CHALMERS UNIVERSITY OF TECHNOLOGY | UNIVERSITY OF GOTHENBURG

Designing Human-Machine-Interface to Promote Eco-Driving Behavior

A set of guidelines for human-vehicle-interaction design generated from research-through-design

Master's thesis in Computer science and engineering

Ziyi Zhao

Department of Computer Science and Engineering
CHALMERS UNIVERSITY OF TECHNOLOGY
UNIVERSITY OF GOTHENBURG
Gothenburg, Sweden 2023

Master's thesis 2023

Designing Human-Machine-Interface to Promote Eco-Driving Behavior

A set of guidelines for human-vehicle-interaction design generated from research-through-design

Ziyi Zhao

UNIVERSITY OF GOTHENBURG

CHALMERS
UNIVERSITY OF TECHNOLOGY

Department of Computer Science and Engineering
Chalmers University of Technology
University of Gothenburg
Gothenburg, Sweden 2023

Designing Human-Machine-Interface to Promote Eco-Driving Behavior
A set of guidelines for human-vehicle-interaction design generated from research-through-design
Ziyi Zhao

© Ziyi Zhao, 2023.

Supervisor: Paweł W. Woźniak, Department of Computer Science and Engineering
Mentor: Roberto Montes, Volvo Group Trucks Technology
Examiner: Staffan Björk, Department of Computer Science and Engineering

Master's Thesis 2023
Department of Computer Science and Engineering
Chalmers University of Technology and University of Gothenburg
SE-412 96 Gothenburg
Telephone +46 31 772 1000

Cover: The user interface of Driver Eco Coaching

Typeset in LaTeX
Gothenburg, Sweden 2023

Designing Human-Machine-Interface to Promote Eco-Driving Behavior
A set of guidelines for human-vehicle-interaction design generated from research-through-design
Ziyi Zhao
Department of Computer Science and Engineering
Chalmers University of Technology and University of Gothenburg

Abstract

As the demand for goods continues to grow in transportation, there has been an increasing focus on utilizing technologies in vehicles to mitigate the environmental impact of transport. One eco-friendly practice is promoting eco-driving behaviors among drivers, and the need for such effective onboard systems arises, leading to the investigation of human-vehicle interactions in both academia and industry. Aimed at safe, effective, and pervasive human-machine-interfaces (HMIs) to support eco-driving behavior, this project followed a research-through-design approach and an iterative design process. This project contributes to a set of design guidelines formalized from the practice of prototyping user interfaces for the onboard Driver Eco Coaching system in trucks, in support of future HMI design for eco-driving systems.

Keywords: eco-driving, human-machine-interfaces, human-vehicle-interaction, persuasive design, sustainable transportation, value-sensitive design

Acknowledgements

I am thankful to my supervisor, Paweł W. Woźniak, for his invaluable expertise and guidance during my design process and thesis report writing. I would also like to express my sincere gratitude to Roberto Montes, my mentor at Volvo Trucks, for his continuous support, aid, and coordination throughout my thesis project. Also, I would like to thank the people in the organization who took their time to guide me and involve in my design process to provide tons of insights to me. I want to thank the participants in the user research as well, especially for their valuable information and feedback in the user questionnaire. Additionally, I extend my heartfelt thanks to my friends for their unwavering support during my thesis.

Ziyi Zhao, Gothenburg, June 2023

Contents

List of Figures

List of Tables

List of abbreviations

BEV	Battery electric vehicle
DECO	Driver eco coaching
IC	Instrument cluster
FCEV	fuel cell electric vehicles
HMI	Human-Machine-Interface
KPI	Key performance indicator
NPS	Net Promoter Score
PD	Participatory design
SID	Secondary information display
SD	Standard deviation
SUS	System Usability Scale
UI	User interface
VSD	Value-Sensitive design

1
Introduction

The energy consumption of transportation plays a significant role in global emissions and sustainability, and how to achieve emissions reduction and energy-saving has been a trending topic in the transportation industry. Since drivers' operational decisions make a significant impact on on-road fuel economy [48], it is important to find ways to encourage drivers to perform less fuel-consuming behavior. In addition, As vehicle-of-Internet and human-machine-interfaces (HMI) have been evolving rapidly in recent years, how to support drivers to adopt eco-driving with the assistance of human-vehicle-interaction has been constantly investigated in both academic research and industrial practices. In this thesis project, which is collaborated with Volvo Trucks, an automotive company specializing in truck manufacturing and service providing, I am intended to redesign the HMI of an onboard eco-coaching system in trucks based on its current interfaces and formalize design guidelines simultaneously to contribute to the field of HMI design for economic driving.

1.1 Aim

This project is aimed to find design strategies for the in-vehicle HMI to support truck drivers in fuel-efficient driving. Eco-driving is a style for drivers to operate the vehicle to save fuel/energy, which is a complex and unnatural activity involving balancing multiple goals and constant information exchange and human reactions [37]. Challenges have been identified in eco-driving; accordingly, means of promoting eco-driving have been explored in past studies. However, two aspects haven't been sufficiently studied. One is that most studies didn't specify the types of vehicles on which their findings were based, which means cars could be the default scenarios instead of middle-duty or heavy-duty vehicles, like trucks. Truck drivers drive for their delivery missions, and they usually don't need to pay for the fuel/electric bills by themselves, which could lead to time-priority driving strategies and lower motivation to perform eco-driving. Thus, effective strategies to increase their motivation for eco-driving need to be explored further. Another limitation of previous studies is that most studies either focus on a strategy level (e.g., persuasive technology), or eco-feedback presentation level, there seems a gap between HMI design and eco-driving, where little information was provided in terms of synthesis of design implications from both levels. Therefore, this project aims to explore patterns of HMI design to assist and motivate truck drivers to adopt eco-driving while balancing between multiple driving goals (i.e., fuel efficiency, safety, and delivery mission fulfillment), and promote a sustainable driving habit in the long run.

As this thesis collaborates with the company, the goals of this project are to design HMI for a driver eco-coaching system and generalize a set of guidelines for researchers and designers in related fields based on my design practice. Methodologies of interaction design and graphical interface design, as well as the knowledge of human factors and persuasive design, will be related in this project to support informed decision-making in the design process and ultimately contribute to the high-fidelity prototype and guidelines.

1.2 Research Question

This thesis is aimed to answer the following research question:

How to design for human-machine-interface (HMI) in the vehicle to support truck drivers of eco-driving?

To keep the topic within an appropriate scope, this thesis mainly focuses on the information communication and interaction patterns between the driver and vehicle, e.g., design strategies utilization and eco-feedback representation, which means no back-end system knowledge will be taken into consideration, such as which driving behavior to be measured or algorithm to quantify the driving behavior.

1.3 Stakeholders

The main stakeholders of this project are Volvo Trucks, an automotive company and their target users, and Chalmers University of Technology. The Company in this report is referred to as Volvo Trucks specifically to avoid some redundancy, and their target group is the truck drivers who use the service provided by Volvo Trucks to improve their driving performance for the truck fuel efficiency. As this project is part of *The Master's Program in Interaction Design and Technologies (MPIDE)*, it follows the requirements of the master thesis course at Chalmers University of Technology.

Furthermore, as this project aims to provide a framework to inform HMI design to promote fuel/energy efficiency driving, researchers and designers within related fields are also regarded as potential stakeholders, who might find this set of guidelines as inspiring and utilize it in their future work.

1.4 Expected Result

The expected result of this thesis is the formalization of a set of design guidelines that contributes to the field of in-vehicle HMI design to achieve the goal of educating and motivating truck drivers to fuel/energy efficiency performance. The guidelines are aimed toward state-of-the-art research within relevant fields, which covers human-vehicle interaction, in-vehicle feedback, and persuasive strategies of eco-driving.

2
Background

This chapter covers an overview of The Company where this thesis is carried out, as well as the product that I work with called Driver Eco Coaching (DECO). In addition, the target group and how DECO functions are presented in the context of this thesis.

2.1 The Company

The Company which the thesis collaborated with is a truck manufacturer that provides transport solutions and digital services worldwide, including Europe, Asia, North America, South America, and Africa. As one of their core values is environmental care, The Company is targeted to shape the future landscape of sustainable transport. What's worth noticing is that The Company provides a range of services to their customers to optimize the customers' truck fleet. One example is that fleet managers and drivers can monitor their trucks in real-time and connect such information with their business thanks to the technology of telematics and connectivity.

2.2 The System: Onboard Driver Eco Coaching (DECO)

The system that this thesis relates to is called Driver Eco Coaching (DECO), which is a digital service provided by The Company on their trucks. It is a real-time system that constantly logs data from the truck, translates it into eco-driving-related information based on the system's algorithms, and communicates such information to the users. The whole system provides both onboard and back-office applications, respectively targeting the individual driver and fleet owners or operation managers. As this thesis focuses on the onboard DECO, only the description of the in-vehicle system is presented as follows.

2.2.1 Target Group

The customers and actual users of DECO are two different groups with an overlap to some extent, as shown in Figure 2.1. The customers who pay for DECO as a service of trucks are usually the owner of the trucks, such as goods transport companies and fleets, who care about saving fuel/energy and optimizing the operation of trucks. Whereas, the users of DECO are truck drivers who perform delivery trips using trucks. They have the options to drive in their own styles, and DECO is expected to coach, support and motivate them to perform sustainable driving, to achieve the goal of decreasing fuel/energy consumption.

2.2.2 Functions

To coach the driver to adopt more sustainable driving, as shown in Figure 2.2, the onboard DECO logs signals from the truck, calculates them into meaningful values related to fuel efficiency, and informs the driver through the instrument cluster (IC) and the secondary information display (SID) in real-time. In a trip, the driver receives instructions on how to change his/her way of driving in the form of text as toasts on the IC (eg. "Avoid kick down to save fuel"), which are triggered by the driver's behavior. On the SID, gauges representing accumulated scores are displayed in terms of a set of Key Performance Indicators (KPIs) (eg. "Speed", "Anticipation", and "Standstill"), and each KPI contains a group of sub-KPIs (eg. "Braking" and "Coasting" under "Anticipation"). In addition, an overall score calculated based on the KPIs' score is shown to the driver. What's more, a list of the three latest-triggered tips is presented on the SID in another view of the onboard DECO.

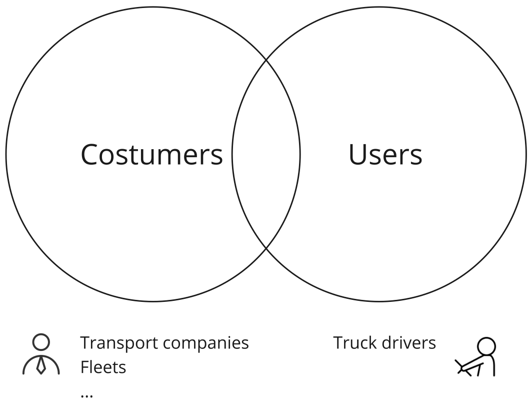


Figure 2.1: Target group of Driver Eco Coaching(DECO)

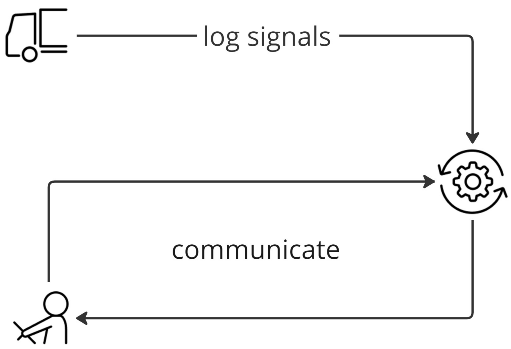


Figure 2.2: How Driver Eco Coaching(DECO) functions

2.2.3 Evolving: from Diesel to BEV

As The Company is releasing Battery Electric Vehicle (BEV) nowadays, DECO is also evolving. Generally, DECO on diesel trucks and on BEVs share large similarities, while differences exist. For example, several eco-driving strategies (eg, moderate deceleration, avoiding idling) are similar regardless of driving a diesel or a BEV. Otherwise, a few strategies unique to BEVs are related to using the engine. This requires DECO's algorithms updating, e.g., what driving behavior it encourages, and which signals to calculate. However, different types of vehicles mainly share commonalities in the HMI design since there is not much difference in terms of interaction patterns and ways of information communication between the driver and the vehicle. It is noticeable that this thesis does not specify which types of vehicle to target but focuses on the general HMI design solutions regardless of whether it's diesel vehicles, BVEs, or fuel cell electric vehicles (FCEVs) in the future.

3

Related Work

In this chapter, related work relevant to this thesis is presented. Previous research and theory are introduced within the domains of eco-driving, persuasive techniques, value-sensitive design, and HMI design.

3.1 Eco-Driving

As the awareness of sustainability has been raised as a global topic, strategies to reduce carbon dioxide emissions in transportation have been investigated in past research [16]. Studies have found that fuel economy is sensitive to driver behavior, which means eco-driving can significantly influence fuel consumption and the amount of vehicle emission [51, 55]. Eco-driving can be defined as the ways for a driver to operate a particular vehicle to increase fuel/energy economy and reduce emissions, and it refers to practices such as keeping a steady speed under the speed limit, moderating acceleration and braking, reducing long-time idling and so on [16, 51, 41]. Eco-driving is influenced by both external and internal factors, and there exist challenges to performing eco-driving continuously; more evidence will be introduced as follows.

3.1.1 Influencing Factors on Eco-Driving

According to a framework of eco-driving behavior, there are four activities to drive economically: (1) monitor system and environmental variables; (2) identify applicable eco-driving strategies based on prior knowledge; (3) choose the strategy with the highest subjective expected utility (SEU); (4) regulate their behavior to align with this strategy [12]. This model clarified the process of eco-driving, and accordingly, factors that influence eco-driving can be identified both internally and externally, respectively drivers' mindset and environmental complexity. On the one hand, drivers' experience, knowledge, attitude, and motivation for eco-driving decide their willingness and strategy utilization [16, 12]. On the other hand, environmental dynamics also influence the performance of eco-driving; for example, eco-driving strategies vary depending on if it's driving in a city, highway, or rural areas [12, 4].

