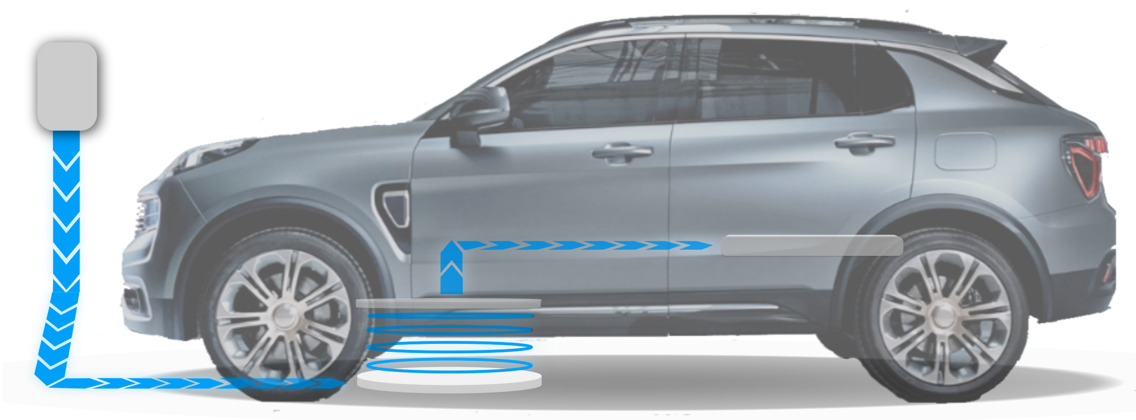


Figure 2.1: The process of wireless charging.

To initiate the charging and to get an as efficient transfer as possible, it is crucial that the VA is aligned correctly over the GA. However, the charging system allows tolerances due to expected misalignments caused by the driver. The maximum tolerance in the XY plane is set to when both X and Y maximum tolerance are reached. (SAE J2954). In figure 2.2 below, the car with the XY plane and placement of the GA are visualised. In table 2.1, the tolerances are listed.

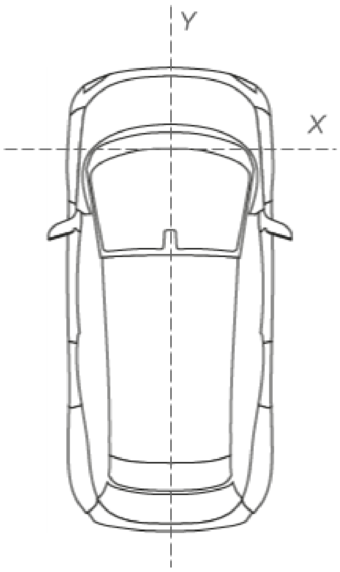


Figure 2.2: The XY plane where (0,0) for the GA is in its centre and (0,0) for the VA is in its centre as well.

Table 2.1: Tolerances for misalignment

Offset direction	**Value [mm]**
ΔX	± 75
ΔY	± 100

2.1 Alignment

Wireless charging of an EV needs a number of communication channels to support the charging and the safety of the surrounding environment. This means that the GA and the VA needs to communicate with each other to accomplish the tasks required, furthermore this communication needs to be wireless. A crucial part of this is, as mentioned above, that the VA is correctly positioned above the GA. A guidance method is therefore needed to assist the driver and the vehicle to navigate into the specific position. (SAE J2954)

2.1.1 Methods of alignment systems

SAE J2954 stresses that there is a need for a standardised method to allow any kind of vehicle with a SAE J2954 VA to be able to align the vehicle to any GA with SAE J2954 standard. Different vehicle OEMs were surveyed to determine which alignment methods to be standardised, where two methods were chosen: Magnetic Field Alignment using existing WPT coils and Magnetic Field Alignment using auxiliary coils.

Low Power Excitation - Magnetic Field Alignment using existing WPT coils (LPE)
Magnetic Field Alignment using existing WPT coils was the first method to use as alignment method. The primary coil in the GA emits a small magnetic field that can be traced by the VA in the vehicle, which can be translated to an alignment guide by the vehicle. (SAE J2954) LPE is functional within approximately 1 m.

Magnetic Vector – Magnetic Field Alignment using auxiliary coils (MV)
The second method in the standardisation is using auxiliary coils for the magnetic field alignment. The difference between the first method is that MV uses another separate magnetic coil system to produce the magnetic field than the coil system that is used for the electricity transfer. The magnetic field used in this method is produced in the secondary coil, i.e. in the VA, and received in the primary coil, i.e. in the GA. The magnetic field is generated by two coils in two axis directions, orthogonal and horizontal, in different frequencies. The GA senses the magnetic signal using three sense coils, where they broadcast a magnetic multi-tone signal in three orthogonal axis directions. (SAE J2954) MV is functional within approximately 5 m.

2.2 Safety Systems

Wireless charging of EVs have two safety systems: foreign object detection and living object protection. These systems ensure that no exposure when charging the car can cause a fire of foreign objects or harm a living object (Mallinson, 2015). When one of these systems detect an object, the wireless charging transfer cannot start or if already started - it is automatically turned off.

Foreign Object Detection (FOD)
Metallic and magnetic objects are a safety hazard for wireless charging of EVs, where the objects get excessive heated when being affected by the WPT magnetic field if being placed between the GA and VA. The objects can vary from small objects, such as coins, to larger objects, such as a soda can. If flammable material is present as well, a fire can be caused by the heated material. (Mallinson, 2015)

Living Object Protection (LOP)
The magnetic and electrical field exposure to humans and animals from the wireless charging of the EV can cause health effects, or sudden IMDs (immune system's ability to fight diseases is compromised or absent). It is therefore important that a LOP system is present and that the WPT automatically turns off when sensing a living object. (Mallinson, 2015)

3
Theoretical Framework

The theoretical framework forms a basis of knowledge and theory required in order to develop a HMI for wireless charging. The framework consists of the definition and meaning of convenience to understand what is needed to develop a convenient product. Cognitive ergonomic is also explained to understand how the human process information and the potential errors that can arise. Finally, guidelines for an interface are listed as well as classification of the vehicle's interfaces.

3.1 Convenience

In chapter 1, it is argued that the solution should be convenient and pleasurable for the user. But what does it mean for a product to be addressed in these terms? In this section, convenience and pleasure with products are discussed and what it means in terms of developing a product or a service.

Convenience is defined as *"anything that saves or simplifies work, adds to one's ease or comfort"*, *"freedom from discomfort"*, *"a quality or situation that makes something easy or useful for someone by reducing the amount of work or time required to do something"* according to Merriam Webster dictionary (2017). Regarding pleasure with products, Jordan (1999) defines pleasure as *"The emotional, hedonic and practical benefits associated with products"*, where the practical benefits are explained as the benefits that arise from the outcomes of the tasks when using the product. The benefits related to the emotional perspective are the ones that concern to how the user's mood is affected when using the product. The hedonic benefits concern the sensory and aesthetics pleasures related to the use of the product. Convenience in this definition is here both regarding the practical benefits of saving time and simplifies work, as well as the emotional benefits of feeling free from discomfort.

Plato early defined pleasure as the absence of pain and is today still the term. Blythe and Wright (2005) means that the absence of pain thinking of enjoyment *"can be thought of as a standard usability approach to pleasure; if an application does not frustrate the user then it is more likely that using it will be enjoyable"*. The emotional, hedonic and practical benefits can be usability tested to see if the product frustrates the user. ISO 9241-11 defines usability as *"the effectiveness, efficiency and satisfaction with which a product is used"*. If the usability of the product is good, the user will also feel pleasure. However, Overbeeke et. al (2005) argue that users search for an experience rather than a product as where the designer needs to create a context for this experience. Taking usability to a further level than just ‘easy to use’, Overbeeke et. al means that creating the context for experience and the aesthetics of interaction brings out the functions that give the user pleasure of the experience.

3.2 Cognitive Ergonomics

Cognition is the basic mechanism of how people perceive, think and remember information. Understanding the human cognitive skills and limitations is a need when designing for humans. (Bruneau et. al, 2004). The human machine system, figure 3.1, shows the relationship between the human and the machine. The focus in this section is how the human receive information with senses and perceive the information. Human errors are also investigated, where the origin and avoidance are central.

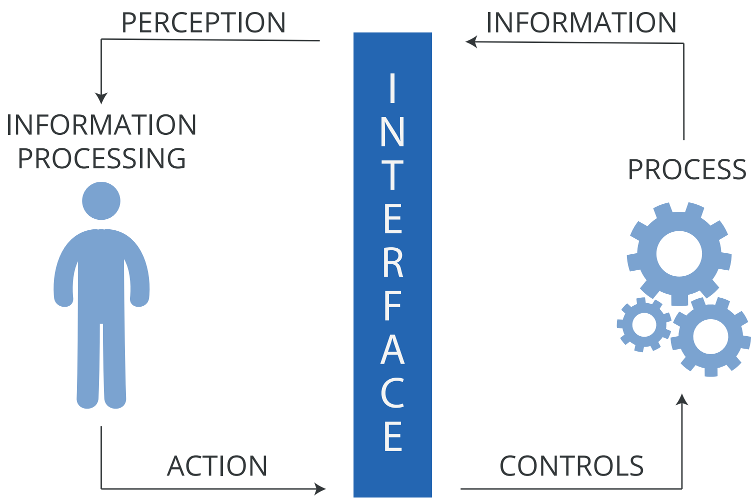


Figure 3.1: The human machine interaction system.

3.2.1 Information Processing

By considering the human as a ‘black box’, the information process and the human cognitive abilities can be analysed. In figure 3.2, the information process is visualised with input and output. The input is how the information is captured, which is done with a sensation. The input is further perceived, which requires the human to pay attention to the information. The gathered information is then processed and relocated or stored in the memory. Finally, the output results with an action.(Bruneau et. al, 2004).

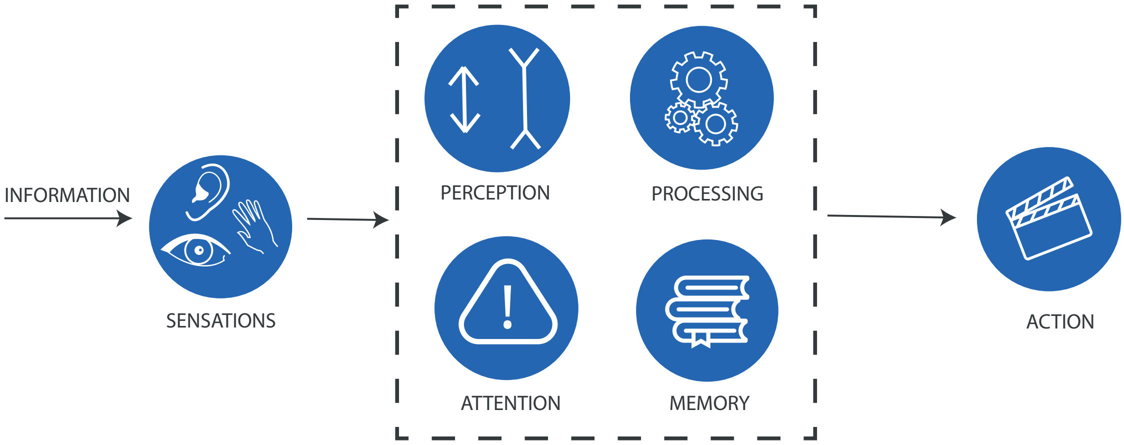


Figure 3.2: Information processing as a 'black box'.

Sensations
The information given to the human is received with sensations. The sensory system is divided into vision, audition, gustation (taste), olfaction (smell), and haptic. The sensations are classified into two groups; exteroceptors, that receive information, and interoceptors, which alert individual status. Together the groups are referred to as the sensory register, where the senses receive information and send responses. Vision is the most dominant of all the sensors. (Bruneau et. al, 2004). When designing with vision in mind - size, colour, lighting, contrast and angle of gaze should be considered. The audition is complementary to vision and is the best way to attract attention. Design factors for audition are direction and location of the sound, loudness, and pitch. The haptic sensory can complement other sensors, and can be used when the other sensors are occupied. When designing with haptic sensors in mind - using form, weight, size, force, and surface structure are important. (Simonsen, 2014).

Perception
The information given needs to be perceived. The human takes up information depending on how sensory inputs are interpreted, processed and organised. Visual perception is the biggest channel and stands for 80 percent of the given information. The visual perception have three main theories where the first is the *gestalt theory*. When the human sees something, it searches for the best fit with the stored knowledge of objects. A failure that could occur is expectation; where the human expects something to be in some way based on stored knowledge. The second theory is the *direct perception*; where the visual information tells sufficient clues to determine what object it is, its position and its movement. Usually, the human vision is accurate, although perception errors can occur known as illusions. The third theory is the *depth and distance* perception. Perception errors in this theory may arise from variation in contrast and motion. For example, when sitting in a stationary vehicle and the vehicle next to you is moving may cause an illusion that your vehicle is moving instead. (Bruneau et. al, 2004). When designing with perception in mind, the context is very important to consider, due to the effects the interpretation of the information gives. (Simonsen, 2014)

Attention

Attention screens out the input of information that is relevant. By doing a direct screening, the attention is focused to the stimuli of interest, consequently avoiding an overload of senses where irrelevant information can be neglected. Visual attention is controlled through physical orientation where the eyes move constantly to sort out the important information. The filtering of the audio attention is done mentally and is thereby more difficult to sort due to the ears ability to take in sound from all directions in the audio spectrum. The sensors receive information all the time and the ability of performing multiple tasks at the same time depends on if the attention required for the tasks interfere with each other. Driving a car and having a conversation is easy, on the other hand having a conversation and writing a letter is hard. In order to execute multiple tasks similarity, difficulty and practice need to be considered. Another design guide is to include features that help direct the attention to where it is needed. (Bruneau et. al, 2004).

Memory

The memory of a human's mind is divided into short-term and long-term memory. The short-term memory has a limit of storing information where five to nine items can be stored for a limited amount of time. During a process, information is stored in the short-term memory and after a sufficient amount of time the information either gets discarded or transferred to the long-term memory. The long-term memory has endless capacity. However, the long-term memory quality depends on how the knowledge is organised and how the information is mentally represented. (Bruneau et. al, 2004).

Higher Order Processing

The processed information that have been stored needs to be understood. In higher order processing, the stored information is processed to meaningful concepts. One of the mental process is thinking which is used in our daily life and is used to make decisions, actions and also form our beliefs. Thinking is part of the processing and is used for problem solving based on three objects; searching for possibilities, evidence and goals. (Bruneau et. al, 2004).

Action

The final step of information processing is action. How the human reacts to its environment is based on different levels of consciousness. Firstly, there are actions with no active awareness, like reflexes and routine actions e.g. opening a door. Secondly, there are actions controlled by routines, experiences and rules, as well as actions based on active thinking. These different types of actions can operate at the same time and create activities based on different decisions and responses. (Carswell & Wickens, 2012).

3.2.2 Human Error

There are various causes where information processing can go wrong and errors may occur. Errors created by the human is a consequence and cause of a non-functional human machine system. In order to avoid the errors to occur, it is important to understand the reasons behind the errors.

Failures that are unintentional and arise in the execution stage are behavioural errors and are defined as slips and lapses. Slips are failures in the thinking process where errors occur in the execution of a task that normally requires little conscious effort. Lapses are failures that occur because of failure in the memory, temporary failure of judgement, or concentration failure. Failures that occur because of unintended action arise in the performance level and are defined as skill-based, rule-based, and knowledge-based errors. Skill-based errors are unconscious and occur during routine tasks where they are caused by misplaced attention or inattention. Rule-based errors occur in familiar and recognised situations. Knowledge-based errors are caused by bad problem solving or no sufficient knowledge for the expected task. (Dekker, 2004)

In order to avoid errors, the design should be created to prevent and reduce errors. The design should also, as much as possible, limit the error consequence, and provide recovery solutions.(Cacciabue et. al, 2002)

3.3 Interface

In the human machine system, see figure 3.1, the interface is a bridge in the system and stands for the interactions between the user and the machine and can be seen as a tool for communication (Macredie & Coughlan, 2004). In order to create a useful interface, different design principles are needed, as well as typical classifications for the vehicle interface.

3.3.1 Interface Design Principles

The focus should be on the user when designing an interface. The design needs to help the user and by collaborating with the user during the development it will result in a usable design (Macredie & Coughlan, 2004). To create a usable interface, it should be designed to match the user's skills, experiences and expectations. In order to create this, there are various design principles that should be considered together. In table 3.1, the design principles are listed together with design guidelines, according to Macredie and Coughlan (2004).

Table 3.1: Design principles

PRINCIPLE	DEFINITION	GUIDELINE	EXAMPLE
CONSTRAINTS	*Constraints based on object properties*	*Use objects properties to inform the user what they can and cannot do*	*A button can be pushed in and out*
MAPPING	*Relationship between different things*	*Clear and obvious*	*The scroll wheel on a mouse and the scroll bar can be used to scroll up and down*
VISABILITY	*Providing the user with obvious information*	*Obvious, usually visual. Use feedback and clues*	*Feedback and clues to tell the user if the action is correct*
CONSISTENCY	*The system work in the same way at all time*	*Consistent design*	*Same button stay on the same place*
EXPERIENCE	*Users existing knowledge*	*Consider what the user already know*	*User is familiar with standard interface objects*
AFFORDANCE	*Obvious knowledge for all users*	*Consider what is obvious*	*A button should be pressed, a chair is used to sit on*
SIMPLICITY	*The task should be as simple as possible*	*Keeping it simple in the design process*	

3.3.2 Vehicle Interface

The vehicle's interface consists of a variety of components and functions. The components are classified into primary and secondary components, based on the relevance and location. The primary components purpose is for the driver to control the car and simultaneously use during the drive. The secondary components are used to control other functions, such as heat, music etc (Gáspár et. al, 2014). In figure 3.3, the LYNK & CO dashboard is visualised with the control clusters and displays. The primary components are visualised with pink and secondary components with blue.

Figure 3.3: Information classification. Pink for primary components and blue for secondary components. Retrieved 2017-03-09 from: www.lynkco.com

The primary components inputs consist, e.g. of the steering wheel and the pedals. The primary output is the information from the instrument cluster in front of the driver, that informs the driver of the driving situation and also a detailed vehicle status (Gáspár et. al, 2014). The instrument cluster behind the steering wheel is defined as the Driver Information Model (DIM) and consists of displays with e.g. speed and fuel information. Information can also be projected onto the windshield and is defined as the Head Up Display (HUD). The HUD enables the user to have the head in a straight position, and therefore reduces the eye-of-road time. The disadvantages with the HUD are e.g. the blockage of the view, disturbance for the driver, that it is not visible due to sunlight, or similar circumstances (Bhise, 2011). The secondary components are used to operate the comfort and infotainment functions. Common is to have a menu with a touchscreen creating a wide range of settings (Gáspár et. al, 2014). The secondary components are often placed at the centre console defined as the Centre Stack Display (CSD).

The control system should not disturb the driving, and when designing the vehicle interface, four different guidelines can be considered; the eye glance time should be as short as possible in order to control the vehicle, control actions with finger and hand movements should be minimal, huge body movement, such as reaching over, or head and torso movement, should also be avoided, and the driver should be able to keep the eyes on the road and the hands on the wheel. Finally, the driver should be able to operate the car with as low mental and physical effort as possible. (Bhise, 2011)

4

Process and Methods

The methodology for this project follows the ACD^3 process. ACD^3 is a framework that aims to provide a clear structure for a development process. ACD^3 visualises the design decisions, although not so strict that it can inhibit the innovation. (Bligård, 2017) The process is developed in such a way that it highlights the activity and usability of the design, which is an advantage for this project since it focuses on user experience and development of a usable device.

With alterations of the ACD^3 process, this project's procedure is visualised in figure 4.1. There are four design levels: needs identification, usage design, overall design, and detail design, that will be considered in this project due to their extent and scope, visualised vertical in the figure. Further, there are four design perspectives; effect, usability, architecture, and interaction. The design perspectives are gathered in the top row in the figure. The grey forms represent the focus for each design level in the process phase. The work distribution for the various design levels overlap each other. However, the structure in this report will present the design levels in chronological order.

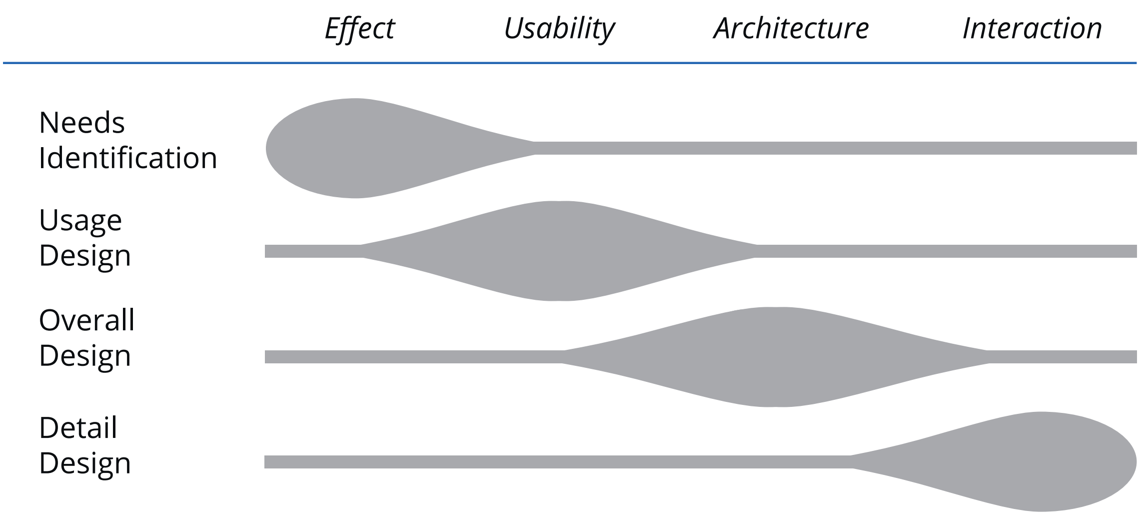


Figure 4.1: Schematic distribution of work within the design levels for each phase of the process.

In each design level, an iterative process is carried out, visualised in figure 4.2. The iterative process contains of five steps; planning, collection and analysis of data, idea generation, and evaluation. Firstly, the planning is made to understand what must be done, then data collection with analysis is carried out to set a base for the development. Thereafter, ideas are generated, and finally the findings are evaluated. Continuously throughout the process, everything is documented to gather knowledge.