3.1.2 Challenges to Perform Eco-Driving

Since eco-driving can be referred to as a process that constantly requires the driver's behavior adaption to environmental dynamics, there exist challenges to accomplishing eco-driving over long periods of time [12]. Driving is a multi-goal task that involves not only fuel/energy efficiency but also safety and time-saving, which requires drivers to adopt flexible driving strategies to achieve a balance among different goals based on various driving scenarios [37].

Also, psychological aspects of eco-driving have been investigated in previous studies. Pampel et al. proves that sustainable driving is not easy to sustain: it is not default nor as familiar and automated as "everyday" driving, so it can occupy mental resources and require more conscious effort. Allison et al. found eco-driving had a negative effect on overall mood and a positive effect on self-esteem. Drivers felt a decreased level of energetic arousal and hedonic tone and increased frustration compared with normal driving, while the feelings of self-worth are fostered by eco-driving. Besides, there exists a false belief in eco-driving; for instance, a study argued that drivers tended to overestimate the speed reduction needed for eco-driving, which accounted for a significant difference in time needed to complete a journey between normal driving and fuel-efficient driving [36]. As a consequence, methods to promote and support eco-driving are worth being explored to assist drivers to adapt to a sustainable driving style.

3.2 Promoting Eco-Driving Behavior

According to previous studies, education has proved to be a powerful means of raising awareness and increasing knowledge of eco-driving. In some countries, eco-driving skills are taught to drivers and tested in both the theory and practical driving exams [21]. Those comprehensive pre-drive training, including both theoretical and practical learning, shows a positive impact on driving performance and fuel/energy consumption [16].

A number of studies into sustainable behavior promotion have focused on persuasive-related technologies and attempted to examine the efficacy of various strategies. Persuasive technologies can be broadly defined as "interactive systems that are designed to influence people to change their attitudes or behaviors" [1]. According to Adaji and Adisa's study, suggestions, feedback and reminders are the most commonly used persuasive techniques to influence sustainable behavior. Suggestions are used to instruct to users on what they can do with a system that leads them towards sustainable goals, feedback is for the system to present an assessment to users based on their input, and reminders are to raise awareness from users to carry out a target action. Similarly, Persuasion Interface Design in Automotive context Framework (PIDAF) has been proposed by Paraschivoiu et al. from a literature review, which integrates intents, cues, persuasive principles, and design options for automotive persuasion.

Although much research in the field of sustainable behavior has established that persuasive technology can serve as an effective way to change the target group's behavior, there are several critical arguments that need to be noticed. One is that there is no clear relationship between the number of persuasive strategies implemented and the effectiveness of the system, which means it is not the case that the more persuasive strategies applied, the stronger efficacy the system will be [1]. Another argument is lying in the limitations of persuasive technology. Most of the persuasive technologies rely on self-report approaches when it comes to validating, which means it might lack standards and robustness in efficacy; also, the long-term influence of persuasive technology is unclear as most studies only evaluated their technology less than two months [1]. Similarly, Brynjarsdottir et al. argued that persuasion should be considered broadly. They suggested including users in the design process and focusing beyond the individual to adapt persuasive sustainability, or even further, stressing reflection and practices instead of prescription and behaviors as revised persuasive approaches.

Relating to the limitations of current persuasive approaches, Knowles et al. developed a list of patterns of persuasion for sustainability derived from *Value Sensitive Design* (VSD), as presented in Table 3.1. Those patterns are targeted to motivate major behavior change by fostering a deep concern for sustainability, which can be referenced in the design solutions of DECO to promote drivers' intrinsic motivation to drive economically.

Table 3.1: 5 alternative patterns for persuasive technology in the field of sustainability based on *values* research [25]

Pattern	Description
Broad Self-Transcendence	Use textual, visual, or audio means to activate values related to selflessness, peace, equality and justice to promote pro-environmental behavior
Consistency	Design persuasive technologies to communicate a single, coherent, and powerful message about why protecting the environment is important
Designing to the value	Facilitate a shift in *values*, rather than a shift in behavior: think about *how to get people to really care about the environment, or understand why they should care, so that they willingly choose to engage in pro-environmental behavior* , instead of *how to engage people in pro-environmental behavior when they do not really care about the environment*
Facilitate reflection	Facilitate chances for users to reflect on the importance of protecting the environment instead of making them feel guilty about what they should have done
Measuring impact ripples	Measure indirect and more systemic impacts of persuasive technology interventions to affect long-term behavior change

3.3 Design for Driver Support Systems in the Vehicle

Various studies have presented evidence that eco-driving takes additional effort to perform and can be deactivated over time or as the workload increases (e.g., driving into traffic congestion), and researchers believed that dynamic intervention from eco-driving systems in the vehicle had positive effects on drivers' fuel efficiency [37, 21]. In this section, literature on how to design an onboard system that supports drivers to adopt eco-driving behavior is introduced as theoretical guidance for this project.

3.3.1 Eco-Feedback in the Vehicle

In a literature review by Sanguinetti, feedback concerning the efficiency of drivers' behavior is argued as the most common strategy used to facilitate eco-driving. It belongs to the category of eco-feedback as "any type of information about resource consumption delivered back to the consumer with the aim of promoting more sustainable behavior", and numerous research has shed light on the eco-feedback design for a stronger and long-lasting effect on behavior change. Sanguinetti et al. proposed a design-behavior framework on eco-feedback design to imply user behavior change based on the behavioral theory. As presented in Figure 3.1, this framework categorized three dimensions of eco-feedback design, namely *information*, *timing*, and *display*. Each dimension affects at least one of the three feedback qualities: precision, salience, and meaning, which are respectively related to learning, attention, and motivation for behavior change. Therefore, when putting this framework into design practice, target groups' level of knowledge, awareness, motivation and baseline performance in terms of the target behavior should be considered to design appropriate eco-feedback.

When it comes to eco-feedback in the vehicle, it is typically provided onboard through digital screens, e.g., the instrument cluster (IC) or tablets, to inform drivers about the consequences of their related behavior and suggestions on ideal ways of driving. To better understand the design trends and implications, more studies contributing to eco-driving feedback design are reviewed below along with the framework of behavior-relevant design dimensions from Sanguinetti et al..

3.3.1.1 Information

According to Sanguinetti et al.'s eco-feedback framework, *information* refers to "what information is present", and there are two qualities of *information*, namely *granularity* and *message*, as shown in Figure 3.2. The degree of detail in the information is referred to as its granularity, which can be categorized into three dimensions: *data*, *behavioral*, and *temporal granularity*. In general, low granularity feedback can be beneficial for goal-setting and tracking overall performance, while high granularity feedback is effective for learning new or complicated actions since it offers a clear correlation between action and consequence [43]. When it comes to *temporal granularity*, there are two types of eco-driving feedback: instantaneous (e.g. real-time

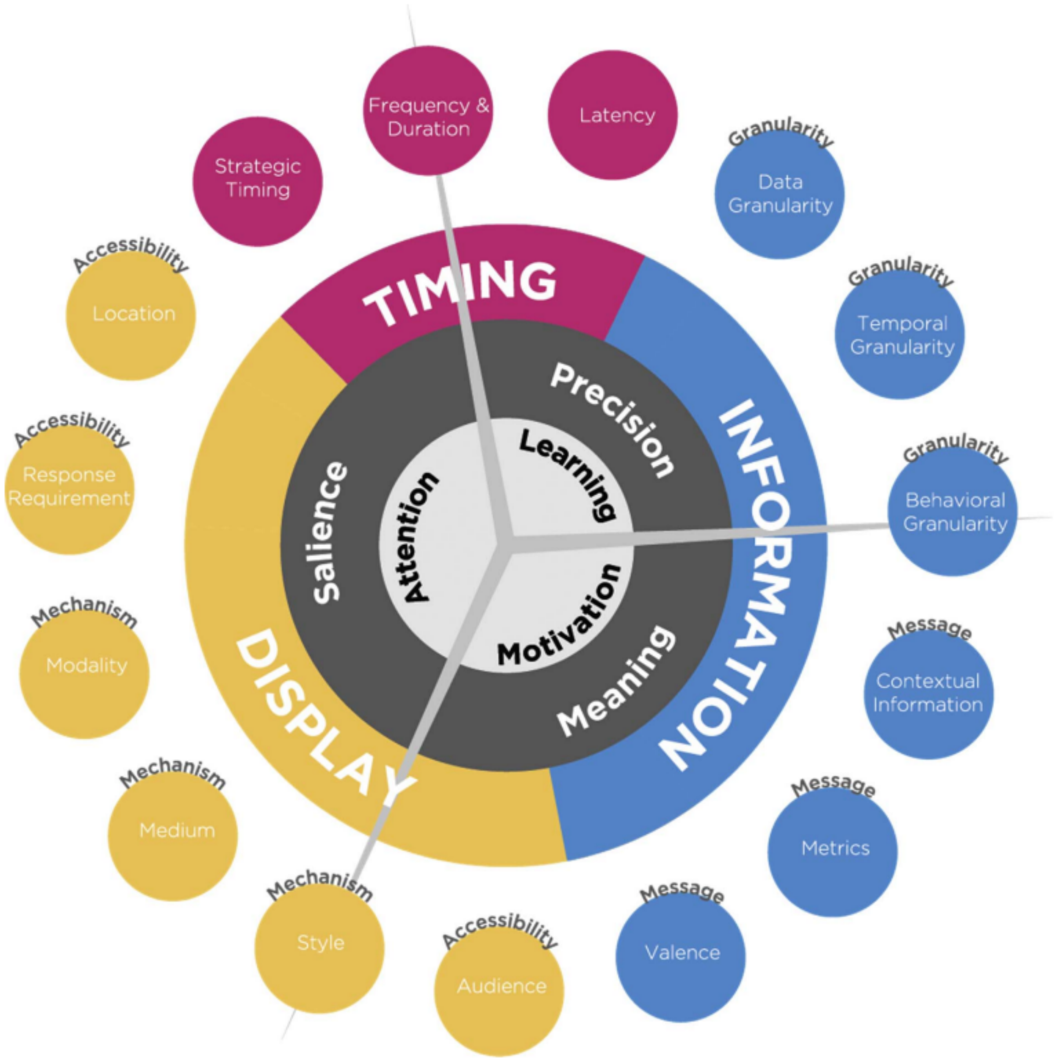


Figure 3.1: Eco-feedback design-behavior framework [43]. Figure adapted with permission from Sanguinetti et al. and Elsevier.

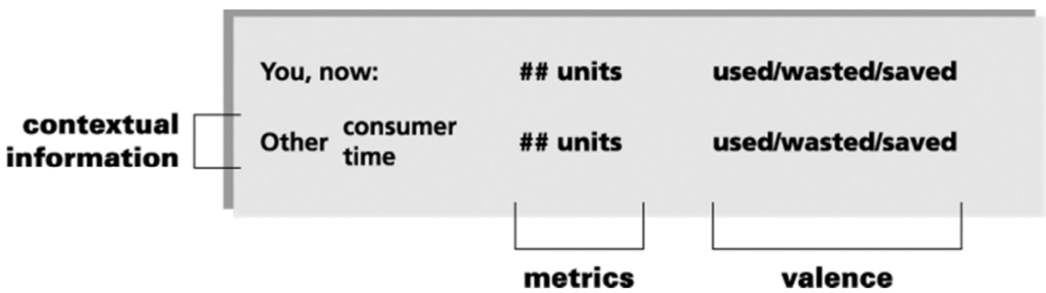


Figure 3.2: Target users can see how their behavior is represented with regards to *metric* and *valence* along with *contextual information* (e.g., comparisons to others or their own historical behavior) [43]. Figure adapted with permission from Sanguinetti et al. and Elsevier.

feedback) or accumulated over some duration (e.g. post-driving summary). Designers should consider (1) the natural duration of the target behavior and subsequent consumption patterns, and (2) the purpose of the feedback, i.e. pedagogy or assessment to design for *temporal granularity*. One example given by Sanguinetti et al. is that eco-driving feedback relevant to acceleration efficiency can be delivered in terms of performance during a certain acceleration circumstance to facilitate drivers' learning, whereas accumulated feedback (e.g., average acceleration efficiency) can be given over the course of an entire trip as a result of the assessment.

The eco-feedback *message* has three main components: *metrics*, *valence*, and *contextual information*. These factors relate to the way information is presented to the user, and they imply how meaningful the user thinks the feedback to be [43]. *Metrics* is refereed to measurement and/or quantitative information in eco-feedback. As scores such as percentage points are considered as familiar and sometimes used in eco-driving feedback, it has been pointed out that such indirect metrics can be misleading due to a lack of accuracy, which should be carefully considered when being used. On the other hand, as energy and emissions are intangible and invisible, related information could be conveyed using more familiar terms, such as the emissions equal to tons of dinosaurs [39]. *Valence* is associated with whether the information is framed positively or negatively according to Sanguinetti et al., who mentioned that a more significant effect for positive points feedback compared to negative points with regards to target user engagement.

3.3.1.2 Timing

Timing concerns the timing of information presentation related to the target behavior, which includes *latency*, *frequency and duration*, and *strategic timing*, and the illustration is presented in Figure 3.3 [43]. When discussing *latency*, Sanguinetti et al. argued that immediate feedback may facilitate the learning process by linking behavior with consequences, while delayed feedback can support reflection. There are some other studies comparing continuous versus intermittent feedback for eco-

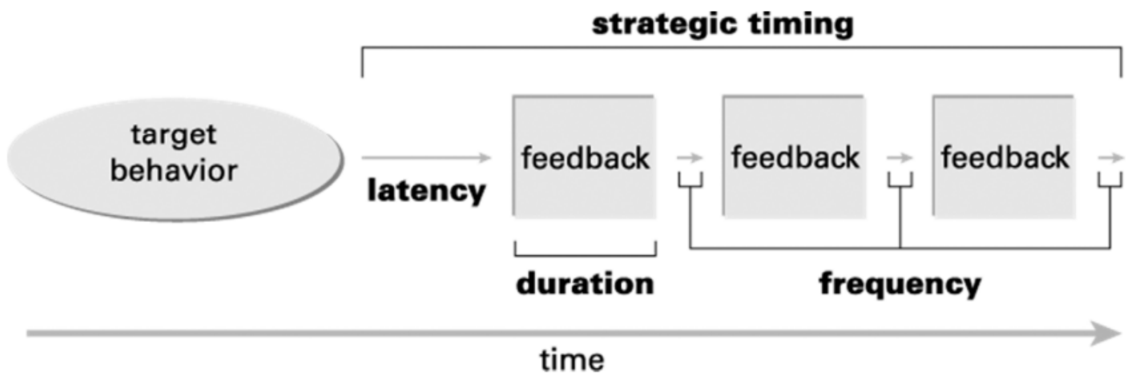


Figure 3.3: 3 dimensions of eco-feedback *timing*: *latency*, *frequency and duration*, and *strategic timing* [43]. Figure adapted with permission from Sanguinetti et al. and Elsevier.

driving. In a driving simulation study, it has been found that the intermittent visual eco-driving advice led to fewer glances and a shorter dwell time on the display than the continuous system, which led to the recommendation of intermittent visual strategically presented in locations that are less demanding for the drivers [24]. Similarly, Jamson et al. suggested providing continuous eco-driving guidance only during a list of carefully chosen "eco-driving scenarios", when significant fuel economy benefits are achievable. Those findings from previous research could serve as design implications for *frequency and duration*, and *strategic timing*.