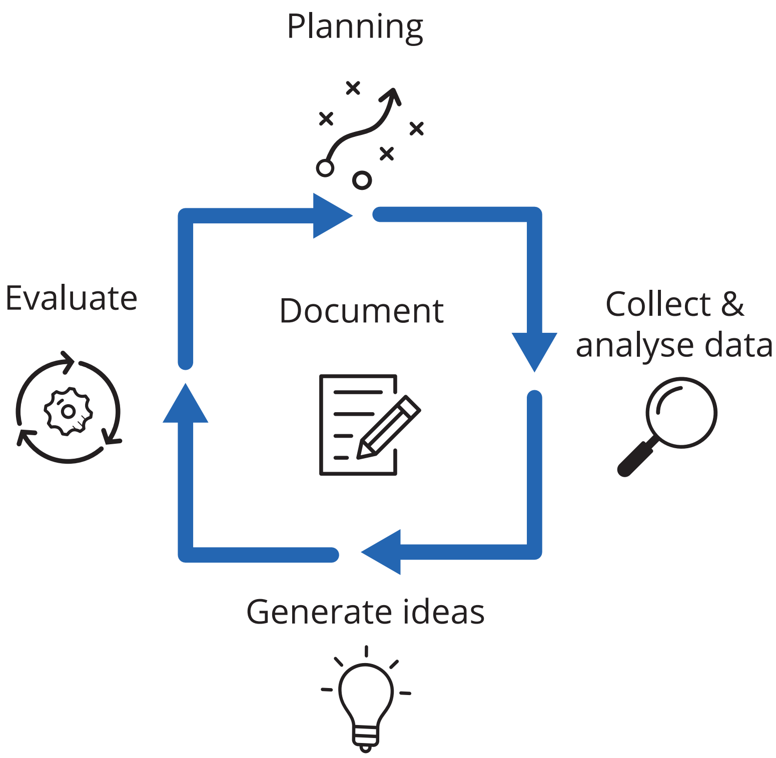


Figure 4.2: The iterative process for each phase.

In the following sections, the design levels; need identification, usage design, overall design and detail design are presented with their various methods used for each level. The final design is also presented with its methods.

4.1 Needs Identification

In this step, the problems, user segment, usage of existing equipment, and solutions are investigated and described. The design perspective's effect and usability are stated in the beginning to understand the main problem. Firstly, personas are created to understand the user segment. A benchmark analysis is executed to examine existing solutions. Further on, a SWOT and a PESTLE analysis are carried out to explore and develop the needs of the market, trademark, and production. The findings in the needs identification are gathered in a roadmap.

4.1.1 Personas

Personas are created to get a reliable and realistic description of the indented user segment. (U.S. Department of Health & Human Services, 2017) Nielsen (2017), argues that having different personas in a product development process helps the design team to maintain the perspective of the users. By always picturing possible concepts being used by the personas, new perspectives can be found and emerged. Nielsen explains the purpose of the personas as *"the ability to imagine the product together with the user"*.

Four different personas were created for this project, with alignment towards LYNK & CO's market segment. The personas have different needs and usage of the car to cover the different aspects of the user segment. By creating the personas, they were thought of during the whole process to keep in mind who the solution is developed for.

4.1.2 Benchmarking

A benchmark is defined as a reference which can be used to compare similar products (Bohgard, et. al, 2009) Kearns (Executive Officer, Xerox) argues that *"Benchmarking is the continuous process of measuring products, services, and practises against the toughest competitors or those recognised as industry leaders."*

In the needs identification, it is important to encompass what type of competitive existing products with the same functionality similar to the indented product are available. According to Eppinger and Ulrich (2012), this is critical to successfully position the new solution as well as it provides a spectre of ideas for the process. Another benefit is that strengths and weaknesses are revealed of the competition.

Existing solutions on market were identified in the benchmark, making it possible to analyse and understand how competitors solve the problem today.

4.1.3 SWOT

A SWOT analysis is a method to investigate internal factors; strength and weaknesses, and examine upcoming external factors; opportunities and threats. (Law, 2016) The SWOT analysis provides an awareness of important factors needed for a decision. This is useful for making new decisions, exploring and identifying new areas, or refining and improving existing business areas. The SWOT helps organisations to understand positive and negative elements to develop strategies, actions or initiatives. To create a SWOT, the four elements; strengths, weaknesses, opportunities and threats are listed. The first two internal factors depend on physical-, human-, and natural resources, but also the current process. The external factors are depending on the surrounding environment and areas the company cannot control. (Fallon Taylor, 2017)

The SWOT analysis was carried out by listing the internal factors by investigating the current product and examining the existing market. A conclusion was made what the product should cover and what can be problematic. The external factors were investigated with a PESTLE analysis. (Doyle, 2016) This was made by examining the political-, economical-, social-, technical-, legal-, and environmental market for wireless charging.

4.1.4 Roadmapping

Roadmapping is a technique used to plan strategic and long-range decisions. Roadmaps are often graphical visualised and provides a structure for exploring and communicating the relation between evolving markets, products and technologies over time. Roadmaps can help to scan the environment and therefore contribute with a focus, stating what the company should develop now in time and a vision for the future. (Farruk. et Al, 2003)

The roadmap was made to understand in which time span and market the solution should be developed for, as well as when other technologies will emerge.

4.2 Usage Design

The usage design step involves the understanding of the needs that are necessary to start designing the solution. Design perspectives that are studied are effect, usability and architecture. In this step, usability tests have been made to get a clearer view of what is needed from the HMI solution in a user centred aspect. The usability test was focused on how the driver experience the positioning of the car.

4.2.1 Expert Interviews

A previous study about wireless charging have been made by RISE (Research Institutes of Sweden) and to get a deeper understanding about their research, two interviews were held. The interviews were made unstructured since there were little information of what the interviewees had knowledge about. A unstructured interview is more flexible and the questions posed can be adjusted after the the answer's received from the respondent. (McQuirre, 2016)

The first interviewee was with Göteborg Stads Leasing AB that have had several cars in the city's carpool equipped with Plugless wireless system. The purpose of this interview was to get a closer insight of the test persons experiences. The second interviewee has held with RISE to discuss how the research project was carried out and what the researchers themselves found interesting.

4.2.2 Usability Test

A usability test is used to gather information from where a user interacts with a product and carrying out relevant tasks. (Nielsen, 1993) The usability of the product is evaluated in a user test where different types of areas can be investigated, such as effectiveness, efficiency and satisfaction of the product or scenario. A normal group of test subjects are 6-8 persons from the user segment, where a guideline is that 75-80 % of all occurring user problems arise within a group of 5-6 test subjects. (Karlsson et. al, 2009)

The user test was executed in two parts. Firstly, an alignment test where the user, on three attempts, positioned the car over a pad which simulated the ground assembly. When the user was satisfied with the attempt, the car's position was measured to calculate the distance between the car and the pad. After the alignment test, an interview with a generative session was carried out to gain a deeper understanding of the user's experience, needs and desires.

The goal for the user in the alignment test was to position the car over the charging pad according to figure 2.2 in chapter 2. The pad was placed on a parking area without any parking lines or references to follow, where the users decided by themselves how to make the alignment.

Sampling

The sampling was collected from a population with driving licence. This was due to the test's purpose of analysing the user's perspective and difficulties of aligning a car. The ten participants for the user test were collected with purposive sampling, to cover the most of the dimension of variation (Sanders & Stappers, 2014). This was made to create a wide range of different needs for different groups. The test participants were therefore collected in a spectrum divided into gender, age, driving experience and frequency of driving. In table 4.1 the sampling of participants are listed.

Table 4.1: The sampling of participants for the user test

AGE	GENDER	EXPERIENCE	FREQUENCY
18-29 (6)	Female (5)	0-5 years (2)	Very often: Several times a week (6)
30-65 (4)	Male (5)	6-15 years (5)	Infrequently: 1-2 times a month (4)
		16+ years (3)	

Observation
An alignment test was executed with the purpose to observe the participants parking the car over a ground assembly and collect data for the positioning between the car and ground assembly. The observation was executed to detect the user's behaviour, i.e. what the user do when trying to align the car, see figure 4.3. The observation form used to study the participants can be found in appendix A. The user got completely free hands of the car and could try repeatedly until they felt satisfied with the position of the car. The mediator gave no influence or guidance and only observed the user. During the alignment test, the user was asked to think out loud. This was made to get an insight of the user's mind during the test which reveals clues about how the user thinks though the task. 'Thinking out loud' can also help the participants to be aware of what they are thinking and help during the reflection after the task. (Rubin & Chisnell, 2008)

Figure 4.3: Alignment test. Left: picture of one test person inside the car. Right: test field with car and pad.

Interview
After the usability test, a generative session was conducted with an interview, the interview guide is listed in appendix A. This was made to gain a deeper understanding of how the user experience the alignment of the car and what kind of guidance they would prefer to facilitate the alignment. A generative session was used to allow the user to take part in the design process and to detect underlying needs and desires. (Sanders & Stappers, 2014).

In order to make the user express themselves and allow them to be creative, the co-creation method *Path of expression* was applied. Path of expression is a method to help the user express their creativity and works as a starting point for ideation. The method avoids people to be fixated on their first idea about the future or preconceived ideas. Firstly, the user is asked to observe, reflect and describe the current experience. Second, the user is asked to reflect on previous experience and memories. During a session, they are asked to discuss memories and current events. Talking about the experience help reveal underlying needs and values, which leads to expressing how they would like their future experience to be. (Sanders & Stappers, 2014).

A toolkit was used as a mediating tool during the sessions to help the users to express themselves. *Toolkit for expression* is an important part of generative techniques and co-creation. The toolkit is developed for its specific session to support the participants. The toolkit could help the user express their feeling, recall memories, making interpretations and connections, and imagine the future. (Sanders & Stappers, 2014). The users expressed the alignment task and how they experienced it with a toy car together with a drawn parking area. Different pens and post-it's were offered to the users to help them express how, when, and where they would like the guidance to be.

4.2.3 Affinity Diagram

Affinity diagramming (also called the KJ method) is a method used to understand research data. (Scupin, 1997) The process of the method contains breaking up the qualitative data into different categories to understand the insights and pain points from a user perspective. (Wilson, 2012)

The transcribed interviews were printed and relevant quotes were cut out. At first, the quotes were divided into different main categories to sort out what kind of categories would be needed. The quotes were added on a whiteboard to get a clearer view on what types of insights and pain points there were, see figure 4.4. The larger categories were thereafter divided into subcategories making it possible to understand the data better and interpret the relevant user needs.

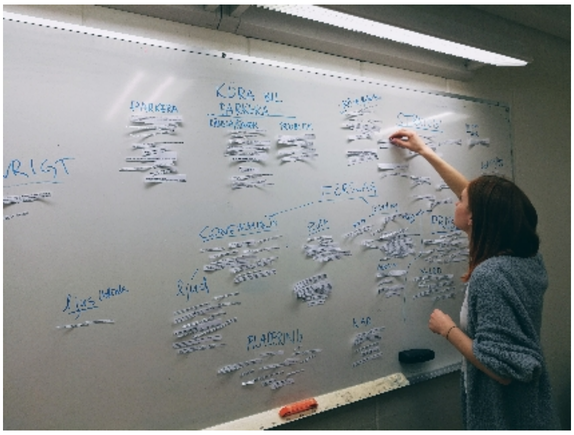


Figure 4.4: The quotes were divided into different categories to understand the user needs.

4.2.4 Hierarchical Task Analysis

Hierarchical Task Analysis (HTA) is used to identify and organise activities in the task and sub-tasks. A HTA is a framework that can be analysed and provides an understanding of the relations between various tasks and sub-tasks. The HTA is created by firstly defining the main goal of the activity and further list various tasks needed to complete the goal. The recommendation is to not have any more than seven or eight tasks to ensure that no important tasks are excluded. The tasks are further divided into sub-tasks and the process is continued until the detail level of the tasks are described sufficient for the analysis. The HTA is summarised to a visual diagram to get an overview of the activity. (Ainsworth, 2004).

The HTA was carried out to break down the activities to charge the car into various tasks and sub-tasks and to analyse critical areas. Each end task was colour-coded with green, orange or red depending on the critical level. This generated an overview on what parts of the charging process are difficult and what tasks demand extra focus. The HTA can be found in appendix B.

4.2.5 Journey Mapping

A journey map is a visual map of the user experience of the product. The journey map provides an outline of how the user experience change over time. The method maps out significant the user's needs and their degree of satisfaction in the phases of the use of the product. A journey map is created by listing the phases of the experience horizontally and various layers are added vertically depending on relevance and interest. For example, the user's feelings and what their needs are in the particularly phase. A journey map provides a high-level overview of the interaction and brings touch-points to realise where the user needs certain things. (Howard, 2014)

The mapping was divided into the different tasks that the user needs to complete to finish the alignment of the car. Each task was assigned with a goal, an emotion and what kind of information that is needed to complete the task.

4.3 Overall Design

In the overall design step, the details on possible solutions for interaction and physical form are created. The concept generation continues from user needs to how the design will look with central design variables, and solutions on the interaction design. A focus group is carried out to evaluate concepts and create additional concepts. The remaining concepts are further evaluated and inferior concepts are eliminated.

4.3.1 External Search

The external search focuses on finding information outside the company and especially finding solutions to the problem or sub-problems existing on the market. Solutions to sub-problems enrich the development team with ideas and widen the generation of concepts, thus it is important to search for technologies used in other types of products that can solve the sub-problems. (Eppinger & Ulrich, 2012)

The external search for existing solutions have in the overall design focused on indirect products, i.e. products that only solve sub-problems. The search was made to keep a wider perspective of how the solution could be realised.

4.3.2 Internal Search

An internal search is executed in the team based on the teams already existing and gathered knowledge from the earlier steps in the development process to generate concepts. The internal search should be carried out by generating a lot of ideas to explore the fully ranges of possible solutions. The wide range of ideas also contributes to lower the expectations of the solution, and therefore originate for more creativity. The team should have a suspended judgement by quick evaluations, presenting weaknesses and improvements. The team should welcome unfeasible ideas to create a wide scope, but also be used to be built on or be repaired. Visual and graphic illustrations are useful to use during the internal search though it is easier to imagine the ideas and communicate them. (Eppinger & Ulrich, 2012)

The concept generation for this project was carried out by firstly individually create ideas and visualise them. The ideas were presented to the other team member and were discussed about function, strengths, and weaknesses. The ideas where then built on and combined with each other to generate more ideas.

4.3.3 Focus Group

A focus group is a form of data collection where information about the human-technology system is gathered, where a group of interviewees are interviewed as well as being able to discuss together in forms of finding information. The benefit of a focus group is that one person's expressions invites other persons in the group to make associations from their own experience connected to the subject. Another benefit is that the loose structure and dynamic of the group generates different kind of information that would not appear in a structured interview. (Karlsson et. al, 2009)

Co-creation is a method based on participatory mindset. The user is given a position of 'expert of their experience' and is included in the design process, having a large role in the idea generation and concept development. Co-creation involves the user, instead of traditional study the user as a passive object. To make the user part of the development process, generative tools are used to explore ideas, dreams, and insights of the people who will be the end user of the product. (Sanders & Stappers, 2014).

A total of five test person, that had been doing the usability test, were gathered to discuss the experience of the task and to evaluate generated concepts. The session started with going through the events of the focus group, where the implications were described as well as getting everyone to make acquaintance. Further, all concepts were displayed for the interviewees to be examined and judged. Their opinions were later discussed together to create a mutual understanding. Thereafter, the participants were asked to further develop the concepts or generate new based on their experiences and discussions.

4.3.4 Morphological Matrix

The morphological matrix is a method to generate a great number of concepts based on various sub-functions. This is made by combining various design options from sub-functions into several concepts. The morphological matrix provides a method to consider new combinations and therefore enables a wide spectrum of all possible solutions. (Decarlo et. al, 2009)

The morphological matrix was carried out by listing the required sub-functions and thereafter plot the sub-concepts from the earlier generated concepts. The matrix was generated in order to combine the concepts sub-functions with each other, and to evaluate and eliminate unfeasible solutions.

4.3.5 Pugh Matrix

The purpose with a Pugh matrix is to evaluate different concepts as well as narrowing down the number of concepts. (Eppinger & Ulrich, 2012) In the matrix, the concepts are evaluated based on different criteria that are related to the performance needed for the solution. The Pugh matrix makes the evaluation and elimination more structured, since all concepts are compared with the same background and not on gut feel. (DeCarlo et. al, 2009)

The Pugh matrix is built up by various criteria in the left-hand column followed by all possible concepts. Each concept gets evaluated with a score (+), (0) or (-) for each criterion, which is decided based on a comparison with a reference concept. Based on the results, one or more concepts are further developed while some gets eliminated. (Eppinger & Ulrich, 2012)

A weighted Pugh matrix has the same functions as a regular Pugh matrix. The difference is that a weighted Pugh matrix focuses on the grade of importance the different criteria have. Each criterion is assigned with a weight, e.g. from 1-5, symbolising the importance of the criterion. If a concept is evaluated with a (+) and the weight is 3, the sum will be +3.

If all sub-concepts would be combined according to the morphological matrix, a total of 504 concepts would be generated. To ease the process of evaluating the different concepts, weighted Pugh, see appendix A, matrices were made for each function group. The sub-concepts were evaluated based on the criteria:

- Is the concept clear?
- Is the concept familiar?
- Is the concept innovative?
- Does the concept cause irritation?
- Does the concept have a low glance time?
- Is the concept easy to integrate?
- Does the concept demands extra installations?

4.3.6 PHEA

Predictive Human Error Analysis (PHEA) is a method used to evaluate user-interfaces and identify specific errors associated with the tasks used when integrating with the product/system. (Karlsson et. al, 2009) The aim of the process is to explore all possible errors and failures that can occur, to be able to know the consequences as well as how it can be prevented. (Embrey, 2004) A PHEA can be used in different stages in the design process where it serves as an aid for the designer. In the beginning of a design process, it can be used to evaluate usability problems in an existing product/service to gain knowledge about competition or how to redesign. (Karlsson et. al, 2009) The method is in this case used to early evaluate concepts to understand how they further can be developed or if the risk of failure is too high forcing some concepts to be eliminated.

The concepts in this phase of the process were evaluated with a PHEA to understand what kind of errors that can arise and how to further develop them to hinder the possible errors. The use errors listed in the tables were found when questioning:

- What action can the user do wrong at the right time?
- What action can the user do correct at the wrong time?
- What happens if the user performs an incomplete action or omits an action?
- What happens if the user performs an error in the sequence of actions?

The use errors were then followed by evaluating the causes for the error, the consequences, the detection and how the error can be recovered. Since the method was used to identify possible development of the concepts, a note was added to the errors with information of how the errors could be solved.

4.3.7 Concept Testing

To test and verify the concepts, the field of view for the driver was examined and how the concepts could help the driver. This was made by performing the task, to align the car in the correct position over a charging pad with the concepts in mind.

To test the possibility of creating a wider view with a front camera, a phone was attached in the front of the car. With a video call between the phone and a tablet in the car the driver could see a live video from the front of the car while driving.

Figure 4.5: The tablet with the front view camera visualisation.

4.3.8 Video visualisation

Video visualisation is a method to show richness and detail of a concept in context of virtual elements. This is useful to visualise the design of tangible parts such as psychical attribute and the intangible parts like the reaction and emotions of the design. The method is useful for conceptualisation and to describe interactions and relationships between activities, elements and people. (Daalhuizen et al, 2016).

Video visualisations were used in order to put the concepts into context and understand the relation between the sub-tasks and sub-concepts. The visualisation was carried out by shooting a movie from the user's perspective when they drive into a parking spot. The concepts were then added with graphical designs to visualise the HMI in the car. In figure 4.6, pictures from the video visualisations are shown. In the pictures, the drivers field of view and a concept are shown.

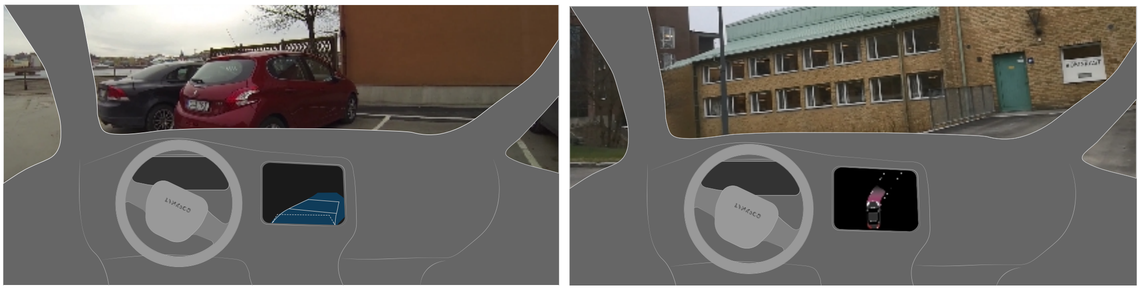


Figure 4.6: Pictures from the video visualisation.

4.4 Detail Design

In detail design, the solutions interaction between the machine, user and surroundings are developed. Four different visualisation concepts were generated in this chapter based on the function requirements set in the previous step. Through a discussion session, the concepts were evaluated and rated against each other to set the final design.

4.4.1 Evaluation

The decision of which visualisation to pursue was based on evaluation sessions and discussions. The first session was an unstructured interview conducted with experts in HMI at CEVT with discussions about the feasibility, placement in the car and how the concepts align with the brand. The second session was informal and executed with other employees and students that provided input about perception and understanding of the visualisations.

4.4.2 Refinement

The final concept was further investigated with a second PHEA in order to analyse potential errors of the final concept. The procedure was carried out as in chapter 4.3.6. However, in this PHEA, a greater focus was to find errors, in which step the errors occur, and generate solutions to avoid them.

In order to create the design for the various sub-functions in the alignment interface, a function architecture was made by listing the functions, and their relation to each other. From the architecture, the needs and requirements for the functions were set.

The design of LYNK & CO was examined to be able to align the final design towards a fit with the existing design. The DIM design, colours and design guidelines were extracted and decided based on the findings.

4.5 Final Design

In this chapter, the design for the alignment interface are presented and how the details are used. The final design was developed with focus to specify the solution in the design, user interface and description of the developed HMI. The material made in this step is presentable and ready for deliver. In order to verify the final design a cognitive walkthrough and needs fulfilment were carried out.

4.5.1 Cognitive Walkthrough

A cognitive walkthrough (CW) is used for analytic evaluation of a user interface. The method analyse the user interaction for a task with a step-by-step procedure. This can be used to investigate usability, errors, and to compare products. A CW can be used in various steps of the design process. (Karlsson et al. 2009)

The CW analysis was applied in the final step to verify the design and test the usability in order to ensure that the design fulfils the need, and are useful and understandable.

4.5.2 Needs Fulfilment

Throughout the project, different needs have been stated. Evaluating these needs in retrospect is important to see if the final solution fulfils them. The needs were gathered together and evaluated if they are fulfilled or if further investigation is necessary.

5
Needs Identification

The purpose with identifying needs is to investigate how the surrounding elements affect the future solution and how the solution affects the surroundings, as well as what the user values in a solution. This is carried out with a market investigation, technology and competitor analysis resulting in needs and initial concepts ideas.

5.1 CEVT and LYNK & CO

China Euro Vehicle Technology AB, CEVT is an innovation centre for future mobility owned by the Geely Group. The organisation is a Chinese-Swedish cooperation and located in Gothenburg, Sweden. CEVT operates on a global market with focus on the US, Europe and Asia market.

CEVT delivers solutions in architecture and components, and share component development with Geely and Volvo Cars. The company also fully develops cars with top hat development and complete vehicle design for LYNK & CO. In table 5.1 CEVT's various partnerships and what they deliver to each OEM.

Table 5.1: CEVT's deliverables and what they develop.

	VOLVO	GEELY	LYNK & CO
Architecture and Components	○	○	○
Shared Component Development	○	○	○
Advanced Engineering and Technologies		○	○
Top Hat Development			○
Complete Vehicle Design			○

Since CEVT is developing full vehicle design for LYNK & CO, the solution will be made with the existing LYNK & CO cars in consideration. The market segment for LYNK & CO is mainly Asia, with focus on China, however, Europa and US will still be considered to create a solution that will fit a great variety of the market.

5.1.1 User Segment

The user segment for LYNK & CO is defined as *"The Open Urbanites"* and is described as the new powerful generation that is born global and the ones who set the new rules. Personal freedom and embracing new technology gives them a life in the city they want. The segment lives a busy contemporary city life and does not have extensive driver experiences. Since the LYNK & CO car is shareable, the user needs to be comfortable when using it for the first time as well as when have using it for a longer time. Another aspect that is important in the user segment is that the user is convenient. They are used to getting things done fast and simple, and value the comfort in new solutions.

The user segment is summarised in four different personas, in figures 5.1, 5.2, 5.3 and 5.4, that identifies the aspects of the users and their needs.

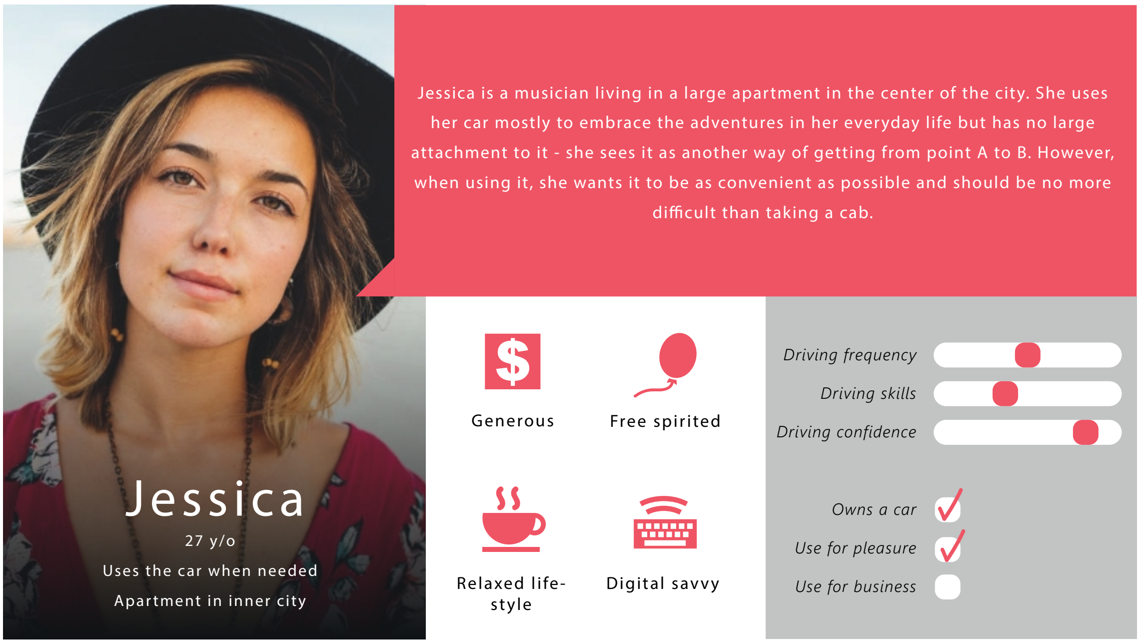


Figure 5.1: Persona 1.

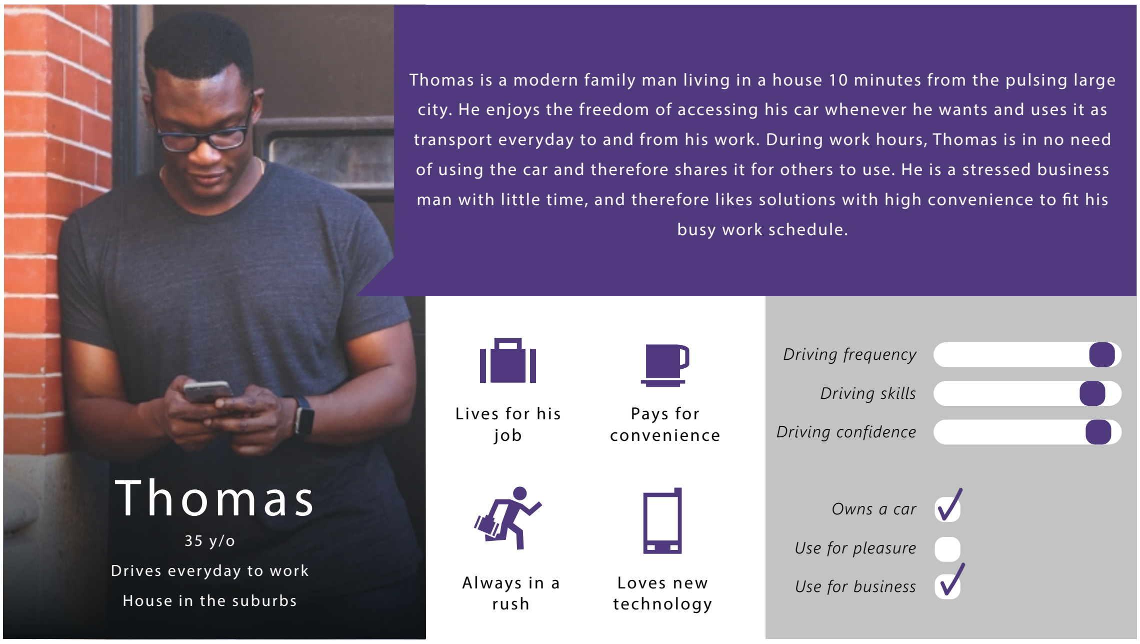


Figure 5.2: Persona 2.

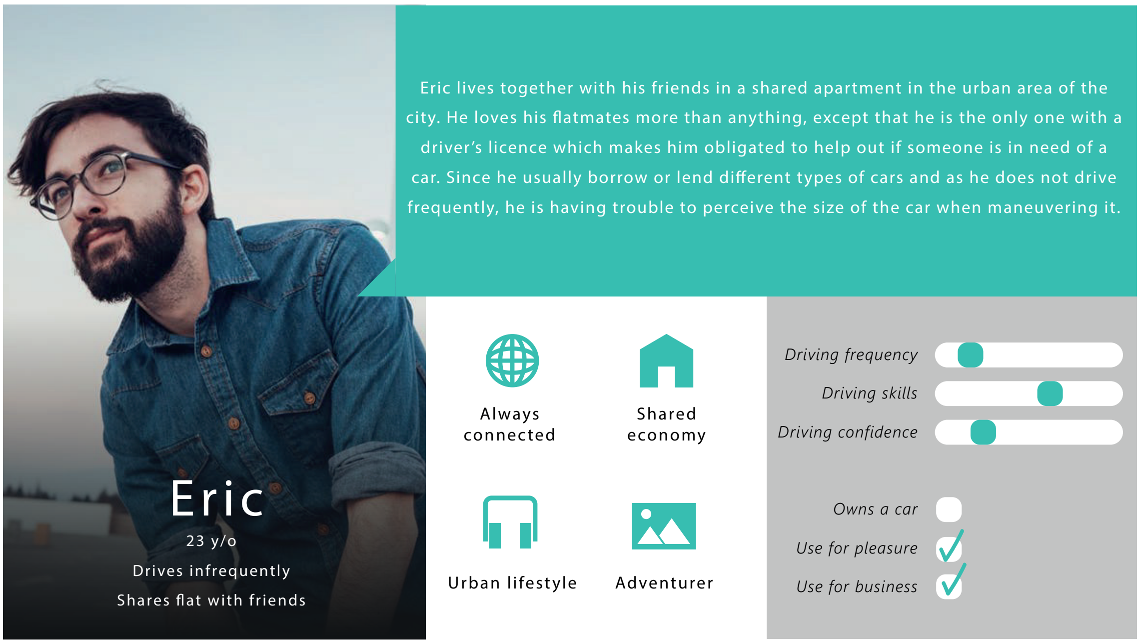


Figure 5.3: Persona 3.

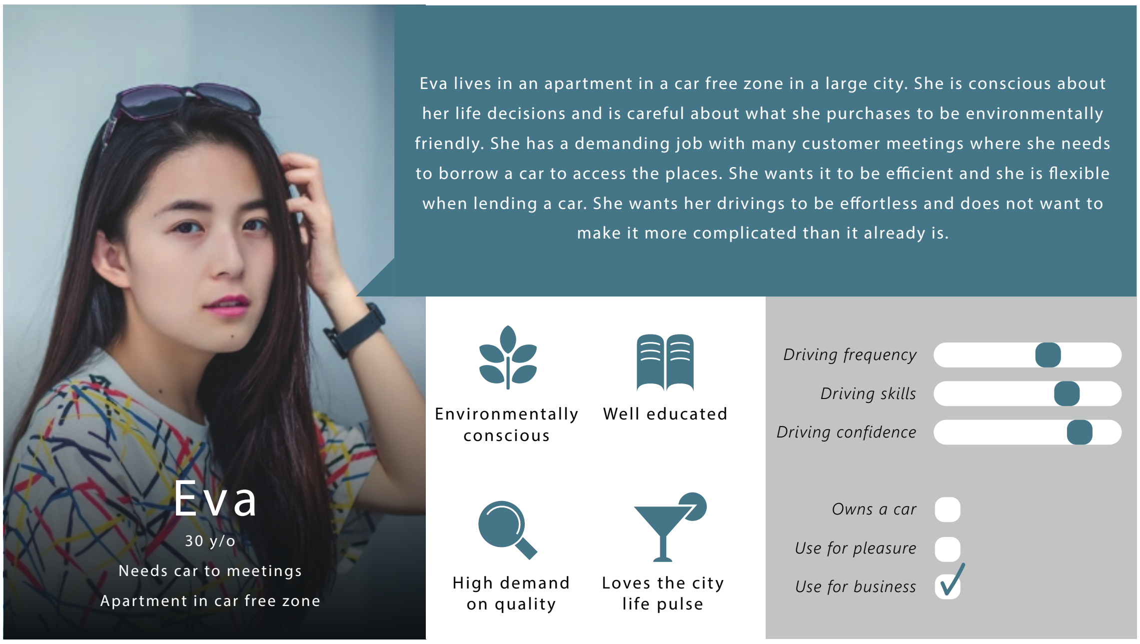


Figure 5.4: Persona 4.

5.2 Technology and Competitor Analysis

A technology and competitor analysis have been made to encompass the existing market as well as where the solution will be positioned. A benchmarking analysis was made to gain knowledge of existing solutions of HMI for wireless charging on the market. A SWOT analysis was conducted to position the intended solution to understand the strengths, weaknesses, opportunities and threats. Finally, a roadmap of the product was made to understand where in time the product will be relevant since the car industry is a fast growing market.

5.2.1 Benchmarking

The benchmarking is focused on what types of alignment interfaces for wireless EV charging are public available today. Several car OEMs are in the development of a wireless charging solution for their electric vehicles (Pyper, 2016), which also means that there is very little information to be found. However, there are companies, such as Qualcomm and WiTricity, developing wireless charging solutions that are aiming on co-operating and delivering solutions to larger companies, such as Audi and Toyota to mention a few. Despite this, the only after market solution available today (2017-02-20) is Plugless that is described below. Although the lack of solutions on the market, prototypes and concepts have been made where different types of alignment interfaces can be found.

The simplest solution is the confirming type, that gives an indication to the driver that the position is correct and that the charging can start. The other type of system is the guiding type, where it is possible to see the car from above and the charging pad. This eases the placement of the car for the driver since the relationship between the coils are visible, which gives the driver feedback on the placement. In table 5.2 below the benchmarking is listed.

Table 5.2: Different HMI solutions for wireless EV charging

COMPANY	SYSTEM	PLACEMENT	TYPE	ON MARKET
PLUGLESS	*Arrows*	*Outside of the car*	*After market*	*Yes*
QUALCOMM	*Circle is being filled in & car's position and GA's position*	*Application*	*Cooperate with OEMs*	*2018 with Mercedes*
WITRICITY	*Camera with positioning (Toyota)*	*Display inside*	*Cooperate with OEMs*	*Soon*
HEVO POWER	*Car's position and GA's position*	*Application*	*Cooperate with OEMs*	*No*
OPPCHARGE	*Light from above*	*Outside of the bus*	*Cooperate with OEMs*	*Yes*
SIEMENS	*Car's position and GA's position*	*HUD*	*Prototype*	*N/A*

Plugless

Plugless Power is a wireless charging station for aftermarket installation for plug in EVs. The product is today (2017-02-22) available for Tesla Model S, BMW i3, Nissan Leaf and Gen 1 Chevy Volt where the VA is installed underneath the car and the GA is placed on a desired location on the ground. Together with this, a control panel is placed in front of the parking space. To be able to align the car correctly, a guiding system is available on the control panel that indicates to the driver to go forwards, backwards, right or left. The forward direction contains of three arrows that flashes slowly if the car is far away and faster when the car is getting closer and closer. When the car is in the correct position, a circle around the logotype illuminates in green. The car is charging when the circle is flashing in a blue light. (Plugless, 2017)

Qualcomm
Qualcomm designs wireless telecommunications products and services, and have now developed a wireless charging station for EVs that they call Halo (Qualcomm, 2017). The solution is not yet on market, but they are in close collaboration with multiple OEMs which soon mean that the solution will be market ready. The alignment interface found on prototypes show two different types of system. The first is a guidance with a circle that is being filled in as you get closer to the GA. The other guidance visualises the car's position relative to the GA's position.

WiTricity
WiTricity develops wireless charging solutions for power needing devices. They are today supplying car OEMs with their technology for wireless EV charging. The parking assistance for a Toyota uses a camera in the rear to guide the user when reversing. Depending on how the driver adjusts the steering wheel, guiding lines appears on the video how the car will be positioned in that alignment. In a test movie, a symbol with a plug in is visualised showing if the car is in the right position or not for charging the car. Besides this, a parking stop is placed on the parking lot to help the driver in the correct position. (Toyota UK, 2014)

Hevo Power
Hevo Power is a company solely focusing on wireless EV charging. The interaction for the charging is condensed in an app that handles the communication between the hardware components and the user. The alignment interface appears in the application automatically when the car is 25 feet away from the GA and guides the driver in visual and audible directions to align the car. Hevo claims that this also can be integrated with the autonomous driving technology, if the car possesses that function. Hevo's vision is that the app should be an all in one experience where you can see where charging stations are available, pay the power transfer bill, etc. (Hevo Power, 2017)

OppCharge
OppCharge is a charging station for electrical buses. The power transfer is not wireless, however it is crucial that the bus is aligned in a correct position to start the power transfer. To guide the driver, a light appears when the bus in the correct position. (OppCharge, 2017)

Siemens
In a mock up video from 2011, Siemens gave an insight of how wireless charging could look like in a few years. The alignment interface pictured is placed in the HUD where the VA's position is visible related to the GA's position. (Siemens, 2011)

5.2.2 Product Positioning

To understand the position of the product on the market, a SWOT analysis have been made. The strengths and weaknesses are listed as a first step in order to understand the initial needs of the future solution. A PESTLE analysis was executed to identify the current market for wireless charging as well as a supporting HMI. The PESTLE studies the U.S., Europe and Asia market to gain a wide view of market. The outcome was further translated into opportunities and threats for a HMI for wireless charging. The SWOT was then complied into table 5.3 with a summary of the found information.

Table 5.3: SWOT analysis of HMI for wireless EV charging.

STRENGHTS	WEAKNESSES
- Enables convenient charging - Easy - No problems regarding a cable - Time saving - Provides information - Reduces accidents	- Conflict with other system - Too much information - Loss of attention - Loss of skills - Expensive
OPPORTUNITIES	**THREATS**
- Growing interest of EVs - Growing development	- New technology - New standards and regulations - Autonomous cars

Strengths
Wireless charging will facilitate for the user, due to the moment to step out of the car and plug in the charging cable will be removed. Thus, an alignment interface that guides the driver to park and charge the car without any effort will make the experience convenient for the user. (see chapter 3.1) This will be achieved through the low level of effort to position the car and be made in one attempt. An effortless charging system should fulfil an easy experience. Consumers today expect convenience in their products where a more convenient product can make life easier and more efficient. (The Nielsen Company, 2015). With advanced technology, customers are today used to value added features. OEMs always strive towards meeting customer demand, and therefore the customer wants better, reliable, and value adding solutions into their cars to align towards a luxury and a comfort experience of the car. (Future Market Insights, 2017)

Other elements that affect the cable such as cold and hot weather, water and dirt, or vandalism due theft of copper in the cable (Boys & Covic, 2013) would not be relevant anymore and therefore create a more pleasant experience. The user will also save time, since they only need to park the car and can leave the car charging without any time spending on picking out a cable and plug it in the car. The fact that the cable will be removed will also reduce the potential risk to drive away the car with the cable still plugged in and therefore reduce accidents. (Birrell et. al, 2015).

Weaknesses
Rapid growth of technology and various interface system have led to many different devices in the car. Adding an alignment interface on top of all devices could create conflicts with existing systems in the car. For example, sensors that detect near objects and inform with sound can interfere or overpower an alignment interface. Another aspect with adding additional system in the car, is that it could lead to too much information for the user. Too much information could result in that the user eventually become unresponsive to the information or have difficulty understanding and sort out the essential information. (Vidulich & Tsang, 2012) A weakness that also could arise is that the user can create inappropriate trust to the alignment interface (Salvendy, 2012). The driver could over trust the alignment interface and therefore only focus on the alignment interface and therefore loose attention to the road and the surroundings, which could cause accidents. Cars today are getting more computerised with different types of systems to help the driver. Although all systems in the car are intended to improve safety, performance, comfort and aesthetics they also increase the driver's workload which can cause other types of incidents and accidents. (Krems & Popken, 2011)

To be able to initiate wireless charging as a norm, the infrastructure needs to be developed in parking spots with wireless charging system. However, the interest for a modern infrastructure is growing, e.g. EU has funded research projects regarding wireless charging for vehicles. (European Commission, 2016) Currently the wireless charging is more expensive and have a higher installation cost (Technavio, 2017). This extra cost could be a determining factor for the user or infrastructure plans. Although, the wireless charging technology is under development and cost will change during time.

Opportunities
Global warming and environmental factors has affected the world to become more environmentally conscious. The climate of the earth has varied throughout time, but as data indicates, the current warming trend is not part of the regular cycle (NASA, 2016). Natural resources are decreasing, consequently making the prices for e.g. gas increase. (Peak Oil, 2017) The trends for greener politics have successively been growing in time. With the United Nations Framework Convention on Climate Change (UNFCCC), governments have been pushed to make a greater impact to ease the emissions (United Nations Framework Convention on Climate Change, 2016) Law and regulation incurring people to consider a better and greener

alternative when purchasing a vehicle. (Technavio, 2016) This has resulted to an increase of electrical vehicle on the market. Today the sales of EVs have increased rapidly. (Office of Energy Efficiency & Renewable Energy, 2016)

The wireless revolution is already here where wireless charging is offered from phones and medical devices to vehicles. The wireless charging for all off these devices involves the same technologies, locations and companies. (Harrop, Ghaffarzadeh 2016) The wireless society where everything is connected will continue to grow. In the future everything will be connected with internet of things (Prasad, Dixi. 2016). From the benchmarking investigation, the next step for electrical vehicles is moving towards wireless charging. The technology is available and different OEMs are developing wireless solutions.

Threats
Implementation and infrastructure is not here yet for wireless charging systems. (United Nation, 2014) Since wireless charging for EVs is relatively a new type of charging for vehicles, the available standards for wireless charging are not fully developed. Standard SAE J2954 - Wireless Power Transfer for Light-Duty Plug-In/ Electric Vehicles and Alignment Methodology (SAE International, 2016), is today the only standard regarding the alignment of the car when charging a vehicle wireless. However, since the technology is in constant development, new standards will be formulated during time. This is applicable for regulations as well. The standards could change or new can be developed through time. The technology continuously needs to be updated and one common alignment system for wireless charging is required to create a global infrastructure.

An autonomous parking system would be an alternative to align the car in a perfect position without any effort from the driver. However, this would make an alignment guide unnecessary due to that the car would find the way on its own. Although, if the wireless charging will enter the market today when automated parking is not a norm (McKinsey&Company, 2016), an alignment guide is necessary.

5.2.3 Roadmap for Wireless Charging

To understand the market and the future for wireless charging, a roadmap was crated, see figure 5.5. In the roadmap, potential products are plotted with technical trends against a time line from 2017 to 2035. The various segments and trends are admitted roughly when they are assumed to be the norm.

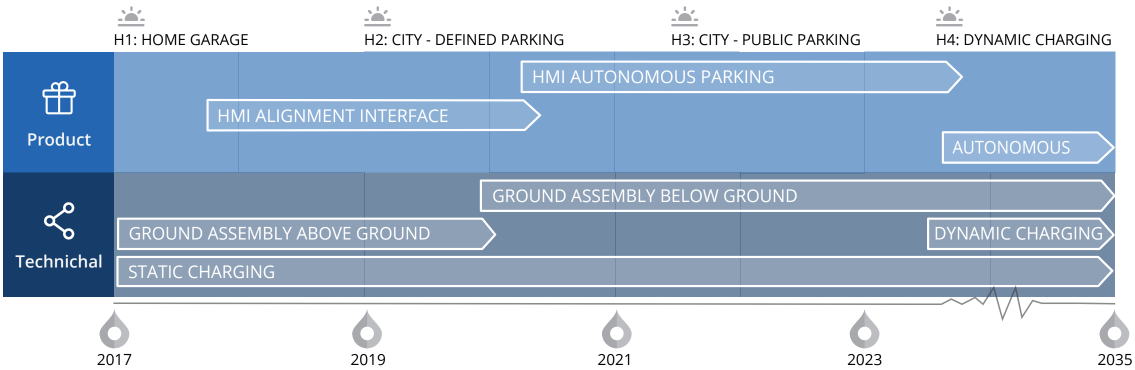


Figure 5.5: Roadmap for wireless charging

The time line is divided into four horizons. The first horizon is the current situation, with infrastructure for wireless charging not yet established. Therefore, wireless charging are directed to *home garage* where the user needs to install it by themselves. In the second horizon, *city - defined parking*, the infrastructure for wireless charging is beginning to grow and wireless charging is offered on some specific parking areas. Horizon three, *city - public parking*, the infrastructure is now fully established and offers wireless charging in public areas. Horizon four,*dynamic charging*, occur in the future after 2023. (Technavio, 2017)

Products for wireless charging alignment will firstly be an alignment interface. Autonomous parking system exists today on the market, but is however not a norm today. Therefore, the manual parking will still be relevant and an alignment interface will be needed. Autonomous cars are predicted to at 2030 stand for 15% of all sold vehicle (McKinsey&Company, 2016). The demand for fully autonomous cars will continues grow and in time take over from the semi autonomous parking system.