3.3.1.3 Display

Display concerns the way of presenting information, which includes the following aspects: *modality*, *style*, *medium*, *audience*, *location*, and *response requirement* as Figure 3.4 shows [43]. As this topic is highly relevant to this thesis, more research is reviewed on several aspects.

Modality is the perception mode of an interface, and visual, auditory, and tactile have been investigated in various studies when it comes to eco-driving feedback. The visual display is most common and effective to give out guidance and help improve drivers' eco-driving performance; however, there are potential negative effects on safety, as drivers look less on the road ahead and they are more distracted from the driving task [21]. As for the auditory feedback, drivers could get voice prompts to broadcast operational information during eco-driving-related scenarios, which do not require drivers to remove the sight from the road, but still occupy attention resources and increase the workload [55]. Another way of presenting information to the driver is through a haptic interface especially a haptic pedal system, which can be useful for providing constant guidance on efficient accelerator pedal position [21]. There is evidence that the haptic interface is less distracting compared to the visual one; however, the range of the information that can be conveyed through haptic feedback is quite limited therefore less informative and efficient than the

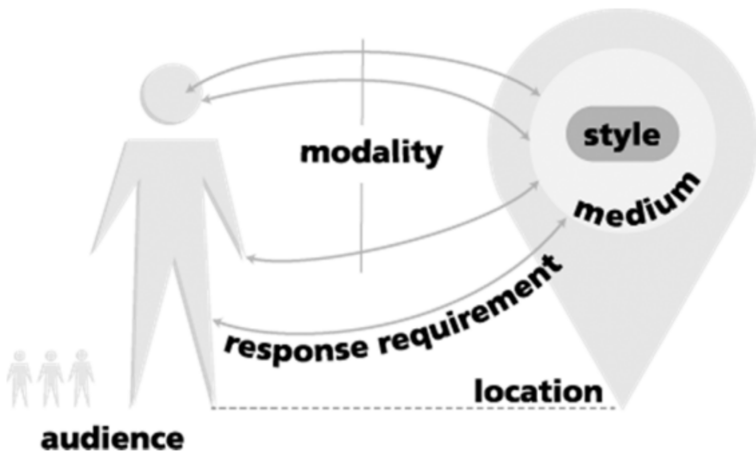


Figure 3.4: Dimensions of eco-feedback *display*: how the audience accesses the information [43]. Figure adapted with permission from Sanguinetti et al. and Elsevier.

other modalities. Xu et al. summarized the advantages and disadvantages of those three modalities through a literature review. Based on those findings from previous research, the best design solution in terms of modality might be a combination of multiple modalities with the possibility for the individual driver to customize their preference [14, 43].

3.3.2 Other Design Strategies

Apart from the dimension of feedback, there are other design strategies that can be considered when designing an eco-driving support system, as listed in Table 3.2. These design implications can be referred to as general principles to inspire the design practices for this thesis.

Table 3.2: Design implications for eco-driving support system from previous research

Prior research	Design suggestions
Franke et al.	• comprehensive feedback • ease of perception • strategy acquisition support • automated functions • system transparency display • configurability
Allison et al.	• increase engagement • encourage positive affect • take time penalty into consideration
Jamson et al.	• adapts to drivers' skills • avoid repetitive and useless guidance

3.4 Summary

A great deal of previous research has investigated the field of eco-driving and attempted to explore methods to facilitate eco-driving. Whereas, they focus particularly either on the general strategies in a rather high level (e.g., persuasive technology, motivation theory) [25, 17, 14, 38], or examining and comparing specific feedback representations [24, 10, 9]; there is much less information about combining those strategies with HMI design patterns in an interaction design perspective. Thus, this thesis attempts to generate fresh insight into design principles in according with the needs and requirements of eco-driving by means of research-through-design [13]. Aimed for a framework informing the HMI design for in-vehicle systems to support eco-driving, I believe this work would contribute to the growing area by adopting the eco-driving promotion theory to the interaction design practice, and inspire practitioners within the related fields.

4

Methodology

This chapter introduces the design process that this project follows to solve the research question. As this project implements an interactive design process, applicable methods are categorized and presented in each design phase.

4.1 Design Process

A design process outlines design stages in a logical consequence. Jones's model of the design divides the process into divergence, transformation and convergence stages [23]. At the divergence stage, designers usually research to identify the context of the problem, such as the objectives, critical variables, and problem boundaries. Then the sub-problems that have been structured are solved at the transformation stage, including a pattern-making process to define design solutions. When it comes to convergence, the goal is to reduce uncertainties by progressively eliminating, combining and evolving possible alternative designs until only one design solution is left.

More concretely, as given in Figure 4.1, a classic life-cycle model in fields shows how the four activities of interaction design are related [47]. Most project initiatives begin with the discovery of requirements, from which alternative designs are produced. The designs are evolved into prototypes being subsequently reviewed. The requirements may be refined during prototyping or based on the result of assessments. This iterative cycle may be followed by one or more different designs simultaneously, and the final product will emerge in an evolutionary form from the initial idea by this cycle.

Inspired by the above two design frameworks, this project follows a design process including four design phases: *discover*, *ideate*, *prototype*, and *evaluate*. It is noticeable that as some of the methods are applicable during multiple design phases, one method is referred to only once with different purposes presented to avoid redundancy.

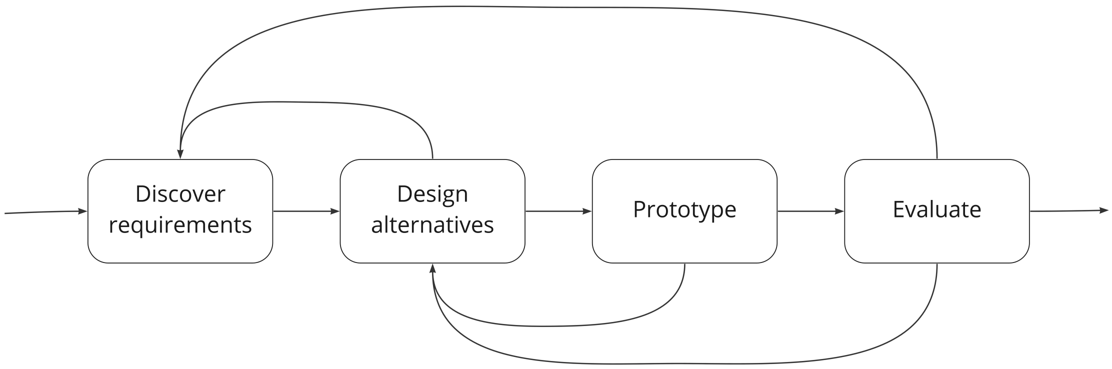


Figure 4.1: An interaction design process model[47]

4.2 Discover

In the *discover* stage, user research of the target group, i.e., truck drivers, as well as the desk research about DECO are carried out with the assistance of the following methods.

4.2.1 Interviews

As a "conversation with a purpose" [47], interviews of stakeholders in this project serve as a way of enriching knowledge about eco-driving and DECO. There are generally three types of interviews in terms of how much structure is, namely open-ended or unstructured, semi-structured, and structured, and which is the most appropriate depending on the purpose of the interview. In this thesis, the unstructured interview is suitable to use, as the main goal of the interviews with internal stakeholders is to understand the context such as how DECO functions, how the eco-driving can be supported by DECO, and what stakeholders' expectations are toward it.

4.2.2 Questionnaires

Questionnaires are a common research technique for collecting information through participants' self-reporting, including demographic data, their perceptions, and opinions about particular topics. There are several advantages of using a questionnaire. One is that a digital version of the questionnaire can easily involve people who are located at a distance or those who cannot attend an interview at a pre-set time; another is that it has the potential to involve a large number of participants without demanding extra data gathering resources [47]. In this project, considering the target group is truck drivers who tend to have a busy schedule with their delivery missions, the questionnaire could be an appropriate instrument to collect their thoughts, needs and experience about the eco-driving support system. What is worth noticing is that as there is no facilitator or interviewer available to explain or to clarify any ambiguities to the correspondents, it is important that questions are specific and worded clearly to help guarantee the validity and efficacy of the questionnaire [47]. In addition, questionnaires including scales can also be used during the evaluation to collect feedback on the design works from the participants in the user tests.

4.2.3 Thematic analysis

Thematic analysis is a bottom-up method to analyze qualitative data [6]. It helps with the discovery of important themes by highlighting the dominant themes in user study data. One way to analyze rich qualitative data gathered from interviews or observation is using affinity diagramming techniques, which is highlighting, moving around, and coding the text into meaningful codes until themes emerge [31].

4.2.4 Personas

By collecting information about users and describing their behavior patterns into representative profiles, personas serve as means for facilitating empathy and understanding to the target group, therefore helping designers maintain a design focus in the *discover* and *ideate* phase. Typically, personas are presented to mold a character, with a name, profile image, goals and typical behaviors related to the design inquiry [32]. In this case, the personas of truck drivers could include drivers' perceptions of eco-driving and related driving scenarios.

4.3 Ideate

In the *ideate* phase, designers and researchers contribute a range of ideas for the design problem. The knowledge acquired from *discover* will be reviewed and synthesized into alternative design solutions through activities such as co-design workshops and sketching.

4.3.1 Co-Design Workshop

The co-design workshop also referred to as participatory design, where end users and stakeholders participate in the design process by activity-based engagement [47]. It is chosen for this project as there are different stakeholders from The Company side who might have various opinions about DECO, and the co-design workshop makes it possible to involve stakeholders and gain inputs from them to help inspire the design outcomes. Generally, a co-design workshop is conducted in a series of creative activities through face-to-face contact; whereas, the development of online collaborative applications such as Miro and Mural brings possibilities to have a workshop online, which indicates a new way of preparing workshop setting, facilitating the workshop and documenting outcomes during the process.

4.3.2 Sketching

Sketching serves as a way of thinking visually, which helps to define the essence of concepts so designers can get tangible with their ideas. With this method of rapid prototyping, designers are able to get a flexible visualized concept that addresses the problem to be solved [19]. It allows designers to communicate with stakeholders from abstract interaction patterns to concrete graphical interface components. During the sketching, it is possible to develop more than one alternative for one idea, present them to the outside to gain key feedback, then return to the elements to choose one of the alternatives to refine in the later stage [47].

4.3.3 User Journey Maps

User Journey Maps is a visual presentation of the process by that a person uses a product or service to accomplish a goal by compiling a series of user actions chronically [45]. In this project, the visualization will be based on a truck diver's driving scenario, where the facts corresponding to the user (e.g., actions, mindsets, and emotions) and the artifact (e.g.touchpoints, internal ownership) are aligned onto the map. By this means, the concepts to be designed would be revealed and move forward.

4.4 Prototype

Prototyping allows designers to refine rough concepts to be more concrete and systematic. In this stage, constant iteration and evacuation are recommended to proceed with design solutions and make rational decisions on what or how to elaborate.

4.4.1 Wireframes

As a means of early prototyping, Wireframing is a method used in interface design to create visual representations of a product's structure, content, and interactions. They can be constructed at varying levels of abstraction, and the format can be either hand-drawn or electronic [47]. The purpose of Wireframes is to facilitate communication about design alternatives to stakeholders, which enables rapid changes in the design specification during the process. To better serve the purpose, Wireframes usually consist of structural, layout elements like shapes, lines, and placeholders, and ignore other visual design elements, such as images, colors, or content text, which are in low fidelity and suitable for quick feedback about the design direction and user flows. They can facilitate communicating design alternatives within the design team and to stakeholders, serve as a for implementation, and. Compared to high-fidelity mock-ups, Wireframes are more inviting for suggestions and constructive criticism during constant validation sessions.

4.4.2 High-Fidelity Prototype

High-fidelity prototyping produces realistic and detailed representations of user interfaces. It enables designers to demonstrate a product's appearance and interactive features of a product in order to gather feedback and improve the design before it goes into production. High-fidelity prototypes promote communication and collaboration within the development team and enable user testing, resulting in iterative and user-centered designs [32].

4.5 Evaluate

Apart from the questionnaires and interviews introduced in *discover*, there are other methods referred to in this project to validate the design solutions and uncover ideas on how to refine the artifact to solve the design challenge and meet the design goal.

4.5.1 Decision Matrix

The decision matrix is a method for deciding which idea to prioritize based on objective and relevant criteria. The ideas can be visually placed in a matrix to be evaluated by two criteria. By representing value to the user with the y-axis and feasibility with the x-axis, the matrix can compare implementation cost to user value to determine the optimal concepts with high user value and feasibility for further development. The axes' criteria can be changed to other relevant criteria depending on the project [46].

4.5.2 Think-Aloud Protocol

The think-aloud technique is to ask participants to verbalize what they are doing and thinking and feeling as they move through the interface to reveal their delight, confusion, or frustration [32]. It is a cheap, flexible and convincing way to inspect usability issues and get to know about users' raw thoughts. It can be applied in user testing as input to qualitative data, for example, during the walkthrough of the user interface mock-ups, to discover what users really think about the design. When conducting think-aloud, the facilitator should prompt participants to keep them talking depending on their personality and task complexity [20].