Technology for static charging and ground assembly is today already developed and exists on the market. Around 2020 the ground assembly will be placed under ground which will enable the infrastructure for public parking with wireless charging. Dynamic charging are under development. (Technavio, 2017) However, in order to establish dynamic charging in large extend, a great development of infrastructure is needed. According to the roadmap, an alignment interface is needed to be feasible with existing technology and implementable now. A HMI is required now for manual driving. However, the alignment interface may be replaced with autonomous technology and therefore needs to be adaptable for changes.

5.3 Identified Needs

The knowledge gathered from the market investigation, technology and competitor analysis are below complied into needs. Table 5.4 below is listed with the needs from this chapter, as well as the needs found in the theoretical framework.

Table 5.4: The needs from needs identification stage.

NEEDS IDENTIFICATION	
NEEDS	
User needs	*- Not conflict with other systems* *- Not affect the user's attention and driving skills* *- Be more convenient than plugin* *- Fit different experience levels of drivers* *- Avoid and recover errors* *- Follow interface design principles* *- Provide user with information relevant to align the car*
Stakeholder needs	*- Feasible and implementable today* *- Align with LYNK & CO's market segment* *- Follow standard* *- Push the infrastucture towards the future* *- Make EVs more attractive on the market* *- Superior to existing solutions*

5.4 Initial Ideation

The initial ideation are general focus areas of which the solution can be divided into; grade of integration, type of aid, and the senses that can be used by the user to receive the information.

5.4.1 Integration

The solution can be developed with three different main categories in mind in order to achieve an implementable solution, see figure 5.6. The first category is that the solution is independent from the rest of the HMI in the car. The second category is that the solution will collaborate with the rest of the car's HMI, meaning that e.g. requirements from other systems will be considered in the development to not make the systems conflict. The last category is to integrate the solution fully with the rest of the car's HMI, meaning that a full solution will be made with all factors included from existing systems. According to the scope *the solution should be integrate with the car*, the first category, *independent*, will be neglected and only *collaborative* and *fully integrated* will be considered for the solution.

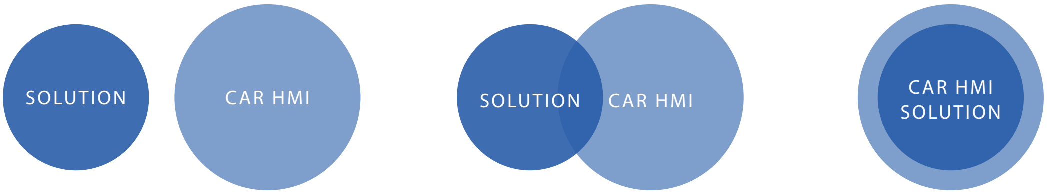


Figure 5.6: Different types of integration. From left to right; independent, collaborative, fully integrated.

5.4.2 Aid to Position the Car

The helping system to position the car in the correct position can be divided into two different categories; confirming and guiding, see figure 5.7. The confirming type indicates for the user if the car is able to charge or if it is not. The guiding type inform the user how to manoeuvre the car to get into the right position, knowing where the car is relative to the charging pad.

Figure 5.7: Categories to aid the positioning of the car. From left to right; confirming and guiding.

5.4.3 Senses

The senses in figure 5.8; sight, hear and touch, are the most important senses that can be used by the user in order to receive the information from the solution. The senses can be used together or separate, see chapter 3.2.1 for more information.

Figure 5.8: Senses to inform the driver. From left to right; vision, audio, haptic.

6
Usage Design

The aim of this chapter is to investigate what needs there are for the user and the intended effects, and to examine the overall solutions that meet the usage needs. This is made by carrying out a data collection, a usability test, and analysis with a journey map. The goal is to design the usability and select the principle of the technical solution and to decide the outer requirements for the usability of the design.

6.1 Data Collection

Before initiating the structure for the user tests, a data collection of existing studies on user needs were made. Two different relevant studies were taken into account; The WiCh project, where the charging behaviour of the user is examined for wireless charging, and parking alignment based on the report *"How driver behaviour and parking alignment affects inductive charging systems for electric vehicles"* (Birell et. al, 2015).

6.1.1 Charging Behaviour and Attractiveness of Wireless Charging

In 2012, the WiCh (Wireless Charging of Electric Vehicles) project started with the aim of studying wireless charging of electric cars from a user's perspective. The aftermarket solution Plugless (see chapter 5.2.1) was installed on 20 EVs that are used on a daily basis in different car pools in Gothenburg and Stockholm. The project made it possible to measure quantitative and qualitative data from the users in real life situations. Interviews and surveys were made throughout the project to know the opinions of wireless charging from the users and also to know how their charging behaviour changed. (WiCh, 2017)

In the beginning of the project, the users had a very positive attitude towards wireless charging were quantitative interviews resulted in quotes as *"It is more convenient than charging with cable and there is no risk of forgetting to connect the cable..."*; *"Good to get rid of the socket and cable"*; *"Nice to avoid handling a cable that easily becomes dirty..."*. The result in the first interviews were positive both on how wireless charging will enhance the usability as well as the attractiveness of the technology. When the equipment was installed and used for four months, the rating of the usability of WPT was inferior to the plug in version. The answers to this negative feedback were all related to the problem of parking and aligning the car correctly over the GA. The users had to make several attempts to position the car which caused irritation among several participants. Noticeable in the study was that the minimum parking time to feel motivated to start the charging was higher for plug in than wireless charging. This means that the users have a higher demand on the wireless charging since they do not want to make any extra effort than just park the car. (Andersson et. al, 2016)

The conclusion, regarding parking, of the project was that the opinions of the usability and attractiveness of wireless charging got more negative during time since it was hard to park correctly on the first attempt in order to charge the car. (Andersson et. al, 2016)

6.1.2 Parking Alignment

The study *"How driver behaviour and parking alignment affects inductive charging systems for electric vehicles"* (Birell et. al, 2015) focuses on the driver behaviour and parking alignment with the same background as for this thesis. Two different studies were made, one retrospective and one dynamic, to measure how drivers park their cars. In the retrospective study, 100 cars in a parking area were measured without the users knowing the background of the test. The dynamic study was made with 10 different drivers trying to align the car over a pad with all background information. Both studies resulted in a more accurate position in lateral than longitudinal. With a mean of 1200-2800 mm in longitude and 200-600 mm in lateral, only 5% of the measured parking attempts would be able to start the charging within the accepted tolerances.

6.2 Usability Test

Based on the findings in the data collection, a usability test was carried out with purpose to understand the user perspective of the difficulties of aligning a car in a specific position. During the test, the participants were observed and the measurements of the positioning of the car relative the pad were collected. A generative session was also conducted after the test that was analysed with an affinity diagram. The goal of the test was to collect data to establish the user needs. Following research questions were stated:

- How skilled are users to position the car correctly?
- Why is it difficult to align the car?
- When, during the task, is it hard to align the car?
- What kind of help would the user prefer?

6.2.1 Observation

During the usability test, an observation was performed by studying the drivers during the alignment attempts. The outcome was that the participants could be divided into two different types. The first type, *easy-going*, were confident and completed the task fast, often with one attempt. This user type did not put their full effort to succeed in the test and had a more cavalier approach. The *easy-going* type often had a more relaxed position. The second type, *the accurate*, took longer time to complete the test. They took breaks and resonated their actions. *The accurate* often made various attempts to position the car in a correct position. In the car, *the accurate* type tried to see the platform on the ground and therefore sat in a forward position.

The reason behind these behaviours could be caused by different things. One reason is the perception of the test. The *easy-going* type might not fully understood the task exactly and the demand of a precise position the car. *The accurate* type took it upon to really try to be the best, like a competition. Studying the test person's characteristics and which type they are, the distribution are fairly uniform. However, a conclusion can be made that the driver with lower driver experience behave more accurate due to their low confidence in their driving.

Commonly for all test persons were that they did not know the relation of the car to the charging pad. The biggest confusion for the drivers were when the charging pad was out of view. A common thing was that the test persons reversed after being over the pad just to see it again to adjust their position. Furthermore, the measuring data from the alignment test had no connection to the different behaviours. Whether people drove on one attempt or were very accurate, the result varied with an even distribution between good result and behaviour types and characteristics.

6.2.2 Data Outcome

After each attempt in the usability test, the car's position relative to the pad was measured in order to understand the first research question, *How skilled are users to position the car correctly?* The results from the collected data showed that only one try managed to position the car in the tolerances (see chapter 2) set from standard SAE J5429 (inner square), see figure 6.1. Due to only measuring the input data with a measuring tape, a margin of 50 mm was added (dashed line square) making the tolerance ±150 mm in Y and ±125 mm in X. With these tolerances, three tests managed to position the car in the asked position.

When studying the results in figure 6.1, a majority of the tries are negative both in X and Y direction. Noticeable is that 90% of the first tries are negative in Y direction and that this changes for try 2 and try 3 where more tries are positive. In X direction, the results are similar where 83% of the tries always were on the negative side. In appendix A, the result with the wheel position is available as well. According to figure A.2, the test persons were unable to position the car straight as well.

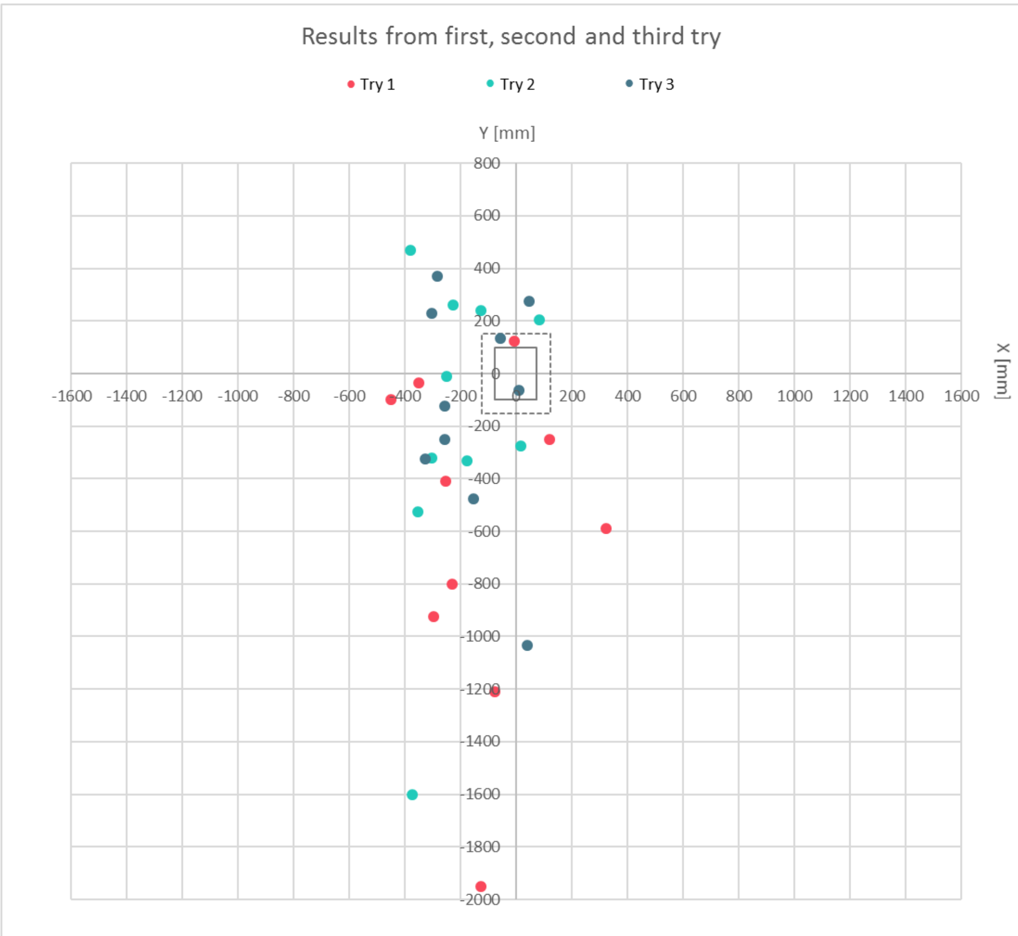


Figure 6.1: The results from the alignment test.

6.2.3 Affinity Diagram

After the alignment tries, interviews were held with a generative session to gather knowledge about the three remaining research questions: *how the user experience the task?* and *what kind of help the user would prefer?*. The interviews were further analysed with the affinity diagram method and resulted in four different categories; problems, strategy, suggestions, and general, each with different subcategories. The categories are visualised in figure 6.2 and described below.

Figure 6.2: The affinity diagram with the different categories found.

Generally - Drive and Park
The majority of the test persons are comfortable with common driving. However, situations with a lot of things going on in the surroundings can be stressful. Regarding parking, most of the test persons feel positive, except when it comes to parallel or a narrow parking where some experience stress or simply avoid it. Problems that may arise are mostly connected to manoeuvring the car, centralise it and determine the distance. *"I do not take the turning radius out completely because I'm afraid of running into another car"* and *"I often have too large margins where I think the car is bigger than it is"*.

Problems Related to Task
There were several problems when trying to aligning the car. Following problems were discussed:

Y direction
The test persons found it hard to estimate the length of the car and especially where the front wheels are located. A test person said *"I could drive further, but you're always scared of driving too far since it usually means something bad. Even if there was nothing to hit, you unconsciously become restrained"*. Not being able to estimate the car's dimensions and distances to the surroundings were the biggest factors why the test persons failed to position the car in the Y direction.

The part when the pad disappeared from sight, were experienced as the hardest part of the test. The persons claimed that they were in control when seeing the pad, but when the pad was outside the field of view caused them to drive in the unknown. Some of the persons directly thought that the pad was under the car when it disappeared from sight which caused a very long distance in Y from the pad.

X direction
The test persons also had a hard time positioning the car correctly in the X-direction. Many of the persons said that they thought they were in the middle but in fact had a hard time knowing where the actual centre of the car was. For example, one test person said *"You overcompensate for sitting on the left side of the car, and that you have less control of the right side"* and *"You don't sit in the middle of the car, so it's hard to know where the middle is when sitting on the left side"*.

Not used to car
For the test persons driving an unknown car, they found it hard to get a grip of the size and the proportions of the car. *"It would be easier to position the car if it was my own car which I'm used to"*.

Not used to situation
Another factor that the test persons found problematic was that the parking needed to be exact. *"It is hard to park when it needs to be that accurately, you never have to do that"*. The test persons said that they were used to parking inside of an area, such as a parking lot, but have never trained on actually aiming at a specific point.

Strategy for Positioning the Car
The test persons had different strategies when trying to align the car in the requested position, one was trying to be straight from the beginning. *"Most important is to be straight from the beginning. It is harder to adjust in lateral direction when you are there"*. Several persons had the strategy on being straight first, making next step by driving forward without moving the steering wheel.

Another strategy was simply feeling: *"It was just luck"* and *"I didn't have any feed-*

back so I just drove until it felt good" were typical expressions from the participants when they were not able to see the pad anymore. Some of the participants used the expression *"..just a little bit more"*, referring to the moment when the pad disappeared under the hood and then drove a little bit more. After realising from the first tries that they had driven too short, the persons did not trust their gut anymore and expressed it as *"When I wanted to stop, I added a bit more since it was too short the first time"*.

Since the test persons did not have any guidelines as they are used to, they tried to use other surrounding objects as a reference. *"I had the gear stick as a reference and thought that the pad should be under it"*. Some of the test persons said that they usually go out and look to get feedback on their position of the car.

Suggestions
All participants felt that some kind of guiding would be helpful when positioning the car. Some felt that they could learn to position the car over time. However, they agreed that in order to change/rent/lend out a car, a guide system is preferred.

The majority of the participants suggested that they would like a confirmation when the car is at the right position. Suggestions of how this could be done is e.g. a light that indicates, voice/sound or that the wheels are locked when they are in the right position. Sound indication was suggested by many of the participants. Some of the statements that were said were *"The advantage of the sound is that you do not need to look at something else than the environment while driving"*. A common comparison was the sound from the parking assistance, *"...but with a more kind sound instead!"*.

Another conclusion made by the test persons were that only an indicator that tells the driver if they are correct may not be enough. *"With just a beep, you do not know in which direction you are wrong"* and *"because I do not see, I need to know how wrong I am. Otherwise I can not find it"*. Participants suggested e.g. to show the distance between the car and the pad. *"It would be very good if you can have a display that shows where you are"*. Another way is to tell the driver the directions needed. *"I would like; a little more to the left, and little more right and then forward."* This could also be done by visualising the car in relation to the pad. *"I would like to have some kind of indicator of where my car is and another one where the pad is."*

If the guide would be placed somewhere, the test persons commonly said they would like the guide to be placed inside the car. *"If it would be something that helps me to drive, then it has to be something inside the car"* Some of the participants suggested in front of them (DIM), other near the radio (CSD) and a few on the window (HUD).

In order to achieve a correct position of the car, most of participants would like the guiding to start when the car is quite close to the pad. Preferable would be to first get directions in X to get the car straight, and then in Y direction so the driver knows when to stop. *"I would like to have an indicator that tells me it is right in*

X-direction and then it gets locked in that position" A few of the participants would only see it relevant to have a guide when the pad is out of view. *"I think I need more guidance when it begins to disappear"*.

Other suggestions that came up were that the participants would like a box or similar on the ground to aid the positioning of the car, or an autonomous parking help that would solve the problem.

6.3 Journey Mapping

In order to translate how the user experienced the task, a journey map was created. The map was developed based on the results from the alignment tests, observations and interviews. The journey map is visualised in figure 6.3 below. The scenario to align the car over the charging pad without any guidance has been divided in to five different tasks. These tasks were identified with a heuristic task analysis (HTA), which can be found in appendix B.

From the HTA, each task was assigned with a goal, emotions, and information required. The emotion and the information is divided for two types of users: *the experienced user* and *the first time user*, due to the requirements to fit users with different level of experience. *The first time user* and *the experienced user* have different types of emotions through the tasks and they also have different needs when it comes to the information.

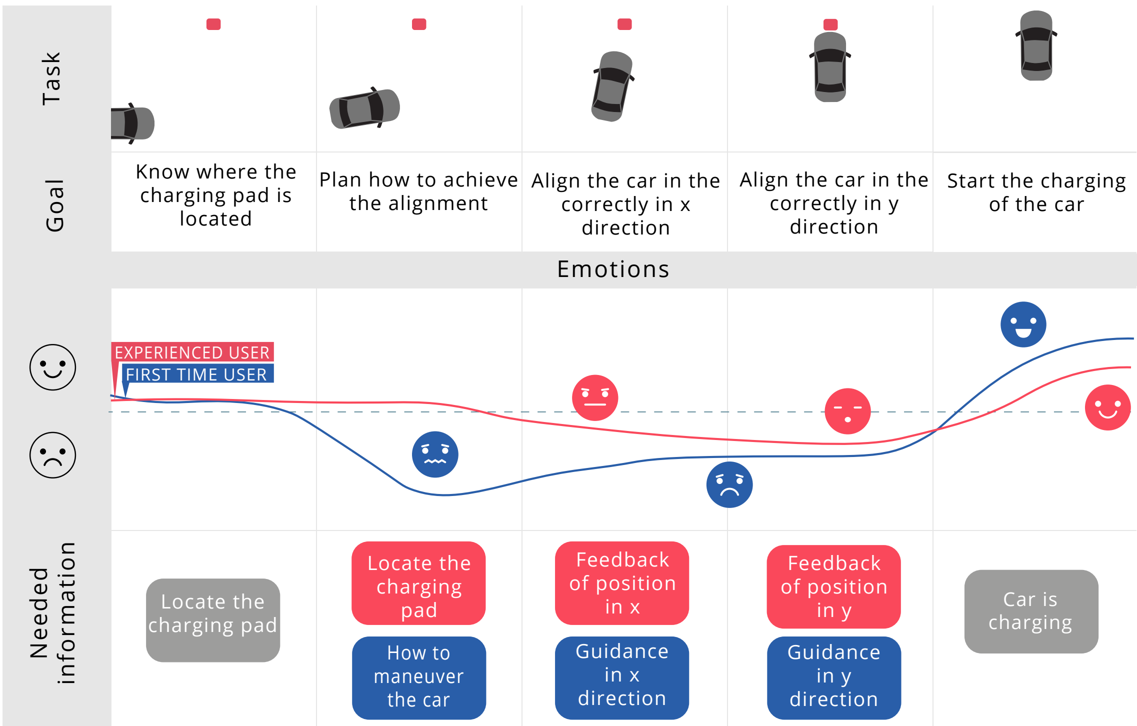


Figure 6.3: The journey map with the two different types of users: the experienced and the first time user.

As visualised in figure 6.3, the *first time user* is very uncertain and the most critical part is the task to *plan to achieve the alignment*. In this step, *the first time user* needs help and support to feel confident. The information should provide how to manoeuvre the car. For the alignment, the *first time user* needs guidance to help them how to act. *The experienced user* is more confident since they are familiar to the task. For them it is important to get feedback of the position to tell them where they are in relation to the pad.

6.4 User Needs

The outcome from the data collection and usability test is translated into user needs and listed in table 6.1 below. The outcome is divided into user needs, stakeholder needs, interface functions and technical functions. To fulfil the needs gathered from the journey map, the guide needs to start more than 5 meters away from the pad. MV will therefore be used in the range of 5 meters, and to make the driver aware that the charging pad is near, bluetooth will handle the first communication outside the range of 5 meters.

Table 6.1: The needs from the usage design stage.

USAGE DESIGN	
NEEDS	
User needs	*- Guide the driver to the correct position* *- Be used while manually driving* *- Guide the driver in the task's different steps* *- Have low glance time*
Stakeholder needs	*- Fit different types of parking spaces*
FUNCTIONS	
Interface	*- First guide to a centralised straight position* *- Second guide to right position in Y-direction* *- Give information of correct position* *- Give information that the car is charging* *- Primary information with visual guidance* *- Secondary information with haptic and audio guidance*
Technical	*- MV within the range of 5 meters* *- Bluetooth outside the range of 5 meters*

6.5 Second Ideation

The initial ideation in chapter 5.4.2, the aids to help the driver are described as either a conformation or a guidance. The captured knowledge from the usability test was that conformation is needed for the driver to ensure that the car is in the correct position. However, only a confirmation is not sufficient and a guidance is required in order to align the car. Three types for guidance were generated, visualised in figure 6.4. The categories are *Direction*, *Ratio* and *Pathway* suggested to create an alignment interface with the explanations below.