4.5.3 Expert Review

Expert Reviews is a valuable evaluation method as the final milestone of a design process, where the design is measured against its original objectives. In this method, an expert or a group of experts with usability expertise and knowledge of the target user and scenarios reviews a product to identify potential usability problems [47]. Noticeably, the reviewer's prior expertise and knowledge of usability principles are vital to the result of expert reviews [5]. To conduct expert reviews, a prototype with a sufficient level of detail is required, and it can be combined with user tests, where the expert's conclusions can be presented during the interview meeting. Expert reviews are complementary to user tests, resulting in a list of usability issues, along with recommendations for fixing those issues.

5

Process

This chapter describes the project's design process, presenting the execution and outcome of the events from the three iterations. Alongside the design process, a literature study was conducted in parallel in the first four weeks, which contributed to the literature review in Chapter 3. The whole process followed Sharp et al.'s life-cycle model of interaction design, while each iteration consisted of several phases and continued the life cycle from the last iteration. As illustrated in Figure 5.1, design methods corresponding to different design phases were applied during the three iterations, where the guidelines were formulated, refined, and finalized as the result of this project.

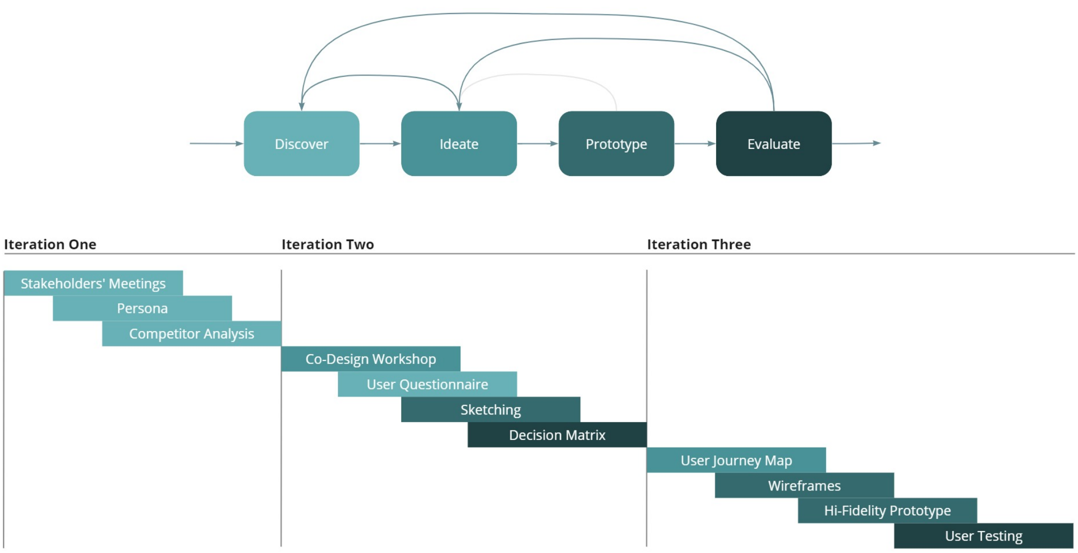


Figure 5.1: A design process of three iterations following the life-cycle model

5.1 Iteration One

As shown in Figure 5.2, Iteration One focused on information gathering about the context of this project.

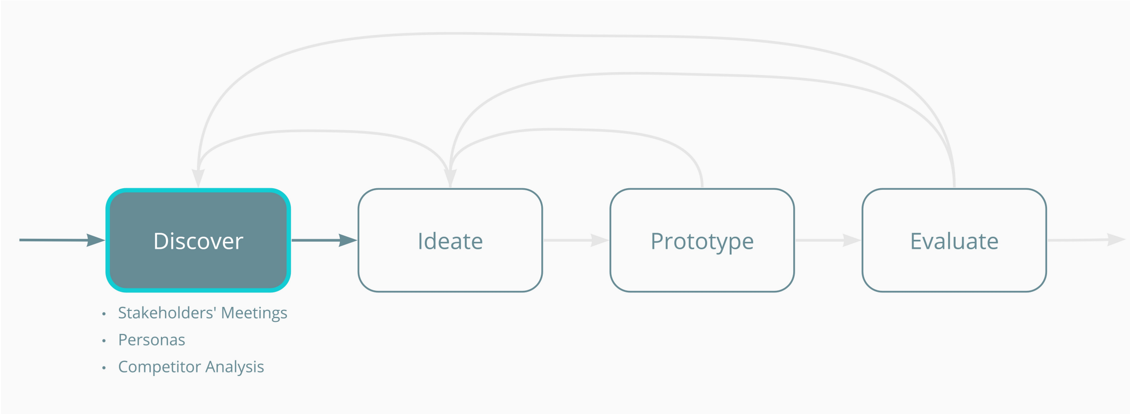


Figure 5.2: Iteration One

5.1.1 Discover

To gain adequate insights into design requirements, research was executed involving the stakeholders, the target groups, and the benchmarks of similar systems which support eco-driving for truck drivers.

Stakeholders' Meetings

At the beginning of the process, The Company offered several meetings with different stakeholders involved to give me an overview of DECO as well as the internal insights and critiques of it, which later on served as design requirements. The conversations were in a casual tone in the form of 1-on-1 meetings or team meetings. In total, 6 meetings were conducted with internal stakeholders, i.e., the UX design team, system lead, epic owner, function owner, business analyst for the back-office part of DECO, and driver development manager from the perspective of fuel efficiency driving and driver training activities. During these meetings, mainly three topics were covered as follows:

- The general introduction of DECO.
- Unique knowledge sharing from the perspective of their roles.
- Expectations of the next generation of DECO and ideas on how to improve.

Notes were taken during the meetings. Afterward, the thematic analysis was conducted based on my notes by coding original interview notes into labels, grouping them based on the affinity of content, and extracting themes by hierarchically rearranging codes [31]. The result as an affinity diagram is shown in Figure 5.3. The major findings lay in four aspects, namely facts of eco-driving training, problems of the current DECO, what to improve as the goals, and how to improve as the solutions. The internal stakeholders believed the UI was out of date and inconsistent to some extent, and they heard complaints from users that there was too much information from KPIs and sub-KPIs to track, with some of which drivers felt like they had little influence from their driving behavior. The goals for the next generation of DECO could be to provide a clear guide and coaching to drivers with less disturbance and strengthen their sense of control over the system. Many ideas about how to design the new UI were mentioned by stakeholders, such as more positive reinforcement, configuration and personalization, and level design and gamification.

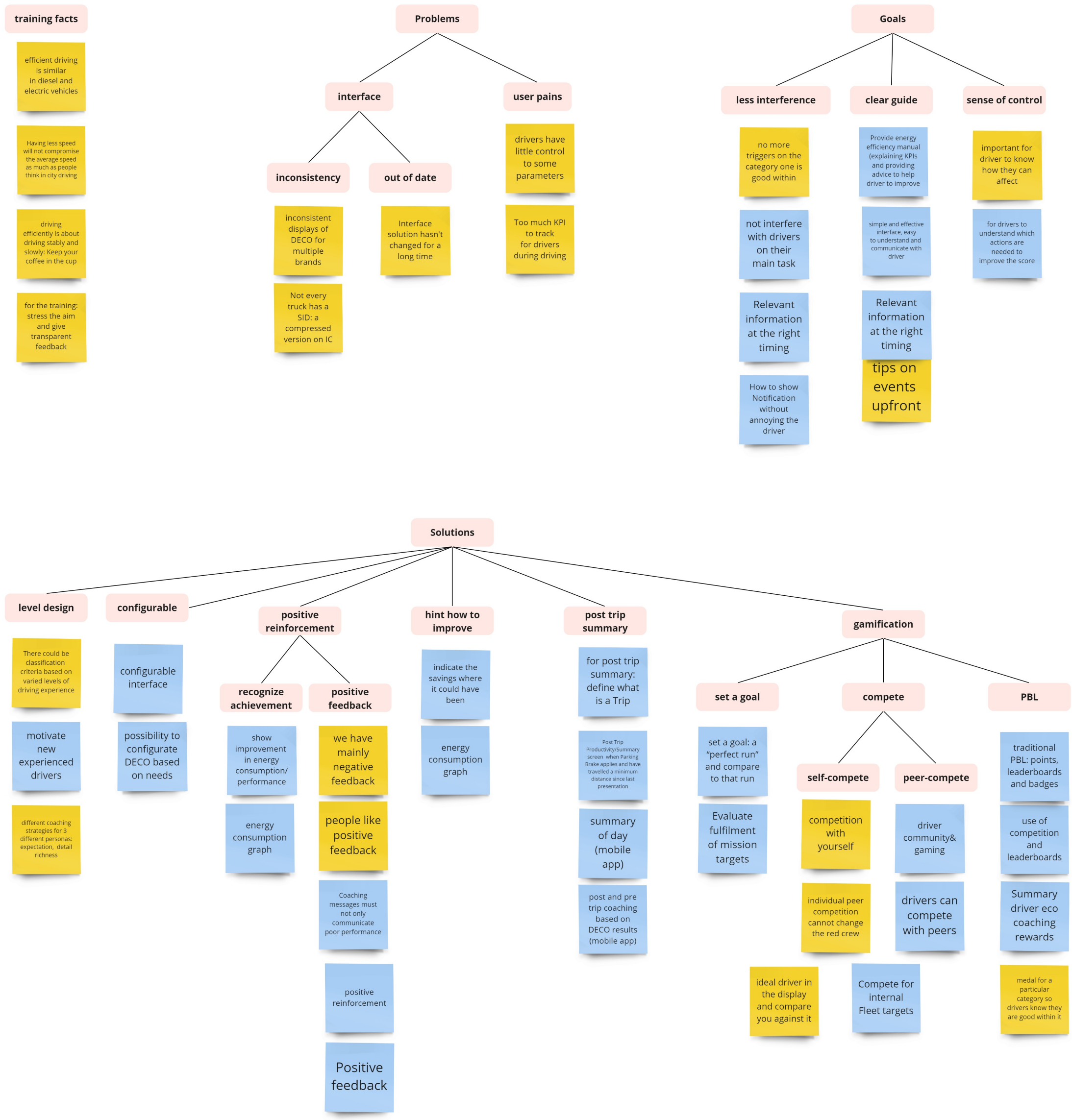


Figure 5.3: Affinity diagram as the outcome of stakeholders' meetings

Study of Interviews Conducted by The Company

To understand the target group, I examined the user interviews that The Company has conducted under a bachelor's thesis project a few months ago. The goal of the interviews was to gather feedback from truck drivers about the user experience and the motivation created by DECO [15]. Gunnarsson et al. did semi-structured interviews with eight local truck drivers, and qualitative content analysis was applied based on the transcribed interviews. By reading their report and going through the original transcribed interviews, I took notes about the interview topics that are directly relevant to this project, and the takeaways were visualized in Figure 5.4.

Comments from drivers were under five categories, which were about the SID, the IC, the whole system, the driver's capability, and their thoughts on several improvement ideas. The main findings are as follows:

- Some of them thought the KPIs were too many and not clear enough.
- They felt the control of fuel-efficient driving, but they did not feel they can influence the results of DECO, which indicated a direct feedback mechanism might still be missing.
- Most of them didn't like the idea of competing with colleagues unless the system can ensure fairness and comparability despite the difference in routes, truck models, traffic, and other external factors.

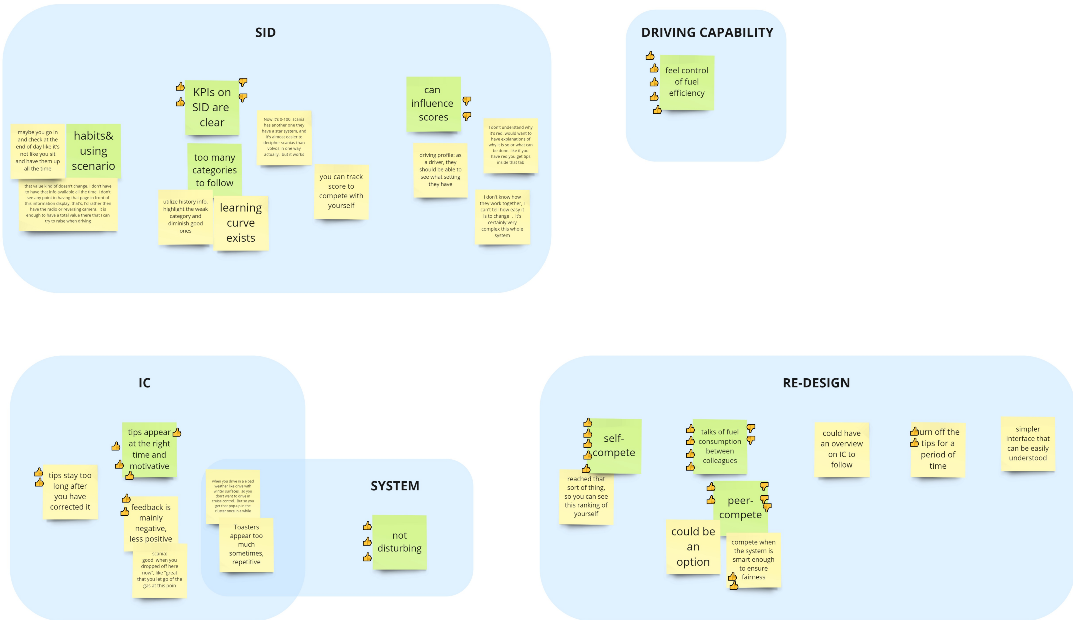


Figure 5.4: Visualized findings from drivers' interviews conducted by The Company

Persona

After having an adequate understanding of the target group, two personas were developed to explore the needs and expectations for the onboard eco-driving support system. By including the context information, the goals, skills, attitudes and behavior patterns with a few fictional personal details [47], 2 different personas, namely Carl and Eric were created which varied in eco-driving experience, age, and vehicle profile, to be able to cover as many scenarios and user needs as possible. As shown in Figure 5.5, the personas were structured with the following sections: *Demographic Information*, *Quote*, *Eco-Driving Experience*, *Personal Details*, *Environment*, *Goals*, *Needs*, and *Frustrations*.