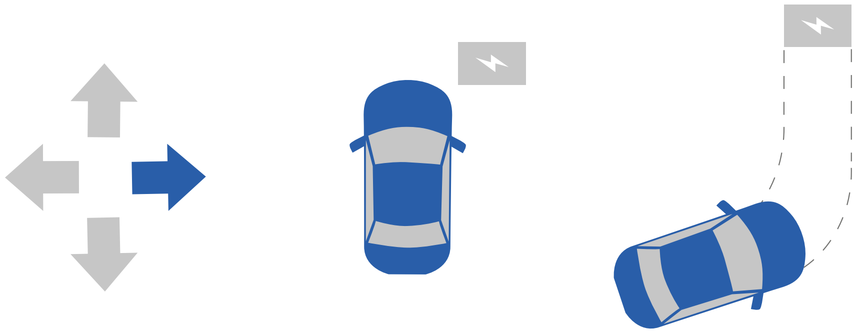


Figure 6.4: Different types for guidance. From right: Direction, Ratio, and Pathway

The first category *Direction*, can be achieved by informing the user to turn right, left, forward, or reverse, e.g. with arrows, or voice. The direction guidance do not inform how much the user needs to turn and does not show the distance between the car relative to the pad, i.e. a full perspective of the car's position and the pad's position is hard to reach.

The Ratio informs the user where the car is in relation to the pad. The user needs to find the way by themselves and is in charge of their own actions, which some users would prefer. Although, this could lead to high mental workload for the user.

The Pathway shows the car in relation to the pad and the path needed to drive in order to position the car correctly. The pathway leads the user and does not require any initiative from the user. This could be preferable for a first time user, however the pathway could result in too much information and/or disturb the user.

Another finding from the generative session was that visuals are required to align the car, and will therefore be used in all further proposed solutions. Audio and haptics are good to support the visual information or create attention. They can be used for conformation with a pleasing sound when completing the task. They can also be used as feedback when e.g. the user drives in the wrong direction, or it can be used as attention when the driver needs to do a different commando.

7

Overall Design

The aim of the overall design is to investigate which elements of the parts in the interface that gives a certain result and to investigate how the interaction between human and machine should be designed. The goal is to develop the overall design and to choose the principle for interaction, aesthetics and shape. The overall design is developed by firstly investigating the existing technology to guide the driver. Based on this, and earlier finding, generate concepts. The concepts are further evaluated and an outcome is presented.

7.1 Data Collection

The data collection for overall design is focused on available technologies that today are used as aids to guide the driver, to gather knowledge and inspiration from existing aids. The data collection focuses on parking assistant systems and augmented reality.

7.1.1 Parking Assistant System

Overall, there are two different parking assistant systems today. For perpendicular parking, the parking systems are helpful when parking in reverse mode. According to NHTSA standards (National Highway Traffic Safety Administration, 2013), a rear camera must be displayed when reversing and OEMs have utilised this by adding a guidance system plotted onto the camera view. Audi's parking assistance for perpendicular parking displays a blue area representing where the car will be if going straight backwards. When the driver aligns the steering wheel, the orange guidelines adjusts after the steering movement, showing the turning radius and how the car will be aligned.

For parallel parking, as well as when the visibility is low, it is common to aid the driver with a warning system showing how close the car is to another object. This system uses both visual information as well as a beeping sound where the frequency gets higher the closer the car gets to the object. The warning system in Volvo Cars displays the car together with the surrounding environment from above. Together with getting a better perspective of the car, it is possible by touch to zoom in on a specific place where a more precise view is needed.

7.1.2 Augmented Reality

Augmented reality (AR) is an upcoming trend among automakers, combining HUD technologies with AR. By visualising information in the HUD, the user does not need to remove their eyes from the road. AR goes a further step by using GPS and sensors to identify objects around the car. With this type of information, the images in the HUD can highlight important objects or visualise the directions directly on the road. (Cunningham, 2017). There are several suppliers and aftermarket manufacturers of AR for cars. WayRay develops Navion and have a partnership with Alibaba. (Shu, 2017). Another company that develops AR is Digilens, that is in partnership with Continental (Cunningham, 2017).

7.2 Concept Generation

Through findings in chapter 5 and 6, an initial concept generation was carried out. The different types for guidance, see chapter 6.5, where further developed and combined into various concepts. This was made with an open mind set in order to gain a wide range of different solutions for an alignment interface. The external data collection was used as an inspiration to create concepts with feasible technology.

The outcome from the concept generation was further evaluated with an elimination matrix to remove solutions that did not meet the requirements. The elimination matrix was based on if the concepts fulfilled the main problem, met the requirements and if they were realisable. This resulted in eleven concepts, listed below:

Concept A - Arrows & Overview
The concept in figure 7.1 guides the driver through two different visuals: arrows pointing in the direction as well as a view from above. The arrows located in the DIM lights up when the driver needs to adjust the car. The car is also visualised in the CSD from above, showing the surrounding environment and where the charging pad is located.

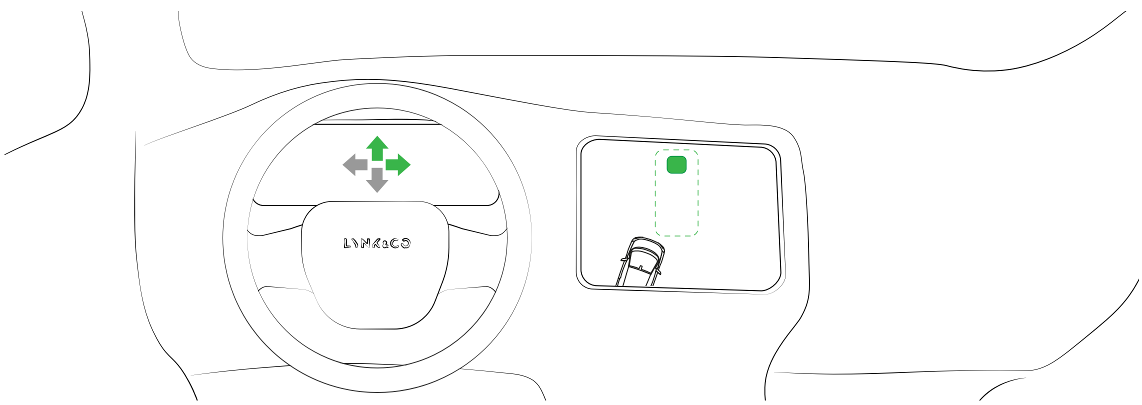


Figure 7.1: Arrows showing directions in the DIM and an overview of the car's position in the CSD.

Concept B - Runway
In figure 7.2 below, a concept with guidelines in the HUD is visualised. The black lines demonstrate the car's position and are still. The green lines demonstrate the position the car needs to be in. When the correct position is reached, the lines meet and shows that charging is initiated.

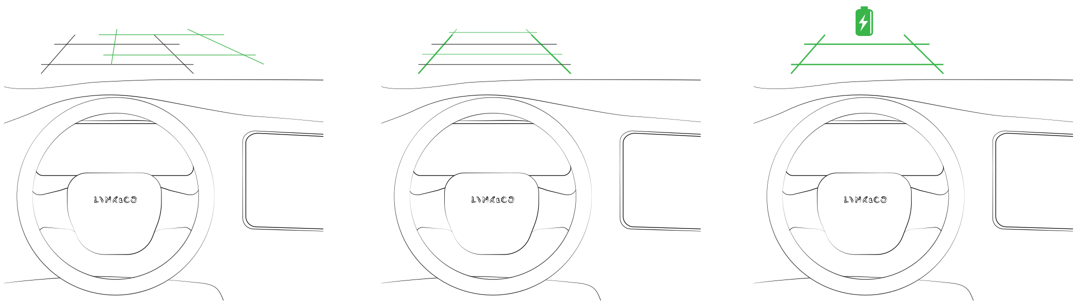


Figure 7.2: Guidelines in the HUD showing correct position in X and Y directions.

Concept C - Pathway
The concept in figure 7.3 uses the HUD to display the guiding for the driver. The pathway to reach the pad is marked and if following the pathway, the charging can start when reaching the pad. However, if driving outside the pathway, the steering wheel will vibrate on the side that is outside and warning lines will appear next to the pathway in the HUD.

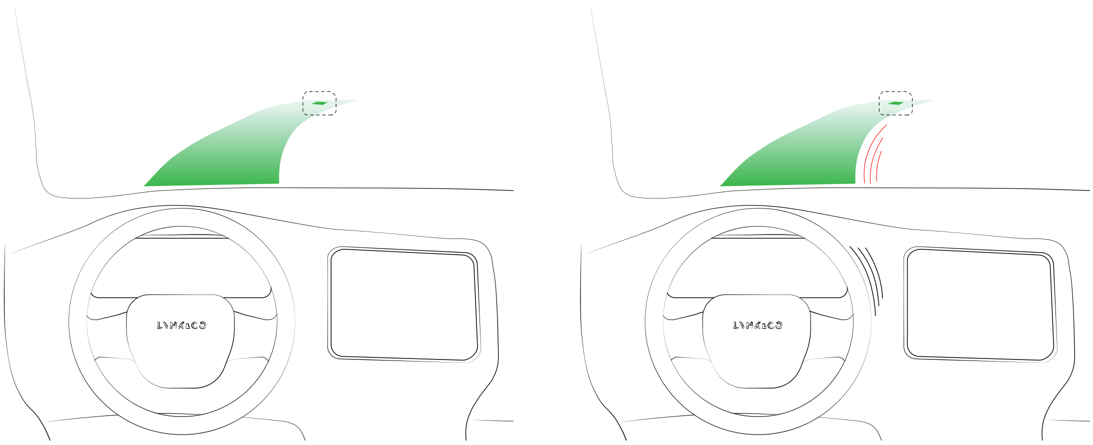


Figure 7.3: A driver's guide in the HUD showing how to manoeuvre the car. If outside the route - vibrations and red markings are showed.

Concept D - Guiding wheel
Concept D, illustrated in figure 7.4, guides the driver using illumination in the steering wheel. A dynamic light on the sides indicates in which direction to rotate the steering wheel, when the correct position is reached - the inner part of the wheel is illuminated and the driver can move forward. When the car is in the right position

in X, the edges of the wheel illuminates and becomes brighter the closer the car gets to the pad. When the right position in Y direction is reached, a charging symbol is visualised.

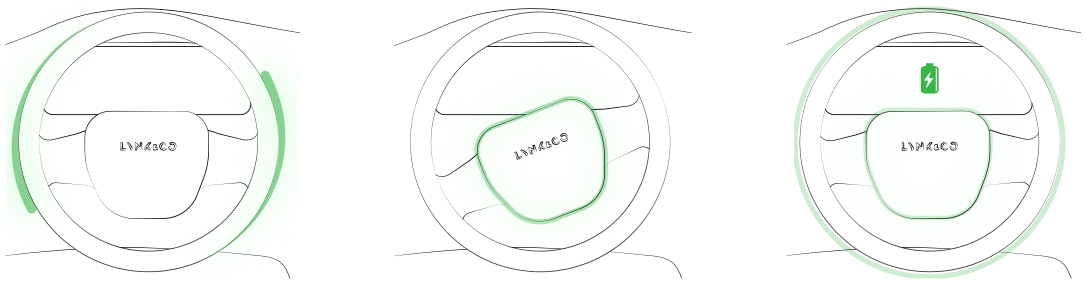


Figure 7.4: Lighting in the steering wheel indicates how to adjust the car. The steering wheel lights up in the middle when the correct position is reached.

Concept E - Guidelines
The concept in figure 7.5, shows an overview of the car and where to position the car to start charging, with the surrounding environment. An illuminated field in front of the car shows what position the car will have when the steering wheel is in the current position. If turning the steering wheel in a direction, the field will adjust to the new position.

Two guidelines are first visualised, indicating that the car should be inside them to align the car correct in X direction. When the X position is correct, the dashed lines turns green. When the X lines turn green, the Y guideline appear. When the car is in the right position in Y direction, the Y line turns green as well.

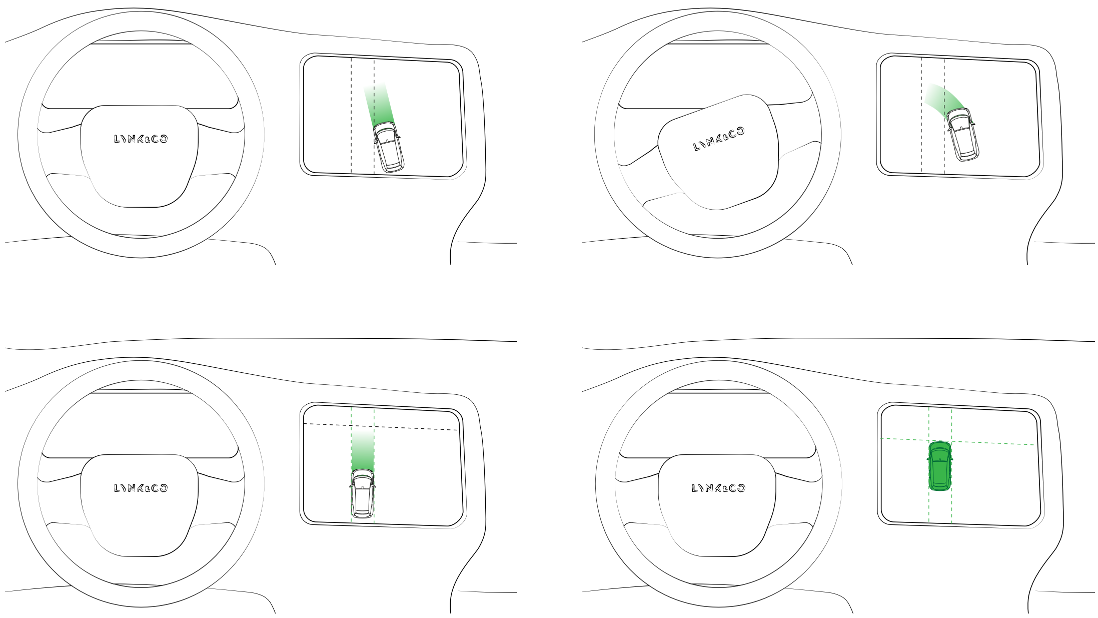


Figure 7.5: An illuminated road in front of the car and the guidelines help the driver to the correct position

Concept F - Aim
In figure 7.6, the concept of using an aim is visualised. Similar to concept B, the aim is still and shows the car's position. The other circle demonstrates the position of the pad. The position is reached when the circle is centred inside the aim.

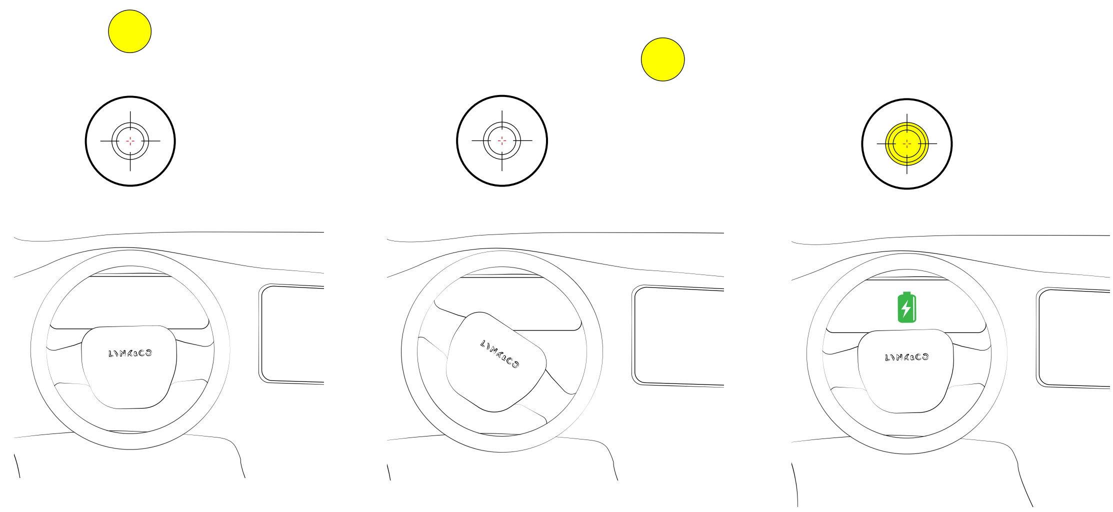


Figure 7.6: An aim is showed in the HUD with the car's position and the charging pad's position

Concept G - 3D view
The concept visualised in figure 7.7 has a 3D view of the car with the surrounding environment. The charging pad is also visualised and allows the driver to see the car relative to the pad. Through touch, the user can adjust in 3D to get the view needed to position the car in the correct position.

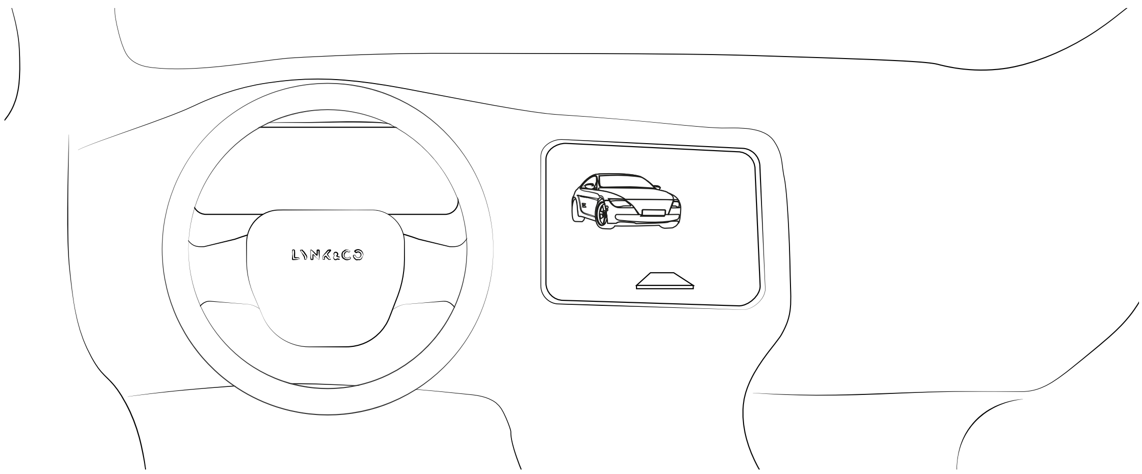


Figure 7.7: A 3D view of the car with the surrounding environment.

Concept H - See through

The concept in figure 7.8 visualises the idea of viewing the pad when it disappears under the hood. First, the pad is located in the HUD showing the driver how to adjust the car in X direction. When driving ahead and when the pad disappears under the hood, it is visualised on the dashboard showing its position. When the car is in the requested position, the visualised pad is located below the CSD.

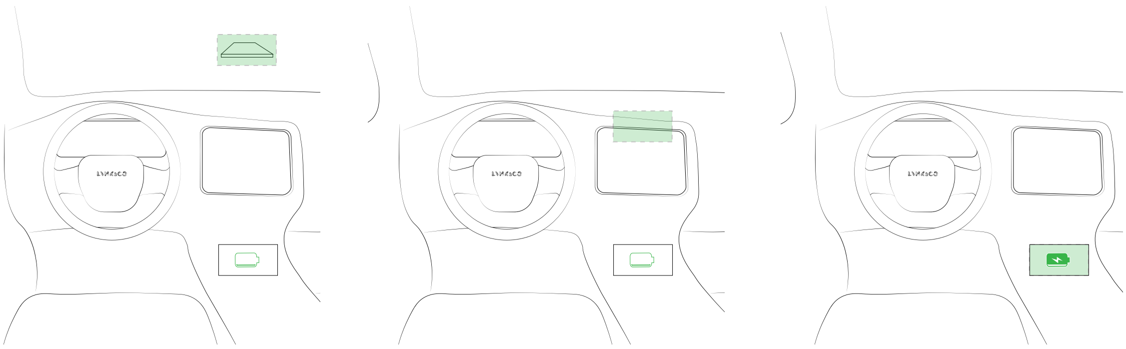


Figure 7.8: When the pad disappears under the hood, the pad is visualised on the dashboard.

Concept I - Under the hood

The concept below in figure 7.9 is similar to concept H, where the need to view the pad after disappearing under the hood is important. A guideline in the HUD helps the driver to position the car in X direction and when the pad is under the hood, the car's front and the pad is visualised in the CSD. Arrows show if the driver needs to go forward or reverse and when the correct position is reached, the pad gets filled in.

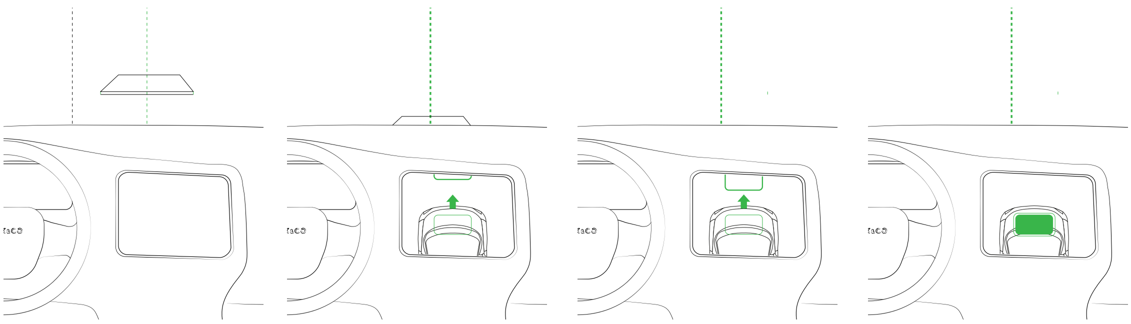


Figure 7.9: When the pad disappears under the hood, the pad is visualised on the CSD

Concept J - Compass
The concept in figure 7.10 guides the driver in X direction through an interface resembling to a compass. The triangles in the bottom indicate in which direction the pad is located. When steering the car towards the target, the dashed line follows the movement. When the triangle and the dashed line meet, they move towards the centre showing that the position in X direction is correct. When driving ahead towards the pad, a charging symbol appears when the correct position is reached.