In the process of creating and comparing the two personas, two findings about the target group and scenarios were gained. One is that driver's eco-driving awareness, knowledge and performance could influence his or her way of perceiving the eco-driving coaching system. For example, as a sophisticated truck driver with adequate experience in fuel-efficient driving, Carl could understand the multiple KPIs of the eco-driving coaching system; however, he does not trust the system enough to use it and follow the instructions all the time but rather believe in his experience. As for Eric, he is quite a novice, so he expects such a system to be pedagogic and easy to understand. Another finding is that the different vehicle profile leads to various driving scenarios, thus there are different goals and needs to use the eco-driving support system. In the personas, as a long-haul driver, Carl usually uses other applications on the infotainment instead of keeping track of his eco-driving performance during the long trip. Instead, as always in demanding in-city traffic, Eric expected the system to present the most important information in a simple and intuitive way, so he could grasp it and improve his driving style without being distracted. To summarize, one aspect of the requirements to design DECO is personalization and customization to fit varied driving scenarios.

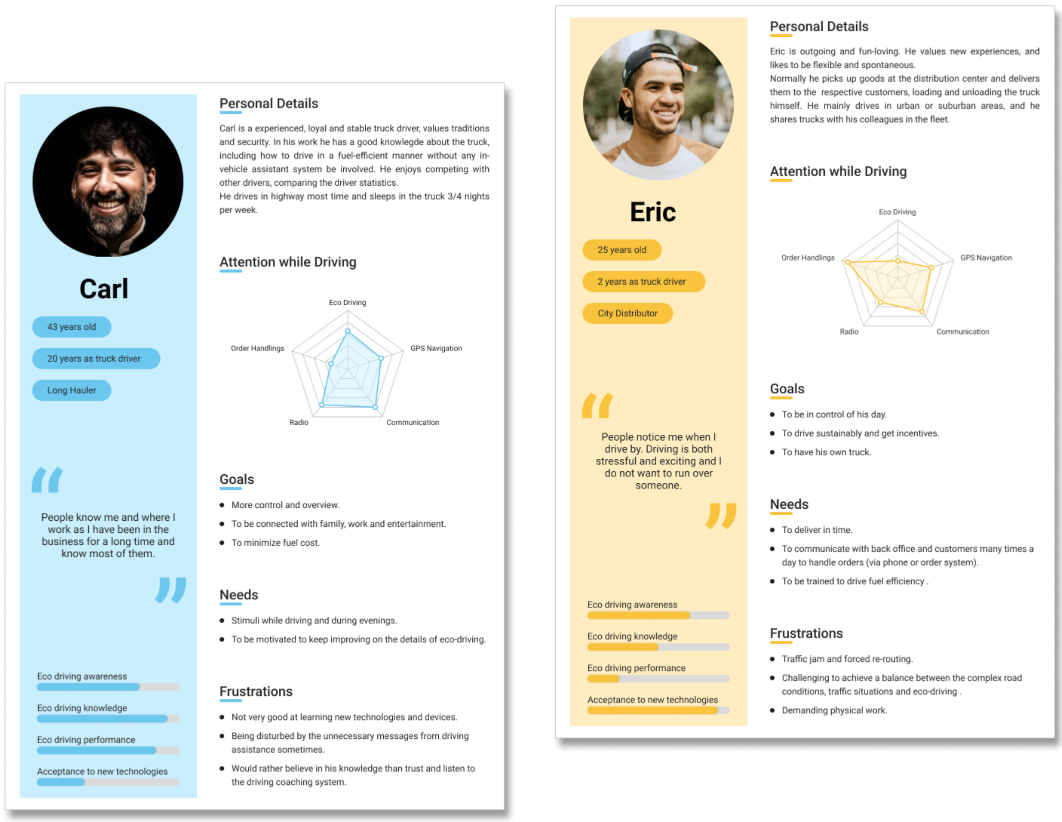


Figure 5.5: Two personas of truck drivers

Competitor Analysis

To identify benchmarks and potential areas for improvement of DECO, I conducted a competitor analysis to gain insight into The Company's competitors and market trends. I started by identifying competitors who had onboard eco-driving supporting systems in their trucks, which turned out to be DAF, SCANIA, Mercedes-Benz, and

Volvo Trucks North America. To collect information on these systems, I reviewed their operation manuals and went to their truck models which were equipped with the systems. I then documented materials in terms of functionality, user interfaces, and design specifications, and the result was summarized and visualized into a functionality checklist as Figure 5.6 shows.

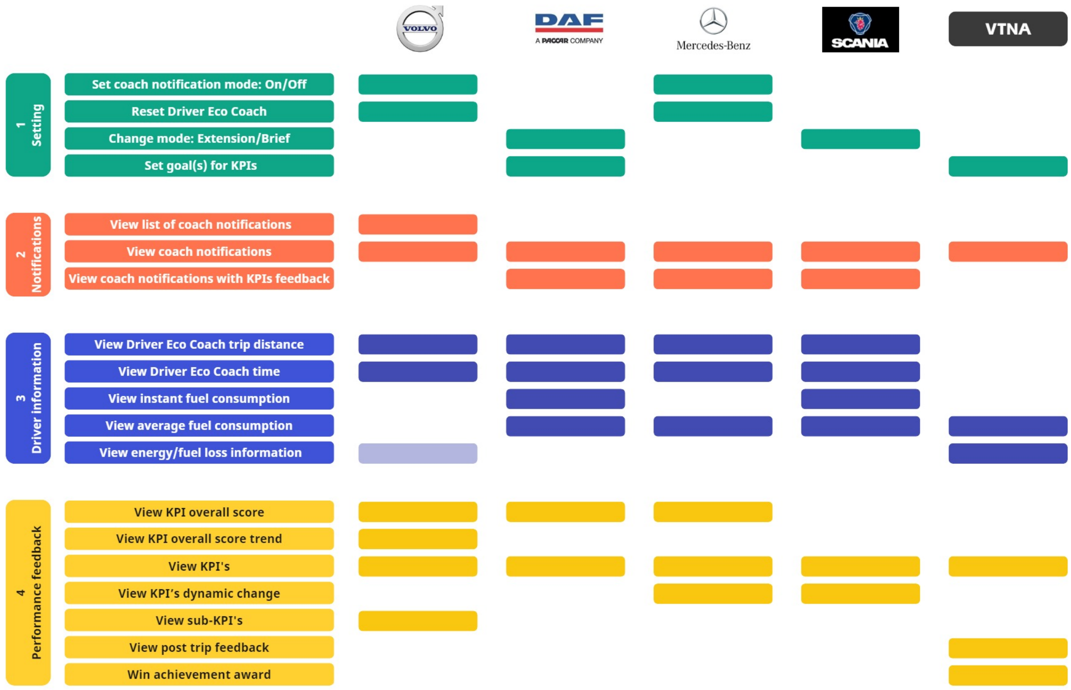


Figure 5.6: Functionality checklist from the competitor analysis

The findings lie in several aspects. First, DAF, SCANIA and Mercedes-Benz use percentage values instead of numerical values as the assessment result of the driver's eco-driving, which is clear about what the values stand for. Second, competitors stress the behavior-consequence feedback pattern by providing real-time and quantified feedback on how specific driver behaviors impacted fuel efficiency, resulting in a more informative feedback loop. Third, proactive notifications were observed in their systems, which offered both constructive suggestions and compliments to drivers, further motivating them to adopt eco-friendly driving practices. These findings highlight the strengths of the competitors' systems and provide valuable insights for enhancing DECO's functionality and feedback mechanisms.

5.2 Iteration Two

After the first round of discovery on the target group and design requirements, Iteration Two started by *ideate* based on the information gathered in Iteration One, and Figure 5.7 presents the progress. With rich and diverse design alternatives generated, I went back to *discover* to conduct another user research to deepen the understanding of users and gather their opinions of the design alternatives; in the meanwhile, these design alternatives were refined during the *prototype*. Then, the *evaluate* to converge the scope of the design solutions wrapped up Iteration Two.

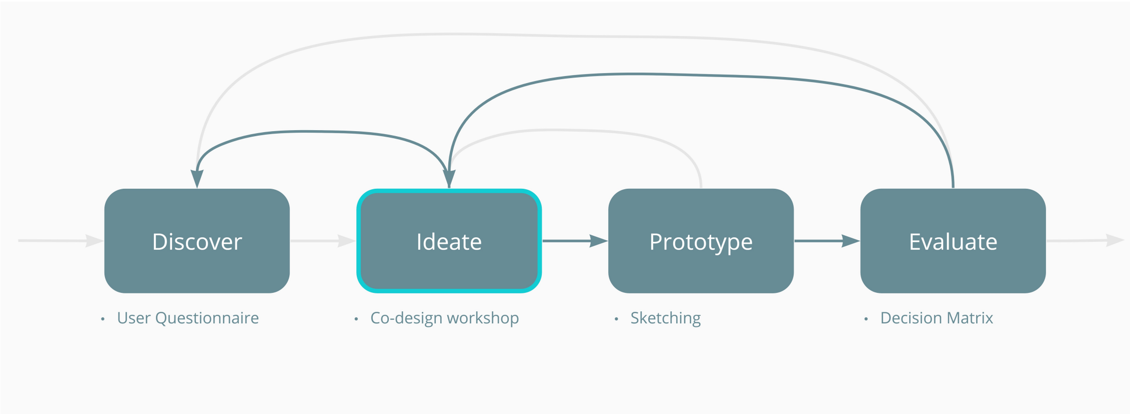


Figure 5.7: Iteration Two began from *ideate*

5.2.1 Ideate: Co-Design Workshop

With the goal of involving stakeholders having different backgrounds and experiences in the design process to practice Participatory Design (PD), I conducted a co-design workshop with design activities of brainstorming and ideas sharing to design for DECO. Following the procedure of Prime, Probe and Generate [32], a series of participatory activities were planned to prime participants for engagement, probe them to self-discovery, understanding and reporting, and generate design ideas. The planned activities for the workshop as agenda can be found in Appendix A.

There were 10 participants attending the workshop with diverse roles in UX design, development team, etc. The workshop was in a hybrid form with one face-to-face group and one online group running simultaneously, where 6 participants attended offline and the other 4 online collaborating on Miro, as seen in Figure 5.8. The 2-hour workshop started with an introduction to participants about the goal and the task for this workshop, also to land participants on the same page regarding the design challenge and target groups. The activities in the group were introduced and done respectively in two groups, the first of which was free talks about good or bad experiences of being coached or coaching as Prime. After the discussion, Why-How Laddering was run in each group, of which the participants picked up the initial statement from the frustrations of the target group, broadened or narrowed the focus by constantly asking "why" or "how" to give them ideas for how to address the original user needs. Then participants moved to generate more concrete ideas by doing 635 Brainwriting (435 Brainwriting with 4 participants), where each participant wrote down 3 ideas about designing the new generation of DECO on a worksheet in 5 minutes, passed the worksheet to the group member next to them, and contributed to each other's suggestions. Due to the time constraint, the workshop did not manage to go through Dot Vote and Sharing as planned, but the outcomes from the two groups were documented and shared with all the participants through Miro after the workshop. As a result, by summarizing the outcomes, I gained an idea pool consisting of 12 suggestions about the features and UI design, as shown in Table 5.1.

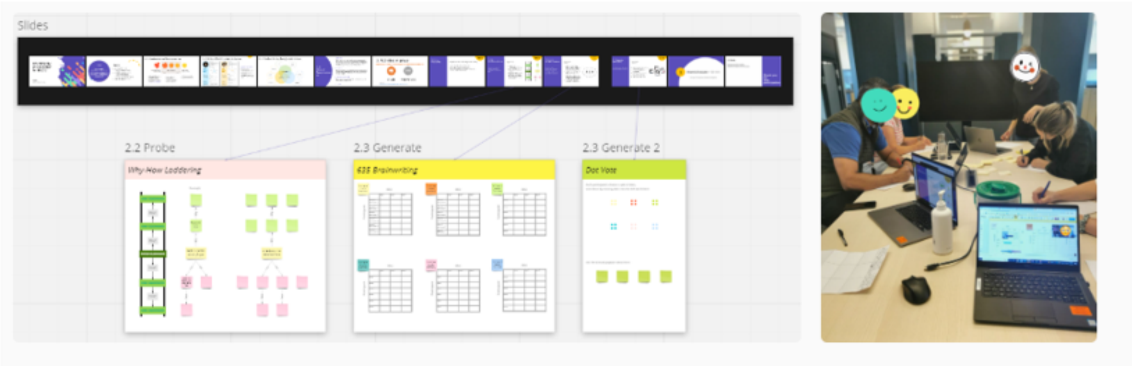


Figure 5.8: Co-Design workshop with 10 participants, being divided into 2 groups: one online (left) and the other offline (right)

Table 5.1: 12 concepts generated from the co-design workshop

	Concept
C1	Have an overview on Instrument Cluster to track your progress
C2	View your achievement: how much fuel/energy you have saved from eco-driving
C3	Get a post-trip summary including your weaknesses and where to improve in terms of eco-driving
C4	Get a post trip summary including what you have improved compared to your historical records
C5	Receive instant feedback (good/bad action) on your behavior related to eco-driving
C6	Receive eco-driving tips in advance before a situation happens
C7	Route fuel/energy map: view eco-driving feedback or tips visualized on a route map
C8	For each trip, focus on a limited number of categories/KPIs (eg. anticipation and standstill) to be trained based on your historical performance
C9	For each trip, focus on a limited number of categories/KPIs (eg. anticipation and standstill) to be trained based on your route
C10	Be able to set eco-driving goal(s) for a specific trip
C11	Anonymous Leaderboard: view your colleagues' scores and compare to them anonymously (driving similar truck on similar route)
C12	Public Leaderboard: view your colleagues' scores and compare to them publicly (driving similar truck on similar route)

5.2.2 Discover: User Questionnaire

After the co-design workshop, an online questionnaire targeted at truck drivers was conducted to gather insights into the user experience of DECO. The purpose of this study is to

- Understand the target group's eco-driving experience.
- Investigate the user experience of the current DECO.
- Evaluate their acceptance of a list of concept features for the future DECO, which were the ideas collected from the co-design workshop.