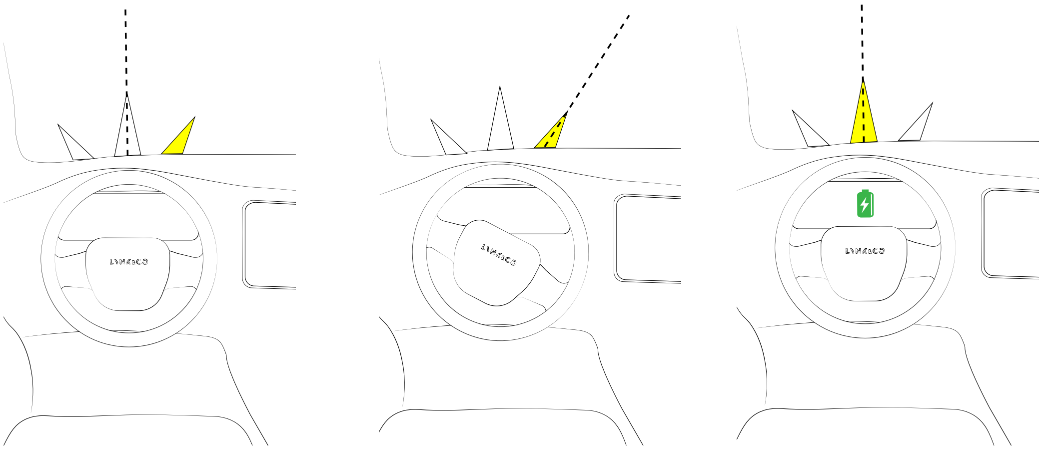


Figure 7.10: A 'compass' is visualised in the HUD, showing how to align the car

Concept K - Axis
Concept K is visualised in figure 7.11, showing how it will guide the driver to align the car. The car is visualised from above with the surrounding environment. The car's centre axis is visible as well as the pad's centre axis. To be in the correct position in X, the two axes must meet. When they have met, arrows on the car visualise if the car needs to be aligned forwards or backwards. The charging symbol appears when the correct position is reached.

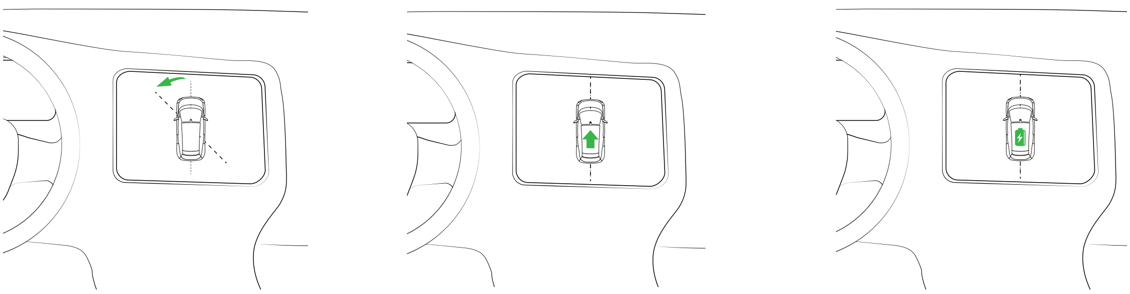


Figure 7.11: Guidelines in the CSD shows the alignment of the car.

7.3 Focus Group

A focus group was set up, with some of the participants from the usability test, to evaluate concepts and generate additional ideas. The participants studied the concepts and got a general understanding where different opinions were discussed and put into perspective. Some of the participants were not supporting the ideas that seemed too unfamiliar, while other participants found them interesting. They all agreed that a help is needed when the pad is under the hood, as well as having a guidance that works step by step. Most the participants found it very helpful to see how the steering direction would change the alignment of the car (similar to a rear camera). Some of the participants said that it would be very disturbing with sound and vibration which *"would only irritate the experienced driver and mock the first time user"*. The concepts with information in two places were criticised due to the division of information and keeping track of two areas at the same time as driving. Another aspect discussed in the focus group was the feeling of the difficulty level of the task. All participants agreed that the interface should be designed to convey the feeling that it is a simple task. When the participants had too diverse opinions, they argued that the solution should be customisable to fit all different users needs. Based on the discussion, two new ideas were generated in the focus group. A visualisation of a camera view in the front of the car and a light that visualises the pad moving towards the car.

7.4 Identified Needs

Through findings in the generated concepts and the data collection from the focus group, additional needs were found and are stated in table 7.1 below. Functions that were decided for the interface are also listed in the table.

Table 7.1: The needs from the overall design stage.

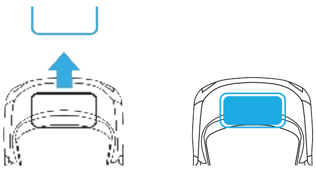
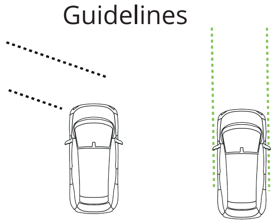
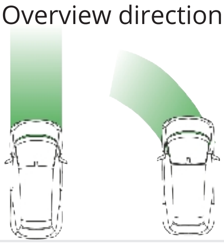
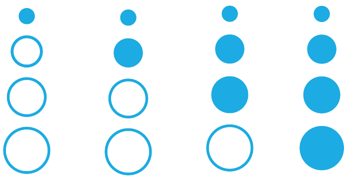
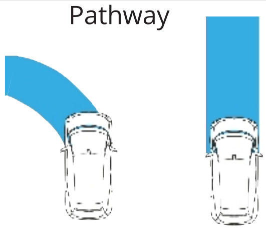
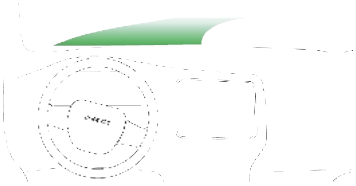
OVERALL DESIGN	
NEEDS	
User needs	*- Make the driver aware of their actions* *- See the relationship between the car and the charging pad* *- Extend the view of sight* *- Remind the user of previous experience* *- Only use one display* *- Be customisable*

7.5 Evaluation

Based on the stated functions in tables 7.1 and 6.1, the generated concepts were disassembled into the fundamental functions for the interface: *steering direction*, *overview*, *Y-direction* and *X-direction*. This was made to easier combine and mix the different functions that the sub-concepts possess. All identified functions and sub-concepts are presented in the morphological matrix in appendix C.

Concepts were eliminated with several weighted Pugh matrices, see appendix C. This resulted in 36 different combinations from the functions remained. Furthermore, sketching the concepts, the function *overview* could be dismissed since it already was a part of some functions sub-concepts as well as it became redundant because of too much information. The functions and sub-concepts left in the morphological matrix are listed below in table 7.2.

Table 7.2: Morphology matrix with the remaining seven sub-concepts.

STEERING DIRECTION	Y - DIRECTION	X - DIRECTION
Front camera 	Under the hood 	Guidelines 
Overview direction 	Receiving Lights 	Pathway 
HUD 		

7.6 Verification

The remaining sub-concepts from the morphological matrix in table 7.2 were tested and verified with a drive test, video visualisations, and a PHEA. The verification was established to get a deeper understanding how the concepts work, the feasibility and to detect possible problems.

7.6.1 Drive Test

To analyse and test the concepts, a drive test was executed. The field of vision was examined where it became clear that not much of the actual parking spot is visible during the majority of the task. Because of this, the idea of using the HUD with a pathway as a mediating tool was dismissed due to that it could only be used before turning into the parking lot, and not during the fine adjustments. Though the HUD highlights the way to drive by augmented reality in the windshield, and since the field of view is hidden by the hood, the visualisation in the windshield became useless. *HUD* was therefore eliminated.

The sub-concept *Front camera* was also tested. The test gave an insight how a front camera provides a view of the hidden part of the road. However, the view gave a irrelevant view, that confused the driver. The car's front has a ratio movement compared to the wheels, which makes the view too far away from the actual movement of the wheels. If lines and a pathway are added on the camera it may become clearer. Although, the reality view from the camera is redundant. The reason for using the reverse camera is to detect objects or persons behind the car. For the purpose to align the car, only the position of the pad is relevant. *Front camera* was therefore changed to *Front view*, that has the same perspective of the view, but without the real life camera.

7.6.2 Video Visualisations

The remaining sub-concepts were combined, and to understand how the solutions affect each other, they were visualised as mock-ups with videos and animations. The video visualisations were made to understand how the concepts act when the car is moving in relation to the user, environment, and the car's dashboard.

The outcome from the visualisation showed that the functions *steering direction* and *X-direction* could be combined directly since they are needed at the same task - to manoeuvre the car towards the pad and centralise the car. Therefore, *Pathway* and *Guidelines* were integrated in *Front view* and *Overview*.

The sub-concepts for *y-direction* are required in the last step and are not depending on *steering direction* and *x-direction*. Therefore, *Under the hood* and *Receiving lights* were considered separate from the rest. Studying the two concepts in action made it clear that both of them provide good information.

7.6.3 Predictive Human Error Analysis

The sub-concepts were investigated with a predictive human error analysis (PHEA) to understand potential errors that may arise with the various concepts and in that way compare them. The various sub-solutions got the same potential errors, except for the comparison between *Guidelines* and *Pathway*. The sub-concepts stand out with different errors depending on the solution. The conclusion that could be drawn was that for the first time user, less errors arise with *Pathway*. However, *Guidelines* and *Pathway* were similar for the experienced user. Since the requirement that the concepts should fit both experienced and first time users, *Guidelines* was eliminated.

7.7 Initial Functions

From the evaluation and verification the functions sub-concepts were set to the following:

Steering Direction
The steering direction can either be visualised with a flat view from above or a view in the same perspective as the driver sees the road.

X-direction
Pathway should be used to guide the driver correct in x-direction.

Y-direction
For the final step, the driver should be guided with *Under the Hood* or *Receiving Lights*.

8

Detail Design

The aim of *Detail Design* is to explore how the solution in detail will behave towards the user and other parts of the system. The goal is to design the interaction between the machine, user and surroundings, and to choose the principles for the details. This was carried out by firstly deciding how the concept should be visualised. Potential errors and how they occur were investigated in order to prevent them. Thereafter, the architecture of the system was created and what including functions are required in the alignment interface. Finally, the graphical design of LYNK & CO was investigated.

8.1 Visualisation

This section is focusing on the development of the visualisation for the defined functions based on the outcome from chapter 7.7. Different generated ideas for visualisation are described and visualised. Further the visualisations are evaluated with various discussions and comparisons.

8.1.1 Visualisations Generation

Four different visualisations were generated by combining the functions remaining from chapter 7.7. A conclusion was made that the solution can be visualised in two different ways, with a car or only the path. *Under the Hood* was chosen to be part of the solutions with a car visualised and *Receiving lights* included with the concepts without a car. This decision was based on that the overall experience would be more logical and intuitive.

Following Arrows
In *Following Arrows*, see figure 8.1, the pathway is visualised with arrows and the steering direction is a coloured line. When the line and the arrows meet, the line turns green indicating that the car is on the right track. The pad is visualised with *Receiving Lights*, where the arrows are filled the closer the car gets to the pad. When the bottom arrow is filled, the car is in the right position.

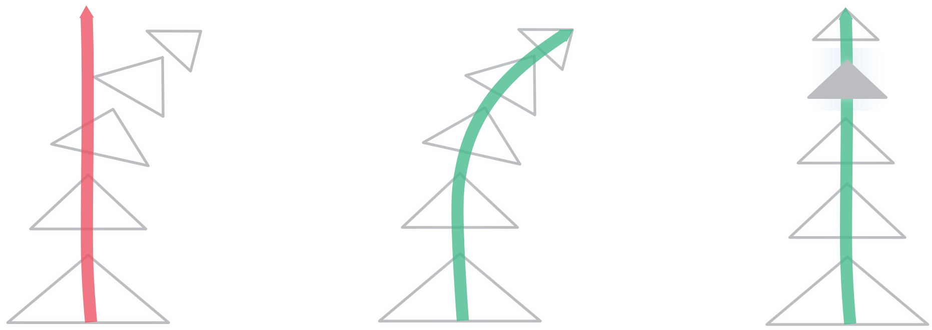


Figure 8.1: The simplicity of the visualisation is a strong focus in *Following Arrows*.

Wayline

The concept *Wayline*, see figure 8.2, is visualised as a front view of the road. The pad is visualised with a blue line moving towards the driver as *Receiving Lights*. The steering direction is visualised with lines at the sides of the pathway.

Figure 8.2: The visualisation gives a perspective of being on the road.

Behind the Car

Behind the Car in figure 8.3 visualises the car from an overview with a perspective from behind. When the correct x-position is reached, the perspective is changed to as in *Under the Hood* to easier position the car in y-direction.

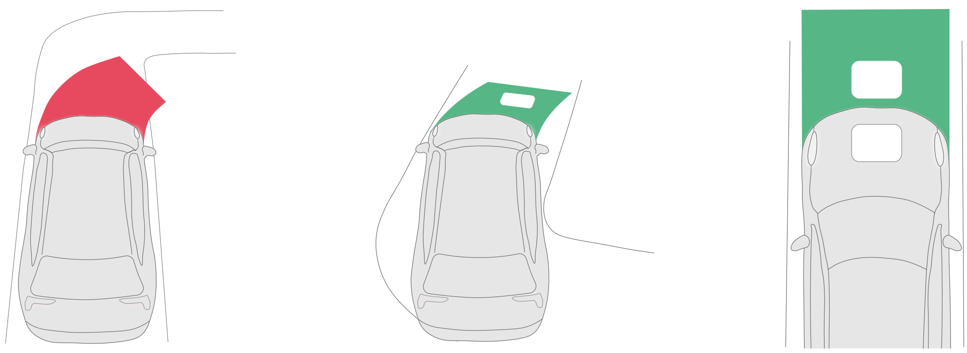


Figure 8.3: The pathway and the car is visualised with a perspective from behind the car. When getting closer to the pad, the perspective is changed and zoomed in.

Overview

In figure 8.4, *Overview* is visualised in the CSD where it is supposed to be integrated with the bird's eye view of the car with the parking sensors. When getting closer to the pad, a zoomed in view is visualised as in *Under the Hood*.

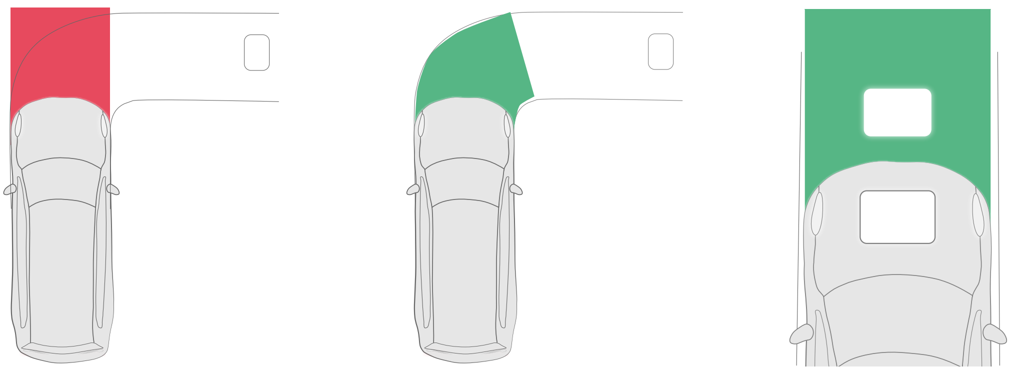


Figure 8.4: The pathway with the steering direction in colour in the front. The visualisation is supposed to be integrated with the bird's eye view.

8.1.2 Evaluation

To evaluate the visualisations, various discussion sessions were conducted. The conclusion from both sessions were that the visualisations with a car were easier to understand. The participants understood directly the relation to the path, the steering direction and the pad. Another strong benefit with the visualisation of the car is the overlap with the car and the pad in the last step. This visualisation provides the clearest feedback that the car is in the correct position. Therefore, *Following arrows* and *Wayline* were eliminated. *Behind the Car* and *Overview* were evaluated with pros and cons during a session. In table 8.1 the pro's and con's are listed.

Table 8.1: Pro's and con's for *Behind the Car* and *Overview*.

	BEHIND THE CAR	OVERVIEW
PRO'S	*+ Placed in DIM* *+ Integrated with roadview*	*+ Integrated with parking assistance* *+ Consist perspective*
CON'	*- Change in perspective* *- Blockage of view*	*- Placed in CSD* *- Messy with surroundings* *- Too much information*

Behind the Car is placed in the DIM where the advantage is the low glance time and the similar perspective as the one the user is driving in. Additional is that the guide can be integrated in the road view already placed in the DIM. Contrariwise, the *Overview* is placed in the CSD and can be integrated with the parking assistance. However, the placement in the CSD will contribute to a longer glance time that require a higher mental effort for the driver. The integration with the parking assistance can also conflict with the information, which can be messy with the surroundings, consequently leading to the driver being unable to sort out relevant guidance from the rest of the information.

Behind the Car requires that the perspective is changed in order to see the pad in the last step. This movement can confuse the driver, due to the movement in perspective at the same time as driving forwards. The car visualisation can also block the view of the path and the steering direction making it hard to see the guide. However, the design for *Behind the Car* can be further developed resulting in that the disadvantage can be overlooked. For the *Overview*, the integration with the parking assistance and the placement in CSD are fixed and therefore the disadvantages will remain. The conclusion from the evaluation is that *Behind the Car* is further developed, while *Overview* is eliminated.

8.2 Predictive Human Error Analysis

The alignment interface consists of different steps and functions where it is important to understand all possible scenarios. A PHEA was made to understand how the alignment interface would work and what types of errors that can occur. The PHEA matrix can be found in appendix D where use error, cause, consequences, detection and recovery are presented.

Potential detected errors that could occur are caused by the driver not following the guide. The reasons can be that the driver does not understand the guide, fail to follow it, or by choice ignore it. This results in that the user drives outside of the path or fails to stop at the right time. These errors can be avoided by designing the HMI understandable, give feedback, and/or update the guide. Another error that can occur is that the charging does not start because of a foreign object is in the way, see chapter 2.2. This is critical though the driver has completed the task correctly, but the charging fails to start anyway. To avoid this, the driver needs to be informed about the error and what kind of action is needed to correct it.

8.3 Architecture of Functions

The functions for the HMI were further generated and compiled into a system architecture. In figure 8.5, the architecture is visualised, with start: *Charging pad detected* to the left and end: *Charging starts*, to the right. The functions are explained with their requirements and specifications below.

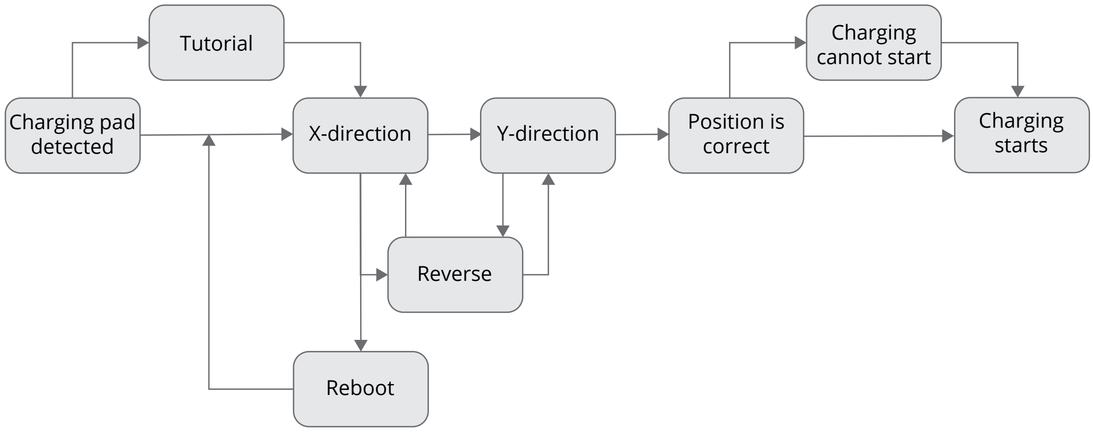


Figure 8.5: The alignment interface's architecture with the functions.

8.3.1 Charging Pad Detected

The start of the alignment interface appears when the car is inside the range to detect the pad. The important part of this function is that it should be obvious that the car has detected the charging pad and make the driver aware of the alignment interface. In order to make the driver aware of the information, attention from the driver is required.

8.3.2 Tutorial

The alignment interface should be designed and developed to fit a first time user. The guidance should be easy to understand and to follow. However, in case that some users do not fully understand the guide, a tutorial is necessary. The tutorial should describe the purpose with the guide, how to follow it, and the functions such as steering direction and pathway.

8.3.3 X- and Y-direction

The functions for x- and y-direction will function as explained throughout the report: Firstly in x-direction with a car from behind and then zoomed into y-direction from above.

As described in the PHEA, various errors can occur making some functions necessary. In the case that the user drives too far from the path or does not stop in time over the pad, the guide should inform the user to reverse. This is needed both in x- and y-direction. In case of the error that the user does not follow the path, a recalculation of the path is required from the new position. This function is necessary if the driver choose another path than what the system informs, by choice or accident. It needs to be clear that the car is generating a new pathway for the driver to follow, to avoid confusion if for example the guide suddenly changes to a new pathway.

Giving feedback if the car is in the right/wrong direction is important in order to help the driver follow the path. Another thing to consider is the tolerance of feedback. If the tolerances of the guide are too narrow, it will be very hard to be correct on the pathway. To avoid this, the tolerance needs to be wide in the beginning and narrowed down towards the end when the exact position is required.

8.3.4 Position is Correct

When the car is in the correct position, it is important to inform the driver that the alignment task is finished. In order to avoid that user drives too far in the end of the guide, the correct position should be highlighted making the user notice the correct position and can stop the car in time. It is also essential to highlight that a correct position does not necessarily means that the charging starts.

8.3.5 Charging Starts

As well as standing in the correct position, it is necessary to inform the user that the charging has started. This is primarily to ensure the user that their car will be charged when used next time. Information of the charging status should be visualised to create awareness of time and battery level.

8.3.6 Charging Does not Start

A warning message must appear in case of error that affects the pad causing the charging not to start. The driver needs to be informed with a warning message telling the driver to clean the pad. It is necessary that the user perceives and understands the information and action needed to correct the problem.

8.4 Graphical User Interface

The graphical design of the solution should fit the existing display design of LYNK & CO and be consequent regarding colours and symbols.

8.4.1 Displays LYNK & CO

The design for the existing displays in the LYNK & CO cars is studied to find ways to implement the design for the alignment interface. In figure 8.6 the DIM design is visualised for the existing LYNK & CO 01. The cluster consists of an overview of the car to the left and in the middle of the cluster the speedometer and fuel status are visualised. In the right there are various information options consisting of car information, navigation, media and communication.

The graphical parts in the alignment interface consists of a car, the pathway, and the steering direction. The design for each part needs to be visualised to fit each other but also to be able to distinguish them from one another.

Figure 8.6: LYNK & COs design of the DIM.

8.4.2 Colours for EV Charging

The feedback used in EVs today, when it comes to charging, is mainly placed where the plugin is located to inform the user directly. Most of the EVs on the market give feedback to the user through coloured lights. It is common with a flashing light when the car is charging, where Volvo, Tesla and Volkswagen uses a green light, while BMW uses a blue flashing light. When the car is charged, all of the investigated cars have a green still light. The red colour is used by all OEMs to visualise that something is wrong with the charging process. Another feedback is a yellow or blue light to show that the contact is placed in a correct position.

The colours that will be used in the graphical design for the alignment interface are set to be green as a correct action and red as an incorrect action. Since the interface both will inform when the position is right and the charging starts, the blue colour will be used for when charging starts instead of green that other OEMs use. Other colours that will be used are the LYNK & CO standard colours in figure 8.7.