This user research activity involved both quantitative and qualitative studies; quantitative data was collected from the Likert scales in the questionnaire, while there were also open-ended questions to gather qualitative data. To investigate the target group's eco-driving experience, questions about their motivation, knowledge, awareness, and performance of fuel/energy efficiency driving were asked. As for the user experience of DECO, the usefulness and frequency of use of key features were investigated to have an understanding of users' habits. Besides, the usability of the system was explored by means of the System Usability Scale(SUS) [7, 35], and Net Promoter Score (NPS) was applied to quantify the likelihood of recommending DECO, which can predict customer behavior [50]. With regards to users' acceptance of the concept from the idea pools, questions on appealingness were asked for each idea as "how much appealing do you think they are to help you drive fuel/energy-efficiently?".

The questionnaire was online using Forms by Microsoft. To avoid the questionnaire being too long for having all questions at once, I developed two instances of the survey which asked questions about the user experience of current DECO from different perspectives: Instance One focused on the usefulness and frequency of use from the level of feature, while Instance Two asked about the usability of the system. The structure of the questionnaires was shown in Table 5.2 and Table 5.3, and the original questions can be found in Appendix B.

Each participant was supposed to answer only one questionnaire, and it was randomized which instance he or she would get. Both instances of the questionnaire were estimated to take six to ten minutes to answer, and the requirements to answer the questionnaire were that the respondent is 18 years of age and he or she works or has worked as a truck driver.

Table 5.2: Structure of the user questionnaire on feature level: Instance One

Section	Content
Consent form	Informing participants of the questionnaire and its goal, and gain consent to the study
Demographic	Questions about age, years of driving, vehicle profile, fuel/electricity bill
Eco-driving Experience	Four 5-point Likert items to self-report on motivation, knowledge, awareness, and performance of fuel/energy efficiency driving
Frequency of use and usefulness	Ten 5-point Likert items for five key features of DECO, one NPS question, and one open-ended question asking general opinion
Acceptance of concept features	Twelve 5-point Likert items asking about the appealingness of twelve ideas from the idea pool, and one open-ended question asking for other ideas for a better DECO

Table 5.3: Structure of the user questionnaire on system level: Instance Two

Section	Content
Consent form	Informing participants of the questionnaire and its goal, and gain consent to the study
Demographic	Questions about age, years of driving, vehicle profile, fuel/electricity bill
Eco-driving Experience	Four 5-point Likert items to self-report on motivation, knowledge, awareness, and performance of fuel/energy efficiency driving
System Usability	SUS consisting of ten 5-point items, one NPS question, and one open-ended question asking general opinion
Acceptance of concept features	Twelve 5-point Likert items asking about the appealingness of twelve ideas from the idea pool, and one open-ended question asking for other ideas for a better DECO

The questionnaire was distributed with the help of The Company. During two weeks, there were 106 truck drivers answering the two instances in total, 74 of whom have used DECO. Respondents were from 10 European countries: Czech, Lithuania, Poland, Finland, Hungary, Belgium, Norway, Switzerland, the UK, and the Netherlands, and their average age was 44 years old. The distribution of the countries, years of driving and vehicle profile are included in Appendix C.

When it comes to their eco-driving experience, the median scores of self-reported motivation, knowledge, awareness, and performance were respectively 5.0, 4.0, 4.0, and 4.0.

Questionnaire Instance One got 40 answers, of which 24 have the experience of using DECO, Appendix C showed the average and median scores of frequency of use and usefulness. From the result, the overall score of eco-driving performance and the scores for KPIs were regarded as very useful (Median=4.0) and were used frequently (Median=4.0). The representation of sub-KIPs' performance was also very useful (Median=4.0), but users viewed it less frequently (Median=3.5). The pop-up notifications at IC were medium useful (Median=3.0) and medium frequently used (Median=3.0), while the page for lists of coach notifications was medium useful (Median=3.0) and least used (Median=2.5) among all the features.

Questionnaire Instance Two got 66 answers, of which 50 have the experience of using DECO and therefore answered the SUS, and the average score was 69.95, which was just above 68, an average SUS score across 500 studies [22]. There were 74 participants answering the question NPS of DECO, and the score was 20 according to the calculation formula, which can be interpreted as "good" [50].

106 participants answered the evaluation questions about the future concepts for DECO, and the result scores of appealingness can be found in Appendix C. This result was referenced when applying the decision matrix, which will be elaborated as follows.

To better understand the "why" behind the ratings given by the respondents, the answers to four open-ended questions about their opinions about DECO were analyzed by means of thematic analysis. Figure 5.9 shows how the original answers were coded into labels, which were categorized into two aspects: positive and negative attitude, namely what participants didn't like and what they liked or would wanted to have in the next generation of DECO, as displayed in Figure 5.10.

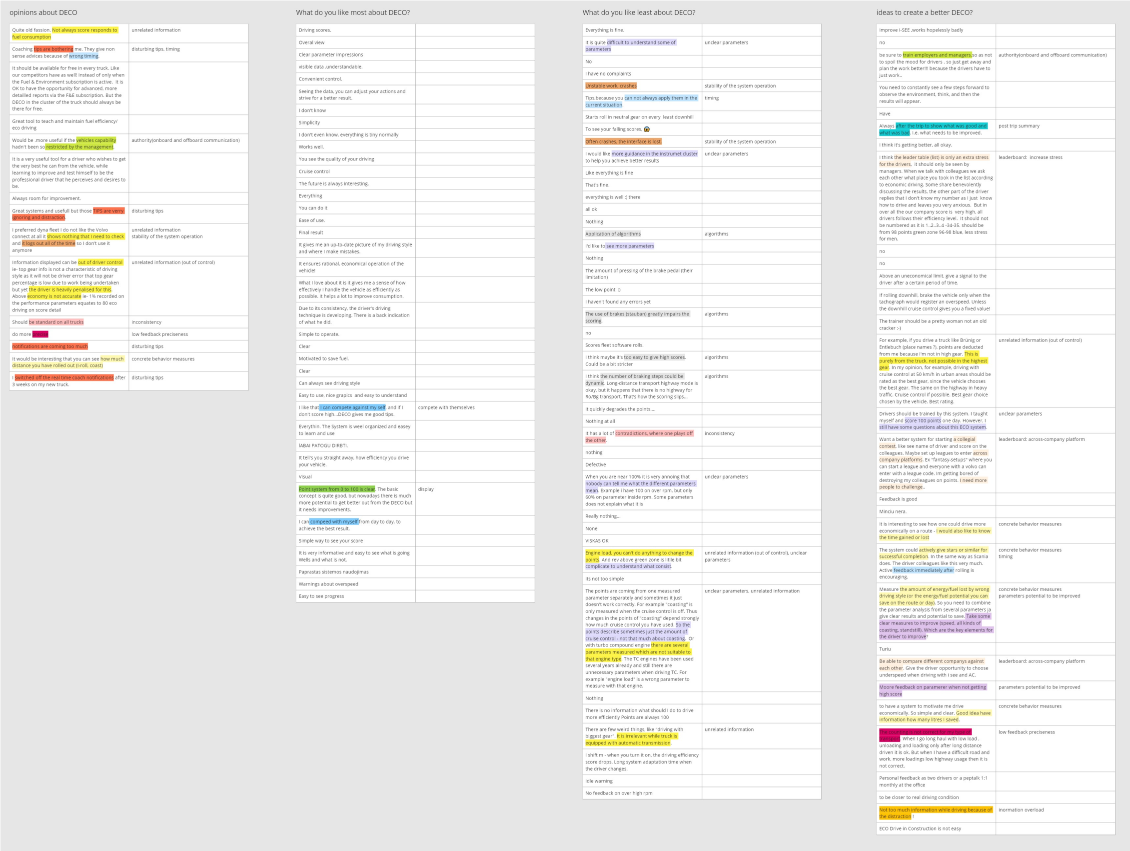


Figure 5.9: Thematic analysis of participants' comments of DECO

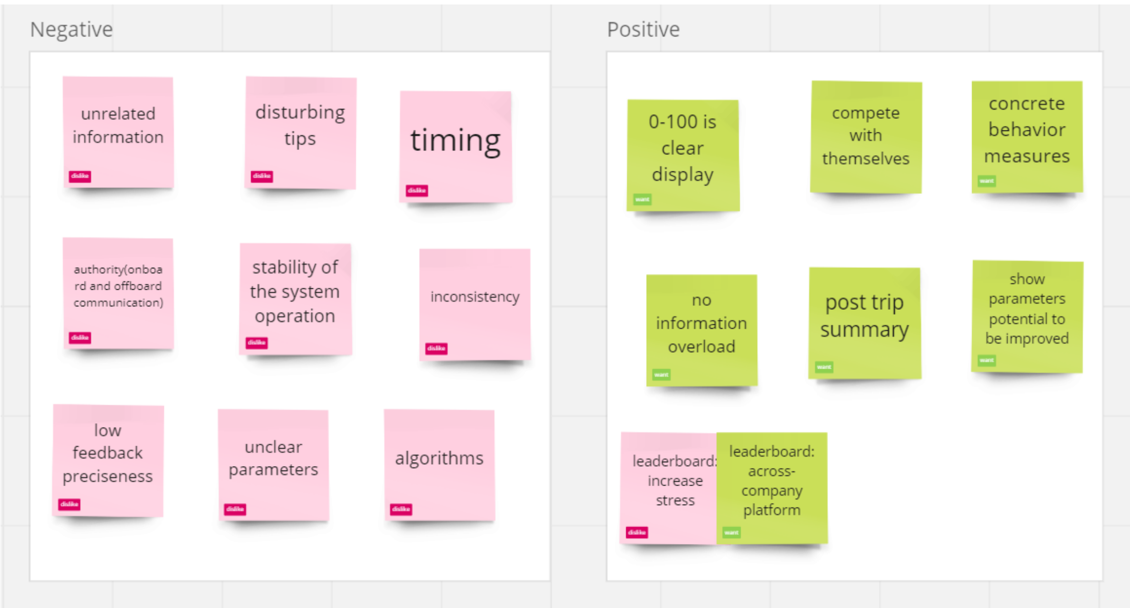


Figure 5.10: Result of qualitative analysis from user questionnaire: red labels are complaints, green ones are what respondents liked or wished to have

As the answers from respondents were general opinions about DECO, which involved both front-end and also back-end parts, e.g., choice of parameters and the algorithms behind, I referred to the eco-feedback framework and mapped the labels above with the model to narrow down the scope of the following work [43], as shown in Figure 5.11. By doing so, it got clear what could be solved by improving the HMI design in this project, and what was beyond the range of this project and need more research from other subjects to support. To conclude, here are the insights for the improvement of DOs and DON'Ts that are highly relevant to the research question of this thesis project :

- Do show a post-trip summary. -*Information, temporal granularity*
- Do use concrete measures which directly respond to fuel consumption. -*Information, message metrics*
- Do make the parameters clear and easy to understand. -*Information, behavior granularity*
- Do highlight the key parameters targeting drivers to change their behavior to save fuel/energy in an optimal way: little change for large saving. -*Information, behavior granularity*
- Do use scores (e.g., 0 to 100) as measurement units. -*Display*
- Do integrate on-board and back-office parts properly by informing drivers of essential information from the back-office settings.
- Don't cause information overload during driving. -*Display*
- Don't force drivers to be compared with colleagues only when they want. -*Information, contextual information*

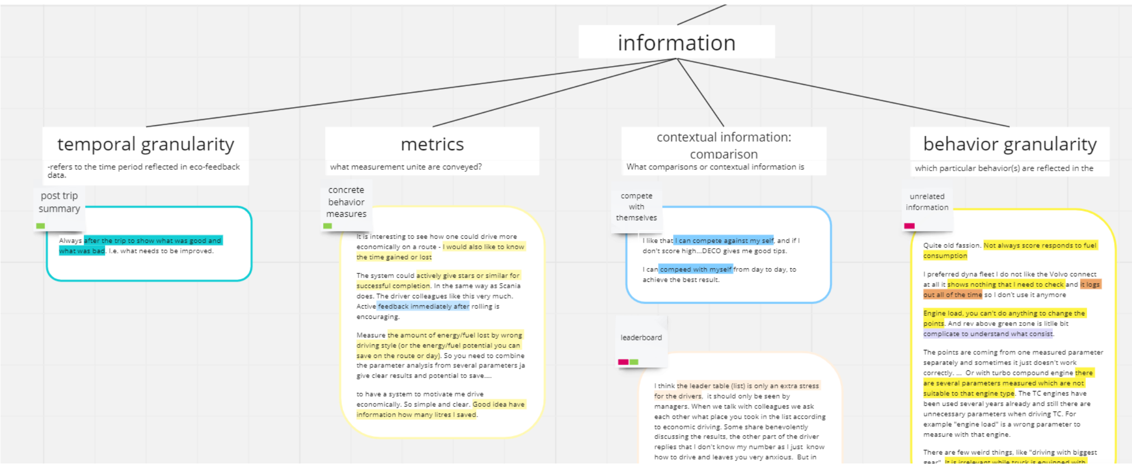


Figure 5.11: Mapping themes into eco-feedback framework

5.2.3 Prototype: Sketching

During the two weeks of waiting for responses to the user questionnaire, I sketched the idea pool from the co-design workshop reported in Section . The example of the outcomes is presented in Figure 5.12. By visualizing the concepts, those ideas got elaborated and prepared as user-interface elements for the further prototype.

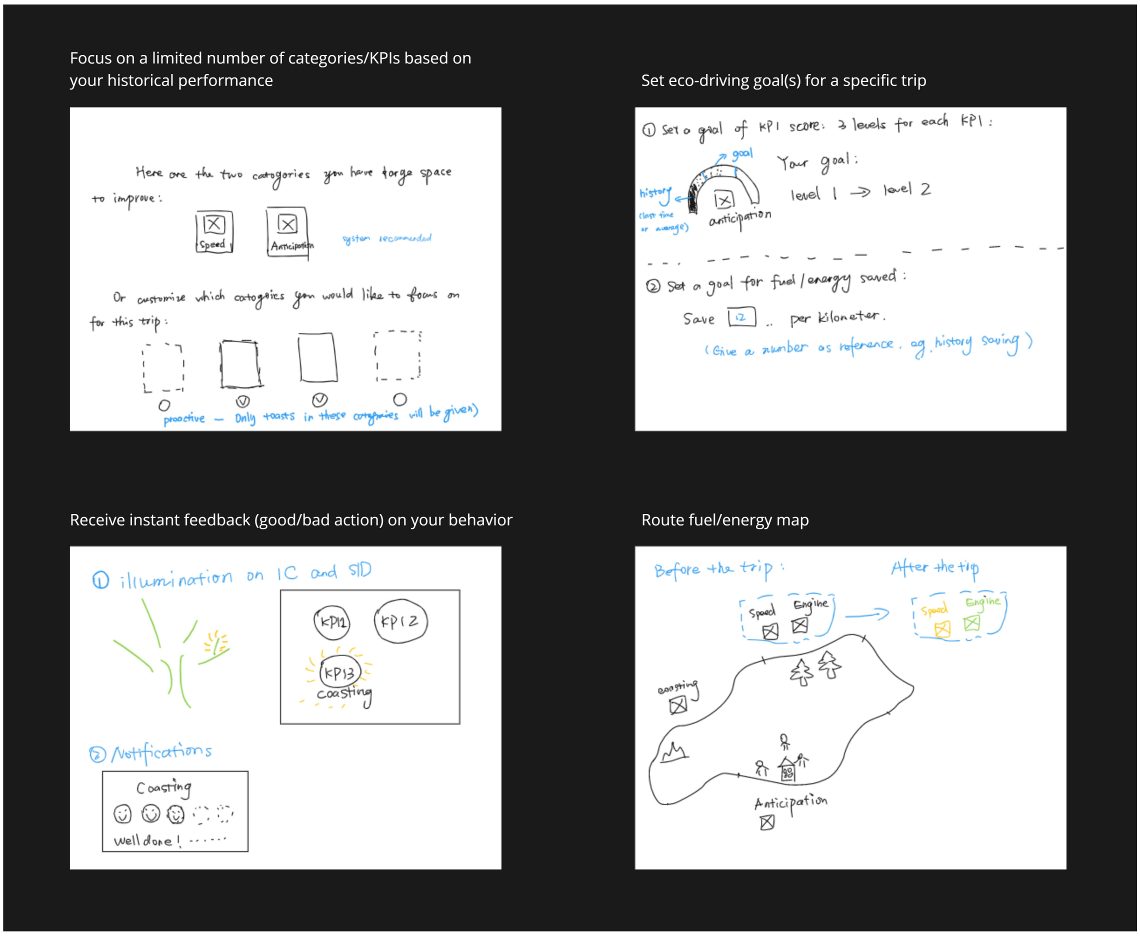


Figure 5.12: Sketchings of the idea pool

5.2.4 Evaluate: Decision Matrix

After the sketching has been done, a decision matrix with *value to the user* and *feasibility* as the two criteria were developed to facilitate discussions between stakeholders and me about what concepts to be elaborated on in the next. The metric can be segmented into 4 quadrants: "yes", "maybe", "maybe", and "no"[46]. The system lead from The Company who is responsible for DECO was invited in the process as a representative stakeholder who has adequate knowledge to evaluate the feasibility of ideas. We had the evaluation result for the future concepts from the user questionnaire (in Appendix C) as a reference of *value to the user*, then we went through the concept sketches one by one, moved them onto the plot, and discussed where they should fall. The outcome is shown in Figure 5.13. As a result, the ideas with low feasibility and low user value were eliminated from the later design process, which was the ones that fell in or near the "no" quadrant.

5.3 Iteration Three

In the third iteration, the design process was converging toward the final outcome by going through the phases of *ideate*, *prototype*, and *evaluate*, as presented in

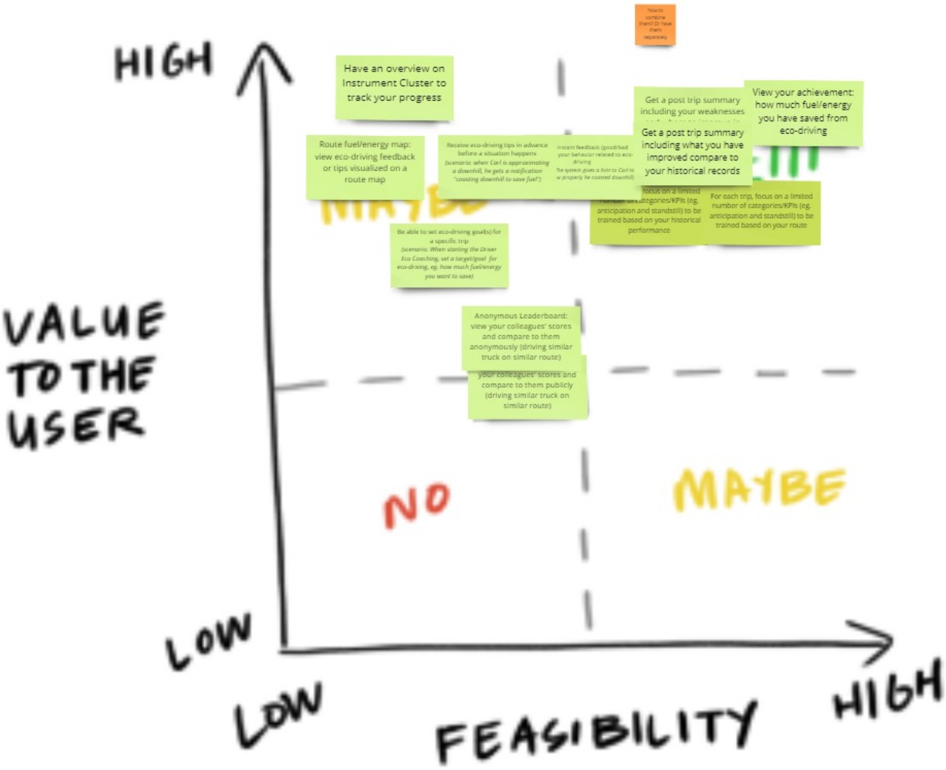


Figure 5.13: Result of the decision matrix

Figure 5.14. With the concepts to be elaborated from the previous iteration, I did *ideate* again to refine the previous ideas by combining them with DECO's user flow, then *prototype* the user interfaces based on the design requirements, followed by the *evaluate* phase, where the mock-ups were validated by user tests.

5.3.1 Ideate: User Journey Map

To create a vision of the involved product features from the user's standpoint in order to improve customer experience, I created a user journey map by synthesizing results from personas, user questionnaire, and decision matrix conducted in the previous iterations, which served as a basis for the design process to move forward [45]. The complete user journey map is shown in Figure 5.15. The driver's journey is divided into 4 stages: onboarding, driving, break, and post-trip; in each stage, there were various actions, needs, and pains from drivers using DECO, which required a series of touchpoints between the user and system to interact with. Those touchpoints then served as the features of DECO to be designed on the user interfaces.

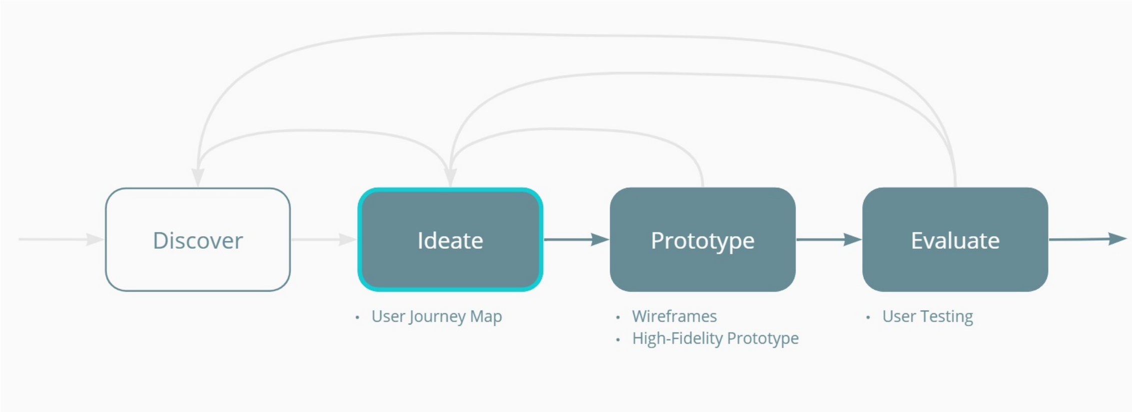


Figure 5.14: Iteration Three began from *ideate*

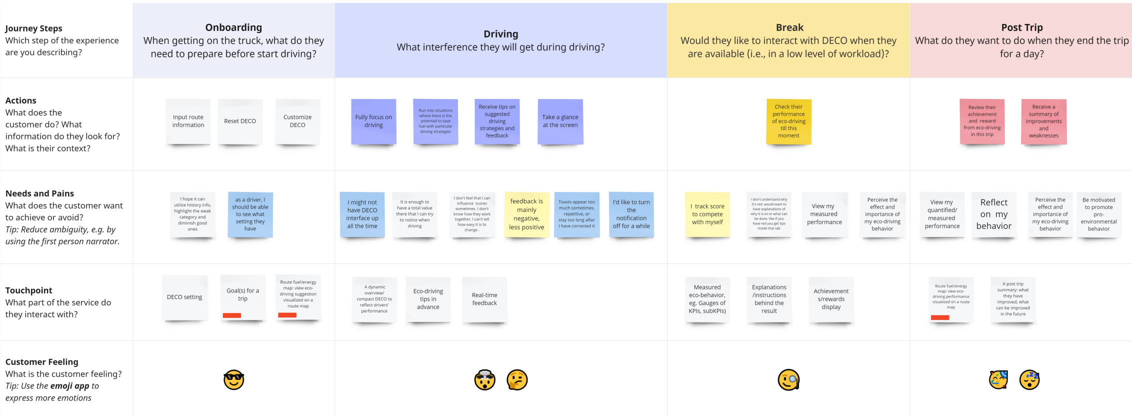


Figure 5.15: User journey map

5.3.2 Prototype

After the features and user stories to be designed were clear, I started prototyping the user interfaces for DECO. I began with creating wireframes, which were targeted to include the essential elements to support user flows with a rough visual style, followed by iterating and being built into high-fidelity mock-ups.

Wireframes

The prototyping was first done in the form of paper wireframes. This involved taking the sketches from Section 5.2.3 and combining them in an experimental way that accounted for the overall user flow and user stories. One example of paper wireframes is presented in Figure 5.16, which is a tree on the overview screen that reflects the target group's eco-driving behavior by the leaves growing big or shrinking.

After that, I moved on to developing digital low-fidelity wireframes using Figma. During this session, elements from the paper wireframes were refined, including the placement of text fields, buttons, and other visual elements. As a result, the basic layout of each screen in the DECO application was set, e.g., the eco tree shown in Figure 5.17. I also experimented with different layouts and designs, and the primary

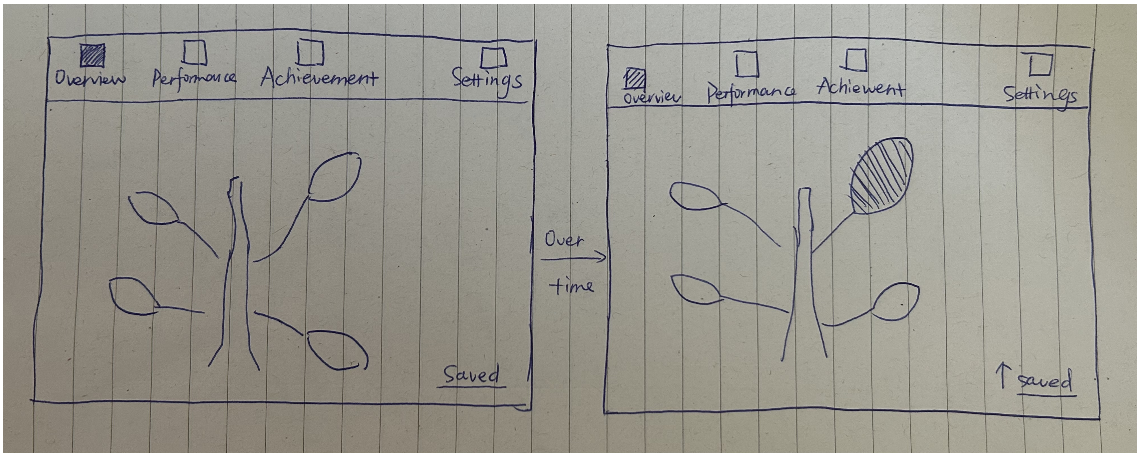


Figure 5.16: Paper wireframe: an *eco tree* as an overview

design alternatives were kept to be decided further, as described below:

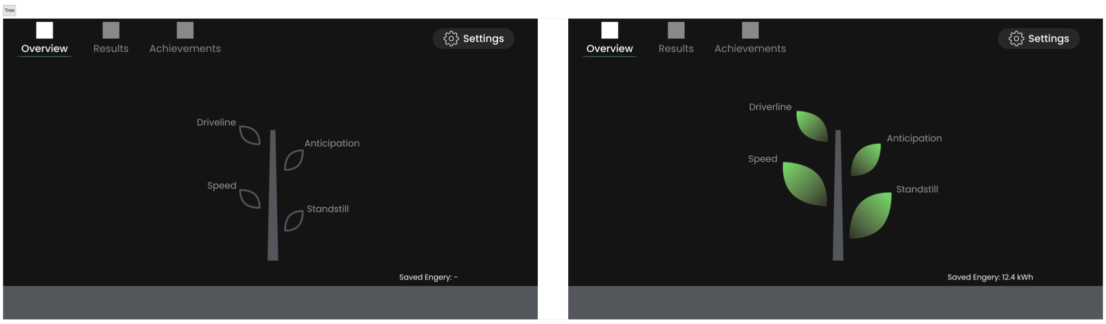


Figure 5.17: Digital wireframe: the *eco tree*

Alt 1.1 **Provide history information for overall score**. To explain the scores to the user, historical records of what events accounted for the ups and downs of the score of eco-driving performance can make this measurement more transparent, as shown in Figure 5.18.

Alt 1.2 **Provide a history view of each KPI**. The historical records can also be categorized and presented on the screen of KPIs, under the assumption that users would want to review the historical events that influenced their scores only when they care about their performance on the level of KPI, as shown in Figure 5.19.