8.4.3 Design Guidelines

The design guidelines have been extracted through analysis of LYNK & COs existing HMI as well as through the homepage. Other factors included have been influenced from trends among other car HMI, but also inspiration from LYNK & COs user segment. This was made to align the solution towards the LYNK & CO market segment.

The mood board visualises the feeling the design should express for the user. The keywords used for the board are: simple, unique, familiar, fun, connectivity, shareable and trending. The colours below in figure 8.7 are found in LYNK & COs existing HMI. The pink colour is primary used as detail colour for symbols, or variation to the white, while the turquoise is the secondary.

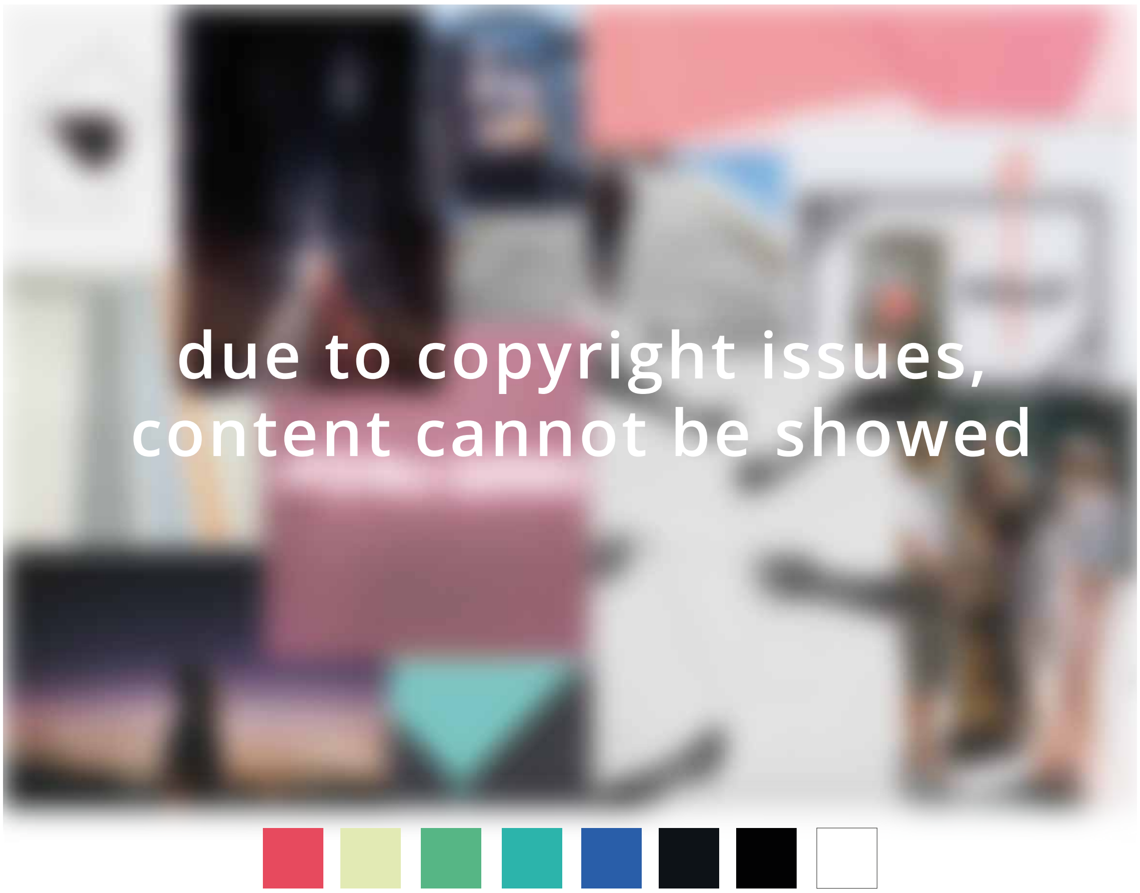


Figure 8.7: The mood board together with key colours.

9
Final Design

In this chapter, the final design for the alignment interface is presented and visualised. In figure 9.1, the overview of the guide is visualised. The chapter consist of visualisations and descriptions of the interface's different functions and stages of the process. The final design is further verified by testing the usability and comparing the result with stated requirements to ensure that the design fulfils the needs.

Figure 9.1: Overview of the alignment interface

9.1 The Alignment Interface

The final design is visualised in figure 9.1 and can be viewed in motion graphics at https://youtu.be/GKdN4UbKZ0Y The guidance is centralised in the DIM to ease the perception for the user, and also to attract attention. The speedometer is moved to the left side when the charging pad is detected while the media is in the same place during the whole procedure.

The alignment interface contains of a several functions depending on where the car is positioned relative to the charging pad. The sections below describes the guidance step by step and how this is visualised in the DIM.

9.1.1 Start

The GA and VA communicate with each other and alert the driver when a charging opportunity is detected. A blue circle appears over the speedometer with the text "Charging Detected" to communicate the information to the driver, see figure 9.2. The speedometer is aligned to the left and changes place with the overview of the car.

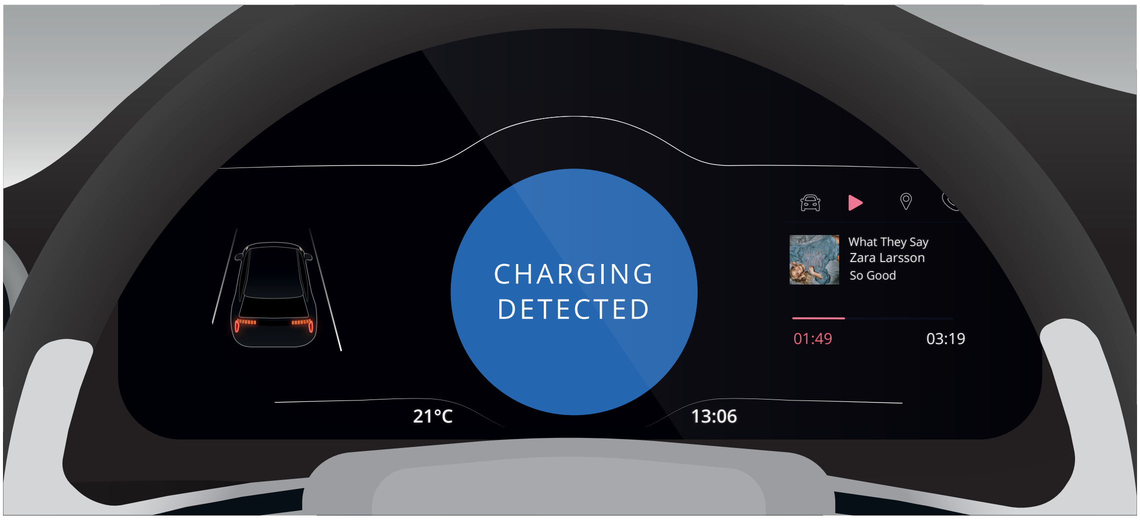


Figure 9.2: The message is showed when the car has detected a charging possibility.

9.1.2 Guidance by Pathway and Steering Direction

The view in figure 9.3 appears directly after the start screen where the overview of the car has been complemented with the steering direction and a pathway that leads towards the pad. The steering direction is green when the steering wheel is aligned and follows the pathway.

Figure 9.3: The car together with the pathway and steering direction. Here on the right track.

When turning the steering wheel, the steering direction in the alignment interface follows the direction. However, the visuals become red when the steering direction is outside the pathway to help the driver align the car correctly, see figure 9.4.

Figure 9.4: The steering direction is here aligned in the wrong direction.

Since the alignment interface is not autonomous, the driver is still in charge of how to drive even if the guide tells him/her how to park. When being too far from the pathway, the system will reboot to the new position to be able to adjust itself for the driver, see figure 9.5. However, if being too far from the charging pad, the system will be turned off assuming that charging was not desirable.

Figure 9.5: The pathway is being recalculated due to human error.

If the user is outside the pathway and drives too far making a new pathway too complex, the system will ask the driver to reverse. The visuals below in figure 9.6 appears with a yellow arrow and a text to make the information obvious. When the driver has reached a more suitable position, a new pathway will appear.

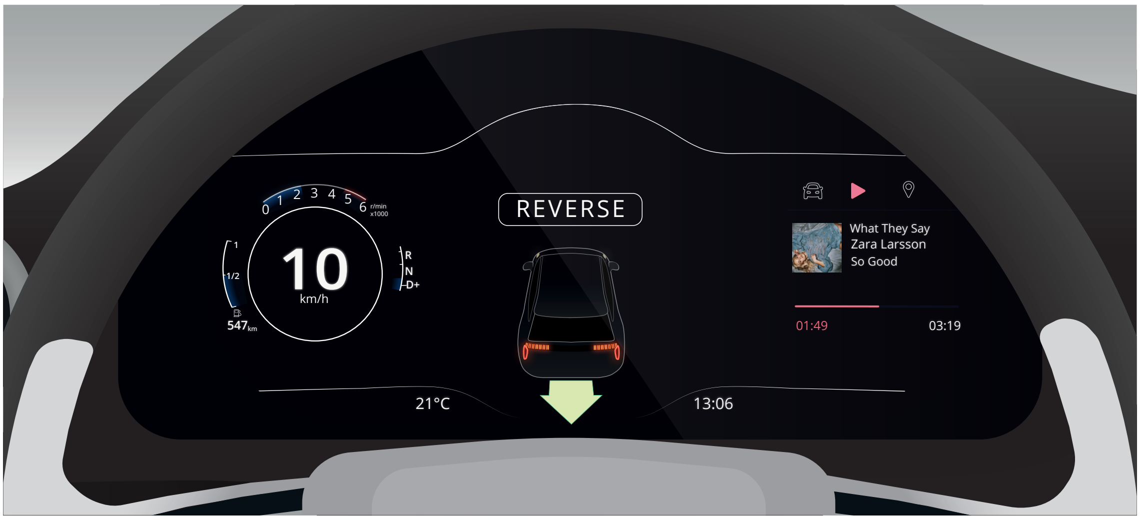


Figure 9.6: The visuals of how the system tells the driver to reverse.

9.1.3 Guidance by Zoomed in View

When the car is getting closer to the charging pad and is aligned correctly in x-direction, the perspective of the car is changed; from an overview from behind, to an overview from above. The view is also zoomed in and the car is assigned with a marking of the location of the VA. The charging pad is visualised in white with a charging symbol on top of it, see figure 9.7. The charging pad is visualised as slightly smaller than the VA to give the driver an impression of that some margins are acceptable. The GA and VA are also rectangular which will make it noticeable if the car is positioned in an incorrect angle.

Figure 9.7: The new perspective with the charging pad and desired position under the car.

As the car moves forward, the charging pad gets closer to the car and being inside the the VA, the pad gets green to symbolise that the car is in the right position. A vibration in the steering wheel and a sound is added to alert the driver to stop the car in the position, see figure 9.8.

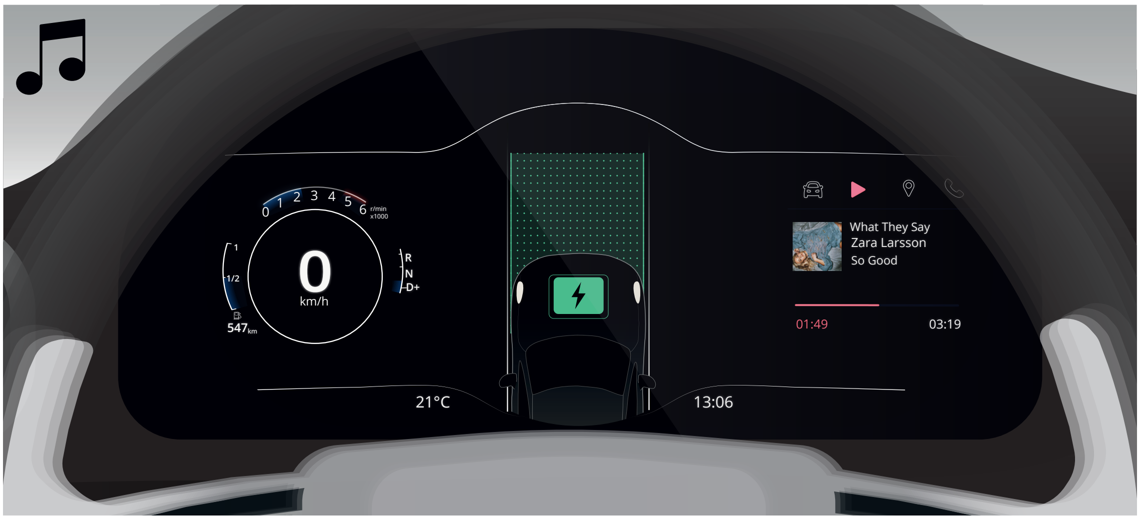


Figure 9.8: The visualisation when the right position is found. A sound and a soft vibration in the steering wheel alert the driver to stop.

If the driver does not stop at the correct position, the alignment interface will inform the driver to reverse the car. To make it clearer that an incorrect action is made, the charging pad changes colour to red, see figure 9.9.

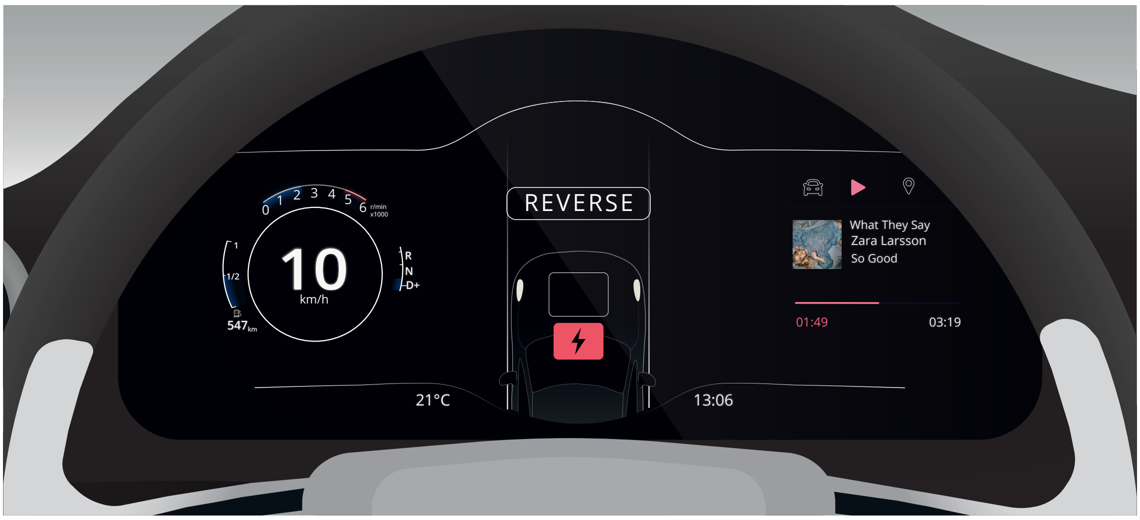


Figure 9.9: How the system tells the driver to reverse.

9.1.4 Start of Charging

When the car is aligned in the correct position and nothing interfere with the process, the message "Car is charging" is displayed to inform the driver that the charging process is initiated, see figure 9.10. The circle has the colour blue, which is set to be the colour of charging. However if a foreign or living object, see chapter 2.2, is between the coils, the charging process will not start. To be able to start the charging, the driver must go outside and take away the interfering object. The message "Foreign object detected. Clear the area on top the charging pad" is displayed with a red background to inform the driver that a demanding action is necessary to complete the task, see figure 9.11.

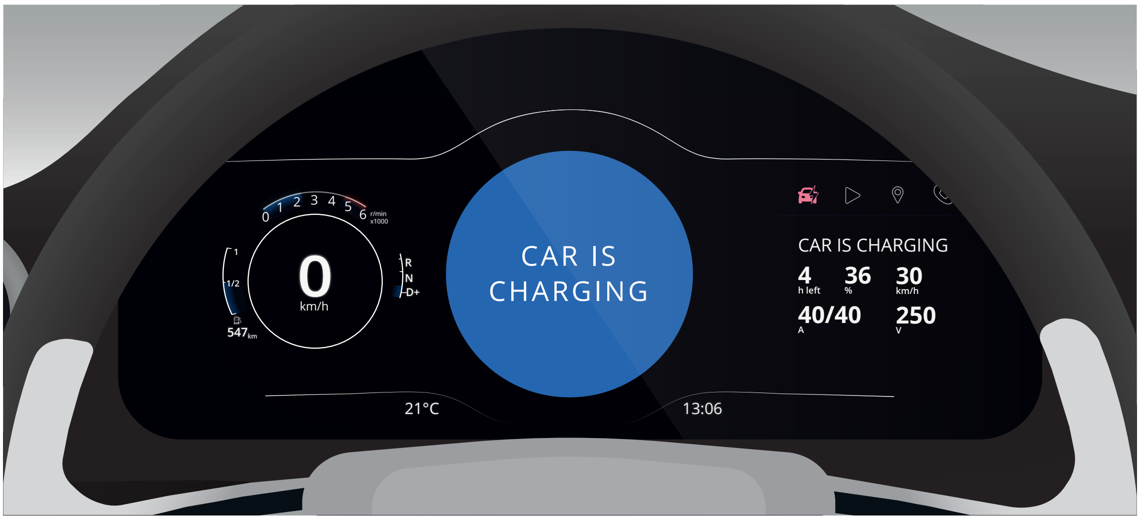


Figure 9.10: When the position is correct and the car starts to charge.

Figure 9.11: Message when one of the safety systems detects a foreign object.

After the message that the car is charging, a visualisation with relevant values for the charging process is visualised, see figure 9.12. The car symbol in the information to the right is market with a charging symbol as well.

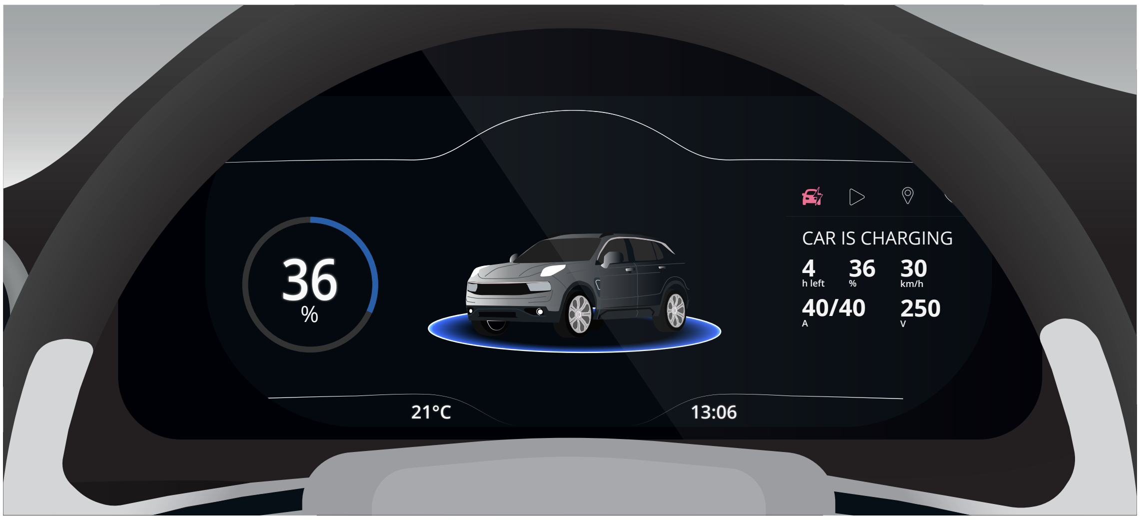


Figure 9.12: The visualisation of the charging process.

9.1.5 Tutorial

The tutorial is placed in the CSD since it is in need of a larger display than the DIM. When a first time user is using the car and is unfamiliar with wireless charging of an EV, it is possible to view a tutorial if the alignment interface somehow is hard to understand. The tutorial can be reached through an information symbol available in the CSD when a charging opportunity is near.

Figure 9.13: Overview of the tutorial.

The tutorial consists of explaining how the steering direction works and that the user should follow the pathway to find the right position to the pad. The last step of the alignment interface is not explained though the user will understand the basics in the beginning of the task. The tutorial can be found in figures 9.13 and 9.14.

Figure 9.14: The tutorial with the different steps.

9.2 Verification of Design

The final design is verified through evaluation and if it has fulfilled the needs found throughout the project. This was made with a cognitive walkthrough and a fulfilment check of the set needs.

9.2.1 Cognitive Walkthrough

To verify the final design, a cognitive walkthrough (CW) was conducted based on the sub-tasks as notice the guide, follow the pathway, stop in the correct position and clear area because of FOD/LOP. The CW can be found in appendix E with the questions, yes/no and success stories. The outcome from the analysis show great results and the user will in each task try to achieve the right effect, notice the correct action, associate the correct action with the effect, and see that progress is being made towards the solution.

9.2.2 Fulfilment of Needs

In table 9.1 below, all needs are gathered together with a fulfilment column with different attributes. A total of 28 of 32 needs are fulfilled by the final solution. All of these needs have been acknowledged through the thesis and will therefore not be repeated here. However, 1.1, 1.2 and 2.1 marked with *investigate* are needs that require further investigations and tests to make sure that they absolutely are fulfilled. The need 1.16 is fulfilled since the actual guidance is only placed in one display. Although the tutorial is placed in another display, it is not considered as a part of the guidance. The need 1.17 has been ignored though the solution fit both type of users and is therefore not relevant. The needs market with a star are fulfilled according to the project's scope, but are in need of development in the next phase.

Table 9.1: The needs from usage design stage.

FINAL DESIGN		
NEEDS		FULFILMENT
User needs	*1.1 Not conflict with other systems*	*INVESTIGATE*
	1.2 Not affect the user's attention and driving skills	*INVESTIGATE*
	1.3 Be more convenient than plugin	*YES*
	1.4 Fit different experience levels of drivers	*YES*
	1.5 Avoid and recover errors	*YES*
	1.6 Follow interface design principles	*YES*
	1.7 Provide user with information relevant to align the car	*YES*
	1.8 Guide the driver to the correct position	*YES*
	1.9 Be used while manually driving	*YES*
	1.10 Guide the driver in the task's different steps	*YES*
	1.11 Have low glance time	*YES*
	1.12 Make the driver aware of their actions	*YES*
	1.13 See the relationship between the car and the charging pad	*YES*
	1.14 Extend the view of sight	*YES*
	1.15 Remind the user of previous experience	*YES*
	1.16 Only use one display	*YES*
	1.17 Be customisable	*IGNORED*
Stakeholder needs	*2.1 Feasible and implementable today*	*INVESTIGATE*
	2.2 Align with LYNK & CO's market segment	*YES*
	2.3 Follow standard	*YES*
	2.4 Push the infrastucture towards the future	*YES*
	2.5 Make EVs more attractive on the market	*YES*
	2.6 Be superior to existing solutions	*YES*
	2.7 Fit different types of parking spaces	*YES*
FUNCTIONS		
Interface	*3.1 First guide to a centralised straight position*	*YES*
	3.2 Second guide to right position in Y-direction	*YES*
	3.3 Give information of correct position	*YES*
	3.4 Give information that the car is charging	*YES*
	3.5 Primary information with visual guidance	*YES*
	3.6 Secondary information with haptic and audio guidance	*YES*
Technical	*4.1 MV within the range of 5 meters*	*YES**
	4.2 Bluetooth outside the range of 5 meters	*YES**

10 Discussion

The discussion in this chapter focuses on the project made in this thesis - development of a HMI for wireless charging. The aim is discussed whether it is fulfilled or not throughout the thesis. The process is also discussed based on the choices and methods used to find the final results. Last but not least, the final solution is discussed with focus on if the solution is realisable or not. The chapter ends with a recommendation for the next step for a HMI.

10.1 Fulfilment of Aim

The aim of this thesis was to develop a HMI concept for easier positioning of the car when parking for wireless charging. This was set to be done by understanding the issues with the task, and to identify needs based on this. As can be found throughout the report, this has been accomplished through different types of methods to specify what is needed for the solution. The final design is also in chapter 9.2 verified in terms of usability and fulfilment of the needs discovered through the project.

To make the task convenient, investigation of the definition stated: *"anything that saves or simplifies work, adds to one's ease or comfort"*. The designed solution, together with wireless charging, makes the task more convenient to charge the car by saving time for the driver and simplifies the work. By ensuring convenience, the task to charge the car is fun and effortless.

10.2 Process

The ACD^3 process has provided a good structure for the project. To generate ideas in each stage with an iterative process has been useful, though the findings in the stages were directly applicable to the development. It was helpful to, in an early stage, generate ideas and build the design, compared to a traditional development process where the generation often is focused in only one phase.

The ACD^3 process has been a new method for both of the writers, which contributed to some confusion. It was sometimes unclear in which stage the ongoing work was in the process. The design levels often overlapped each other, which resulted in that work was made in two stages at the same time. This often made it feel like work had been made too far ahead, which required a step back to finish the earlier step. However, when it became clear in which phase each task belonged to, the ACD^3 process provided a clear structure of the development.

10.2.1 Usability Test

The participants for the usability test were collected with purposive sampling based on requirements in order to gather a wide spectrum of diversity. However, due to limited access of time to find willing participants, the sample was mainly collected from acquaintances. The fact that all participants were familiar with the conductors could have affected their behaviour, for example say and act in a way they thought the conductors would like them to. Anyhow, since the usability test was based both on an observation and an interview, the behaviour and answers could be compared and therefore created a believable result of the participants experiences and opinions.

The data collection from the usability test was measured directly with a measuring tape and a tolerance was added to compensate for errors. This tolerance could be too small or too big. However, the purpose of the data collection was to understand if it is hard to align the car in a specific position. The outcome proved that it is hard, regardless of the potential measuring errors.

Another thing is that the test was executed without any guidance or help, such as lines on the ground. It may had been useful to also perform the test in a parking lot to understand the differences. The lines could have helped the users to be more correct. Anyhow, reports that have been studied show that people have difficulties to park centralised in a square. Also the fact that the alignment interface should work in all scenarios concluded to that a test with a parking lot was not needed.

10.2.2 Focus Group

For the focus group, some of the participants from the usability test were gathered. This was decided since they already had knowledge about the task and the difficulties to align the car. It also facilitated concerning time since there was no need to find new participants and explain the task. The fact that the same persons were used for both interviews and focus group could however influence to a narrower view of the problem. Although lots of different aspect were discussed and the outcome was only considered as a feedback.

10.2.3 Concept Testing

The concepts generated throughout the project consist of different types of feedback. To test if the driver understands the feedback was difficult, though it needs to be tested in real time. Although some tests were made, they had little connection to how it would be in reality and some of the concepts were eliminated due to the lack of knowledge of how they would behave in different situations. Consequently, the evaluation of the concepts may have been aligned towards what the writers imagined to be feasible. If e.g. simulator tests would be available, it would enable an easier way of performing concept testing in an early stage to understand how the concepts would behave and an equitable evaluation would be possible.

10.3 Solution

The developed solution have been made with focus on usability and factors found through analysing the problem of the task to position the car. An issue with developing a solution as a thesis work consisting of two team members is the lack of a cross functional development and to include all requirements of the alignment interface. By only focusing on the usability, the technical and electrical parts of the system are neglected. Consequently, it is questionable if the developed solution is realisable or not due to the complexity of how the interface can be calculated. However, if the solution is realisable, the variable of the cost has not been included in the development. If the system is complex, the cost is probably high.

The lifespan of alignment guidance is considered from today until autonomous cars and/or parking assistance become a norm. This may be a quite short lifespan, due to that mobility is instantly developed towards self driving cars. This factor has limited the generation of radical innovation. In order to implement the interface now, existing technology and components have been studied more than new technologies. If the lifespan for the alignment guidance was longer, the outcome of the development may have been more radical and innovative.

In the final stage of the development process, when the design of the final solution was set, BMW released their solution for aligning the car for wireless charging. BMW's solution have many similarities with the developed design in this project. BMW's solution have similar functions: a pathway, steering direction, the change of perspective and the last alignment with the close up view. It is more or less the same principle as the solution *Overview* that was eliminated in the last iteration, where the alignment is integrated with the parking assistance and bird's eye view of the car. However, this verify the identification of needs and development of functions, as well as a confirmation that the solution would be feasible. It is also a verification to the writers that the work made in the thesis has the outcome similar to one of the largest OEMs.

10.4 Recommendations

When continuing with this project, it is necessary to generate a test version of the alignment interface to be able to test the alignment with the guidance. Preferable would be to perform a user test to see how the user experience the interface. A test version is needed to be able to know whether the solution is feasible or not. Investigation of technical and electrical details need to be done, in order to detect requirements necessary for realisation.

The infrastructure for wireless charging needs to be further developed in order to fully implement wireless charging. This means that in the first step, EVs still need to be equipped with plug-in while wireless charging will be an extra add on. However, a person willing to pay for an add-on as wireless charging, could as well desire a more exclusive model and all extra functions included with it. Function as parking assistance are quite common in the exclusive models, and could easily replace an alignment guidance. If the car could park itself exactly over the charging pad, the guidance would be redundant. Although, if the infrastructure is more developed, wireless charging will be offered and available to more people which will make the wireless charging to the same status as the plug-in and in turn make the autonomous parking to the exclusive part. A recommendation is to further investigate the lifespan and market for wireless charging.

11
Conclusion

The foundation of this master thesis have emphasised the development of a human machine interface for the alignment when charging an electrical car wirelessly. The results from the project is an alignment interface in the car that guides the driver to the correct position to be able to initiate the wireless charging. The solution has been developed through continuously setting needs and requirements throughout the process of the project based on findings in data and research collection of the usability problem.

The outcomes of the thesis are based on the different design levels where different focus areas have been investigated and ideas developed. By investigating the market and the technology, wireless charging was proven to be an emerging technology and that several OEMs currently are developing solutions to the alignment task. Another finding is that the expected solution would only be relevant until an autonomous solution is developed which would make the most convenient alternative to charge the car. Based on this finding, the development of the solution was set to be implementable in cars today. Through analysis of the usability and the voice of the customer, it was detected that users have difficulties to align the car and that a guidance is desired. In a usability test, only approximately 5 % succeed to align the car in the correct position without any guidance. The users have difficulties to know how far to drive when the charging pad is out of sight and have low perception and knowledge of the car's dimensions.

From various iteration of development, the most relevant functions that fulfils the gather needs are; how the steering direction affects the future position of the car, a pathway that show how to align the car into the right position, a close-up view when the pad disappears under the hood, and indications telling the driver that a correct/wrong action is made.

The final design for the interface is placed in the DIM where a view of the car is displayed in the middle with a pathway showing how to align the car. When turning the steering wheel, the user can see the exact direction displayed in front of the visualised car. When being right on track, the steering direction is green, and when steering towards an incorrect angle, it turns red. When being closer to the charging pad, the perspective of the view is changed to see where the charging pad is relative to the position that is correct under the car to be able to start the charging process. This solution provides a convenient experience, though the user can park the car and charge it effortlessly. The developed interface makes it fun to charge the car.

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A

Usability Test Material

Interview questions

1. For how long have you had your driver's license?
2. How frequently do you drive?
3. Do you feel comfortable driving a car?
4. Do you usually feel about parking?
5. How did you experience this task?
6. Can you show with the toy car where it was hard?
7. Did you think the result became better throughout the tries?
8. What did you do to align the car better?
9. How did you decide when you had finished the task?
10. Would you prefer some type of guiding?
11. Can you show with the car where you would want the guidance?
12. What type of guidance would you prefer?
13. Where would you want the guidance to be placed?
14. What kind of information is important to you inside a car?
15. How to you want the information to be given to you?

Table A.1: The form filled out during the observation of the user test.

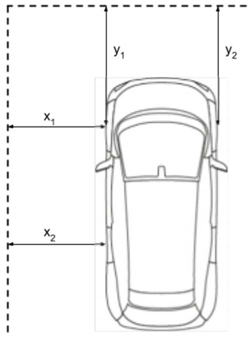
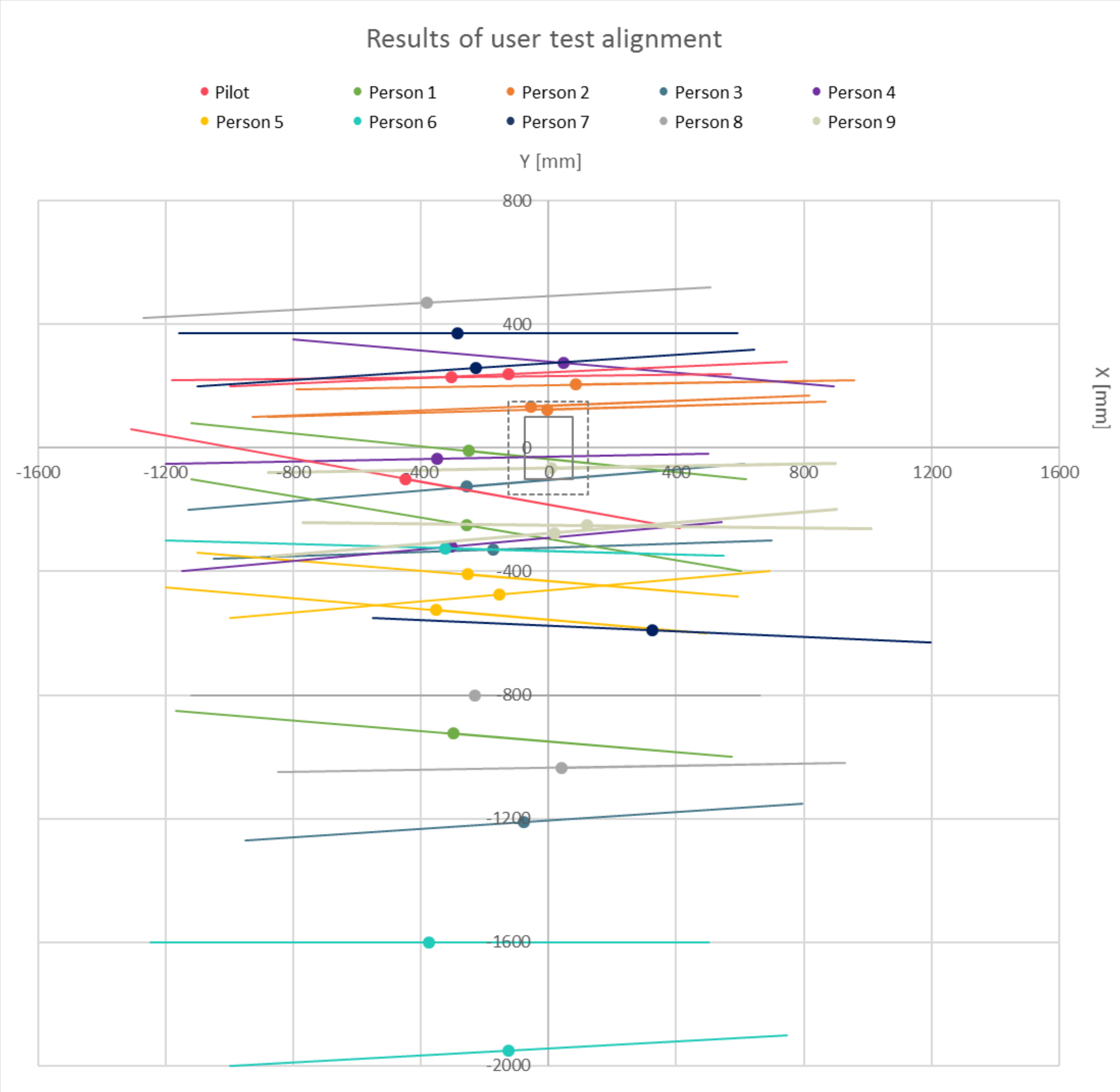
Test person:					
Age:					
Gender:					
Driver experience:					
Driving frequency:					
Date:					
Test field:					
Car:					
	1	**2**	**3**		
How many tries?					
Length in x_1?					
Length in x_2?					
Length in y_1?					
Length in y_2?					
Time from start to finish?					
The driver is	**Don’t agree**		**Ok**		**Agree**
Aware of the car's proportions					
Calm during the task					
Confident about the task					
Sitting in a normal position					
Satisfied with the position					
Comments					

Table A.2: Angle of the car in the user tests.



B

Hierarchical Task Analysis Tree

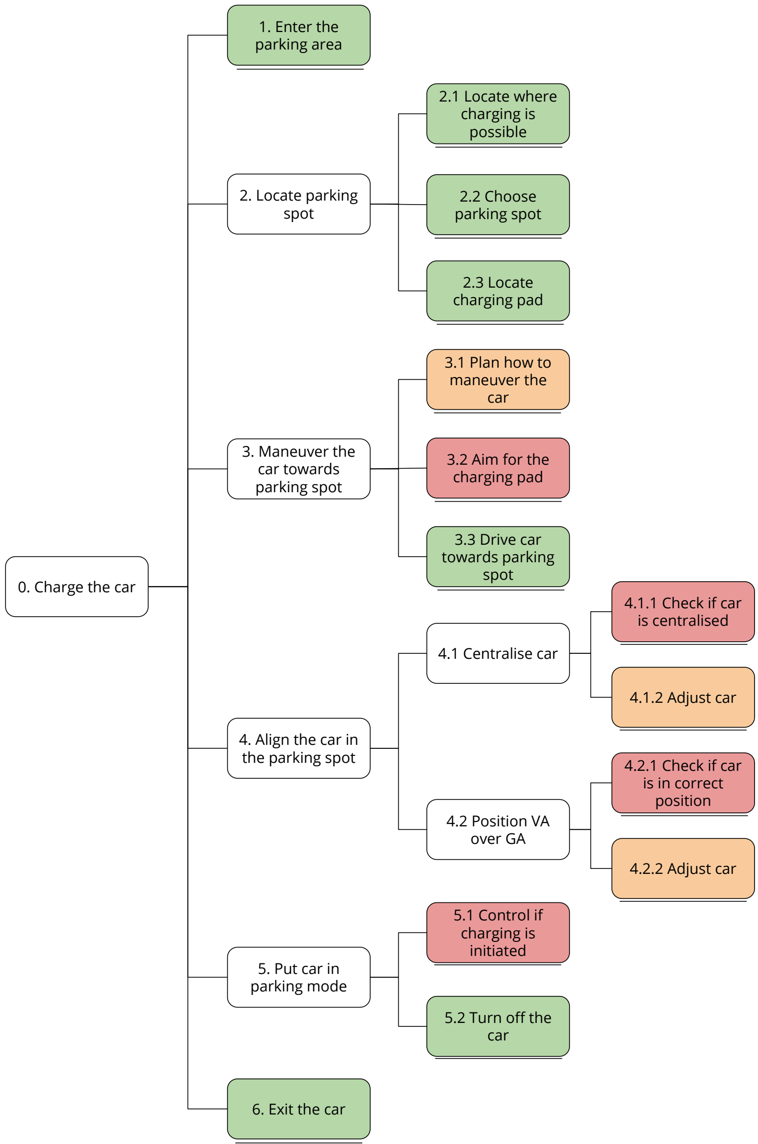


Figure B.1: The hierarchical task analysis

C

Evaluation Matrices

Table C.1: Morphological matrix

STEERING DIRECTION	OVERVIEW	Y-DIRECTION	X-DIRECTION
Front camera with lines	Runway	Under the hood	Guidelines
HUD with lines	Overview	See through	Runway
Overview of the car with lines	Guidelines	Receiving lights	Compass
	Aim	Arrows	Guiding wheel
		Overview	Lines in under the hood
			Axis
			Arrows
			Pathway
			Aim

Table C.2: Pugh matrix for function Overview

CRITIERAS	WEIGHT	RUNWAY		OVERVIEW		LINES IN GUIDELINES		AIM	
Clear	3	0	0	+	3	+	3	-	-3
Familiar	2	-	-2	+	2	+	2	-	-2
Cool	2	+	2	0	0	0	0	+	2
Causing irritation	2	-	-2	+	2	+	2	-	-2
Low glance time	1	+	1	0	0	0	0	+	1
Easy to integrate	2	+	2	-	-2	-	-2	+	2
Demands extra	1	-	-1	+	1	+	1	-	-1
Result			**0**		**6**		**6**		**-3**

Table C.3: Pugh matrix for function Y-direction

CRITIERAS	WEIGHT	UNDER THE HOOD		SEE THROUGH		RECEIVING LIGHTS		ARROWS		OVERVIEW	
Clear	3	+	3	0	0	0	0	-	-3	0	0
Familiar	2	+	2	-	-2	-	-2	+	2	+	2
Cool	2	-	-2	+	2	+	2	-	-2	0	0
No Causing irritation	2	+	2	-	-2	+	2	+	2	+	2
Low glance time	1	0	0	0	0	+	1	+	1	0	0
Easy to integrate	2	-	-2	+	2	0	0	0		-	-2
Demands extra	1	+	1	-	-1	0	0	+	1	+	1
Result			**4**		**-1**		**3**		**1**		**3**

Table C.4: Pugh matrix for function X-direction

CRITIERAS	W	GUIDELI NES		RUNWA Y		COMPAS S		WHEEL		LINES		AXIS		ARROWS		PATHWA Y		AIM	
Clear	3	+	3	0	0	-	-3	-	-3	+	3	-	-3	-	-3	+	3	-	-3
Familiar	2	+	2	-	-2	-	-2	-	-2	0	0	+	2	+	2	+	2	-	-2
Cool	2	-	-2	+	2	+	2	+	2	0	0	0	0	-	-2	+	2	+	2
Not causing irritation	2	+	2	-	-2	-	-2	0	0	+	2	+	2	+	2	-	-2	-	-2
Low glance time	1	0	0	+	1	+	1	+	1	+	1	0	0	0		+	1	+	1
Easy to integrate	2	-	-2	+	2	+	2	+	2	+	2	-	-2	+	2	+	2	+	2
Demands extra	1	+	1	-	-1	-	-1	-	-1	-	-1	+	1	+	1	-	-1	-	-1
Result			**4**		**0**		**-3**		**-1**		**5**		**0**		**2**		**7**		**-3**

D

Predictive Human Error Analysis Matrix

Table D.1: Predictive human error analysis

	USE ERROR	CAUSE	CONSEQUENCES	DETECTION	RECOVERY
1	Fail to position the car	Not able to follow the guidance	Fail to charge the car - no fuel	Steering direction is red when outside the pathway	Redo alignment
2	Drive into something	Not observant on surroundings	Car and/or surrounding get destroyed.	Accident	Car needs to be fixed.
3	Do not follow pathway - active	- Do not trust the guide - Do not understand - Want to start from another position	- The user needs to find their own way - The guidance is neglected	The car is not inside the pathway and the steering direction will be red	- Restart the system from new position - Find path again
4	Cannot follow the path	- Lack of driving skills - Do not understand	The user is unable to charge car	The car is not inside the pathway area	
5	Drives to long and needs to reverse	- Do not follow the path - Do not understand	Needs to reverse from the position	Too far from the path, reverse is only option	Reverse and restart task
6	Turn too much or too little	- Think it is necessary to be in right position	- Outside pathway	The steering direction is red	- Adjust the steering wheel to a green steering direction
7	Believes the task is finished	- Think the parking is enough	- Charging will not start	- The guidance is not showing the end tasks - Car is not charged	- Finish the task

E

Cognitive Walkthrough Matrices

Table E.1: Cognitive walkthrough for notice guide

SUBTASK: NOTICE GUIDE		Y/N	SUCCESS STORY
1	Will the user try to achieve the right effect?	Yes	The driver is aware of the car's information system
2	Will the user notice the correct action is available?	Yes	Message appears and there is movement in the DIM
3	Will the user associate the correct action with the effect that the user is trying to achieve?	Yes	When the guide starts, the user understands that it relates to the task
4	If the correct action is performed, will the user see that progress is being made toward solution of the task?	Yes	By noticing the guide, the driver gets help to position the car

Table E.2: Cognitive walkthrough for follow pathway

SUBTASK: FOLLOW PATHWAY		Y/N	SUCCESS STORY
1	Will the user try to achieve the right effect?	Yes	The user will try to be in the centre of the pathway
2	Will the user notice the correct action is available?	Yes	The steering direction is green when when inside the pathway and red when outside
3	Will the user associate the correct action with the effect that the user is trying to achieve?	Yes	The user will understand that the pathway leads to the pad
4	If the correct action is performed, will the user see that progress is being made toward solution of the task?	Yes	The steering direction is green if the car is inside the pathway

Table E.3: Cognitive walkthrough for stop in correct position

	SUBTASK: STOP IN CORRECT POSITION	Y/N	SUCCESS STORY
1	Will the user try to achieve the right effect?	Yes	The user knows that it is necessary to be positioned over the pad to charge the car
2	Will the user notice the correct action is available?	Yes	The pad and the desired position is visualised in the guide
3	Will the user associate the correct action with the effect that the user is trying to achieve?	Yes	The user will try to fit the pad inside the desired position
4	If the correct action is performed, will the user see that progress is being made toward solution of the task?	Yes	The pad turns green; a sound is played and the steering wheel vibrates.

Table E.4: Cognitive walkthrough for FOD/LOP

	SUBTASK: CLEAR AREA BECAUSE OF FOD LOP	Y/N	SUCCESS STORY
1	Will the user try to achieve the right effect?	Yes	The message tells the user what to do
2	Will the user notice the correct action is available?	Yes	The message is visualised
3	Will the user associate the correct action with the effect that the user is trying to achieve?	Yes	The car is not charging and the user understands that an action is necessary
4	If the correct action is performed, will the user see that progress is being made toward solution of the task?	Yes	When the pad is cleared, the car will start charging