Alt 2.1 **Reset in the tab**. As presented in Figure 5.20, the function of resetting the system is used by the drivers when they want to make the onboard DECO back to the default state. By enabling the button in the tab which is always there on the screen, users can reset without clicking multiple times.

Alt 2.2 **Reset in the setting**. By including Reset in the settings view, there are fewer visual elements in the tab thus less visual excise, which is presented in Figure 5.21.

Alt 3.1 **Equivalence on the left**. On the achievement screen, the element visualizing saved fuel or energy is on the left, as shown in Figure 5.22.

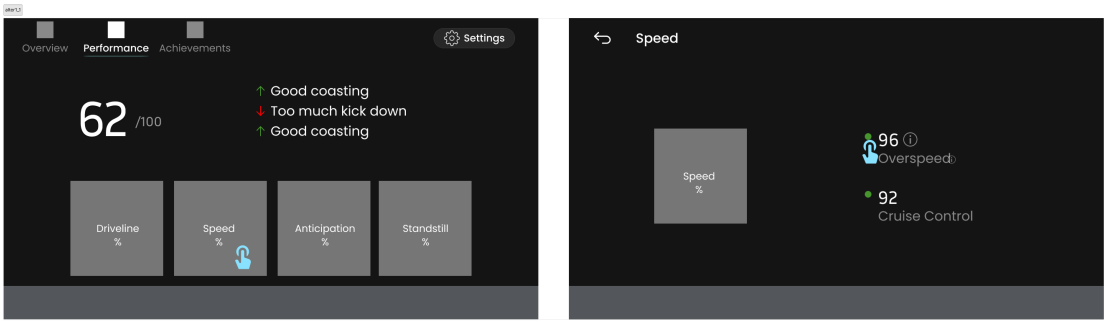


Figure 5.18: Wireframe alternative 1.1

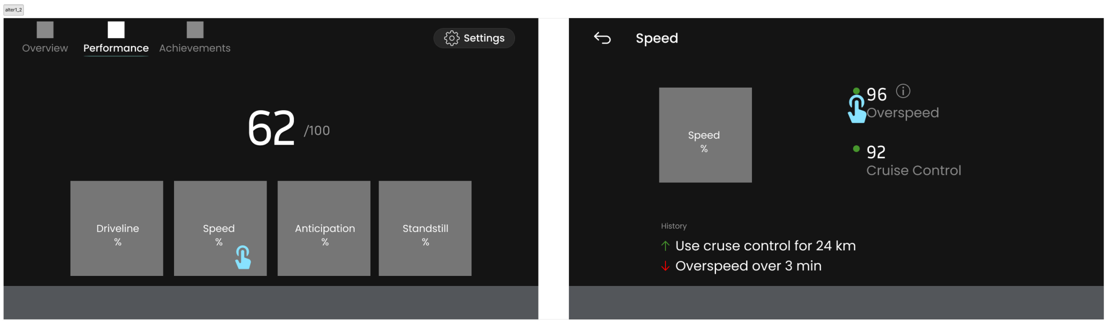


Figure 5.19: Wireframe alternative 1.2

Alt 3.2 Parameters on the left. On the achievement screen, the group of parameters is on the left, as shown in Figure 5.23.

High-Fidelity Prototype

Before finalizing the high-fidelity final mock-ups, a design review was conducted with the system lead at The Company. The purpose of this review was to decide which alternatives to elaborate further and which ones to discard. After discussion and careful consideration, Alternative 1.1 and 1.2 were combined, which means both overall historical events and categorized events were kept in the design. Additionally, Alternative 2.1 and Alternative 3.2 were chosen based on the consideration of functionality and their aesthetic appeal.

To maintain a consistent visual style and brand impression with other applications developed by Volvo Trucks, the design system and user interface design guidelines from The Company were referenced during the design process, including font, color palette, UI components, and so on. This ensured that the final prototype throughout DECO was in line with The Company's branding and design philosophy. However, to avoid disclosing the design identity of The Company, all high-fidelity prototypes presented in this report have been purposely modified in terms of typography, icons, and color scheme.

Similar to the process of developing wireframes, I created high-fidelity mock-ups using Figma, and connected each screen to make the prototype interactive. With

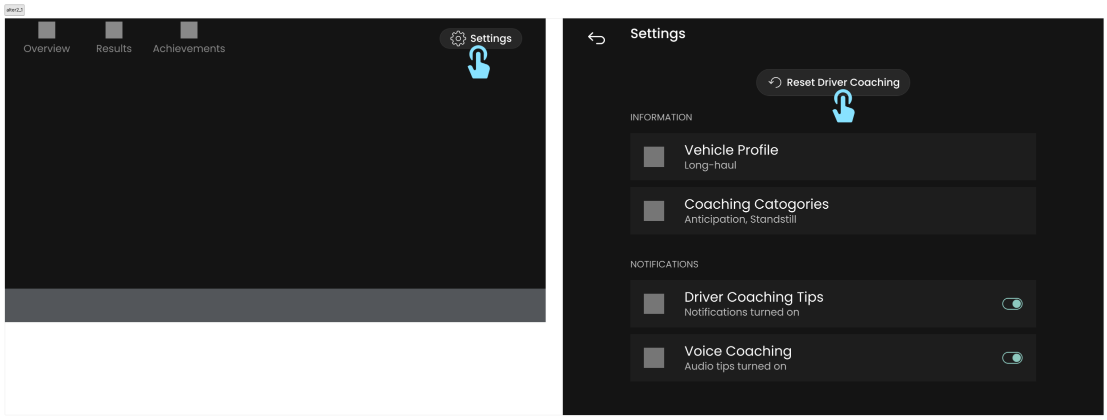


Figure 5.20: Wireframe alternative 2.1

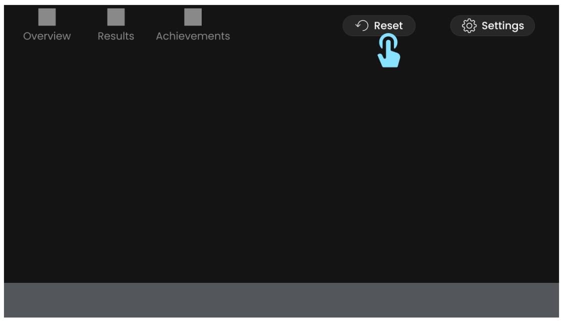


Figure 5.21: Wireframe alternative 2.2

the goal that the prototype would later serve the purpose of user testing, screens were meticulously crafted with the user's path in mind. The user flows were based on the user journey map developed in Section 5.3.1. Consequently, prototypes were presented following the main user flows as below. To distinguish my design work from DECO, it is referred to as DECO PRO as follows.

Follow eco-driving overview. During driving, drivers can view the *eco tree* efficiently with a glance to keep track of their eco-driving performance without too much attention being distracted. There were four leaves on the *eco tree*, each of which represented one category of eco-driving being measured. As presented in Figure 5.24, the leaves were outlined without filling at the initial states; as the driver started to drive fuel/energy efficiency and save energy or fuel compared to non-eco driving, the leaf would illuminate accordingly to the driver's behavior and then be filled in green. Consequently, the leaves would grow or shrink in size along with the driver's performance.

See the details and understand. When the driver has more mental workload and attention resources to care about the eco-driving, he or she could switch to the Performance screen to follow the details, where quantified performance was communicated as scores in percentage shown in Figure 5.25. There were four areas that eco-driving behavior can fall into, namely the four KPIs: driveline, speed,

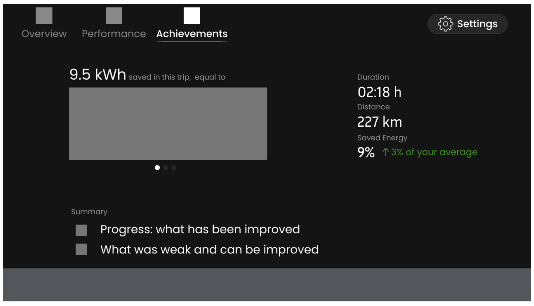


Figure 5.22: Wireframe alternative 3.1

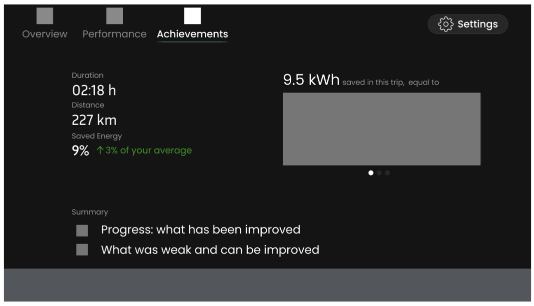


Figure 5.23: Wireframe alternative 3.2

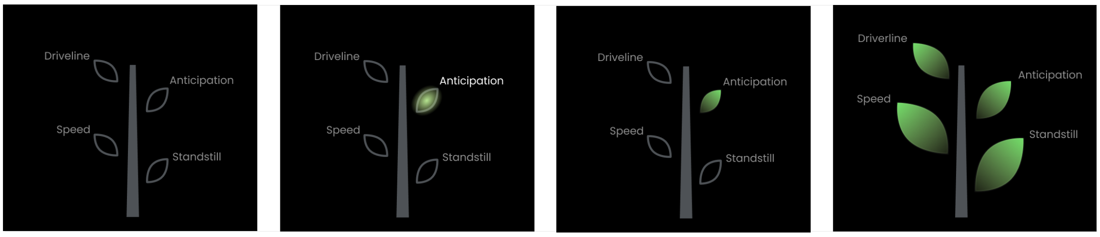


Figure 5.24: How the *eco tree* changes over time to provide drivers overall feedback

anticipation, and standstill. The four gauges were the same design as DECO, which uses a color scheme of 3 colors: green, yellow, and red, with each representing a certain score range. The element of the past events showed in the recent order a list of records of the driver's actions that were captured and taken into the measurement of scores. The KPI's gauge also served as a button, which can be tapped and it will navigate to the screen of KPI (Figure 5.26), where there was sub-KPIs' information as DECO. What is new is that there were ups and downs of the score displayed at the bottom of the screen. By pressing the sub-KPI, a dialogue would pop up to explain the parameter by text, to make the measurement and calculation mechanism more transparent and pedagogical, as shown in Figure 5.27.

Get real-time interference. Also during driving, the driver can be informed proactively by notifications from DECO PRO displayed on the instrument cluster. There were two types of notifications, one was pre-event tips for eco-driving, and the other was post-event feedback, as shown in Figure 5.28. The tip was triggered automatically by the system, which would take into consideration the upcoming driving scenario based on the route and the transportation environment. It gave advice on how to drive efficiency in the form of text and specified the related KPI, with the possibility to be broadcast by setting. The feedback toast was also in real-time and would pop up after an event, which presented the assessment of the driver's behavior by quantifying it on a 5-leaf scale, along with a short explanation.

Get a post-trip summary and reflect on it. When it comes to an end of a trip, the driver can view the summative information as shown in Figure 5.29. Parameters related to eco-driving, such as duration, distance, and saved fuel or energy were

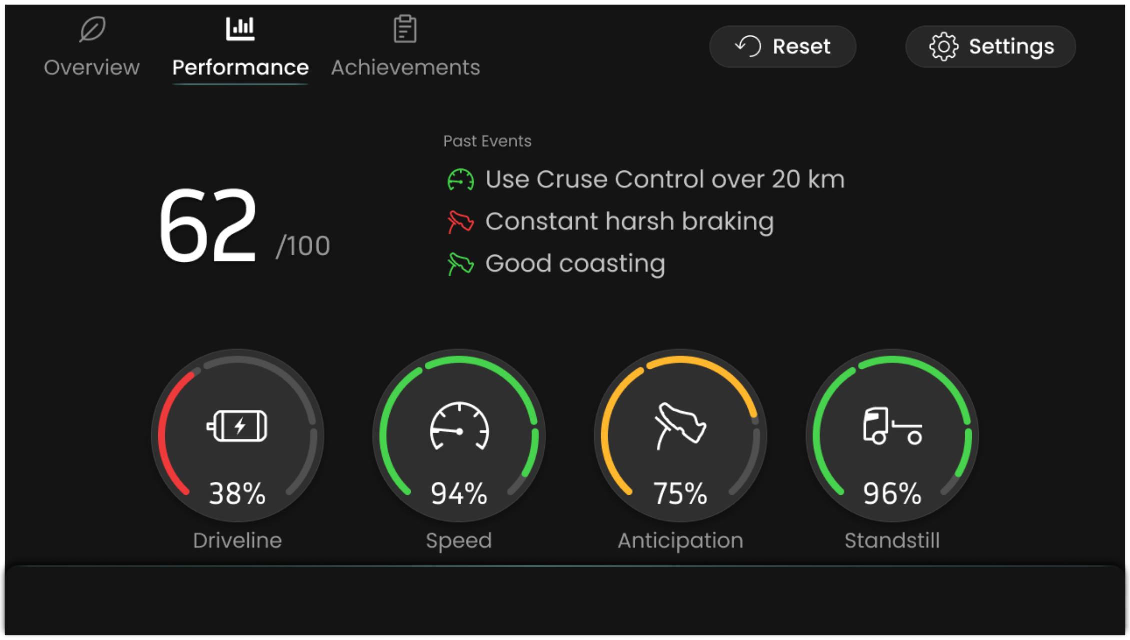


Figure 5.25: Overall score and KPI's gauges to inform concrete performance

displayed. What is worth noticing is the equivalence, presented in Figure 5.30, which conveyed energy using concrete, tangible and familiar terms: the amount of saved energy can be used to drive trucks for how much distance, to light a bulb for how many hours, or is equal to how long a wind turbine works to generate energy. In addition, the driver can read the "highlights" from this trip, which pointed out what the driver has improved, and what eco-driving behavior is still weak and can potentially be improved.

Reset and customize the system. As long as the system was enabled, the driver could reset the system, so it came back to the initial state. Instead of having all four KPIs, the driver can configure coaching categories by deselecting KPIs, as shown in Figure 5.31, and the default selection would be based on his or her historical performance as well as the route for this trip. The disabled categories would then be hidden throughout the whole application, from both the *eco tree* and gauges on the Performance screen.

5.3.3 Evaluate: User Testing

After the high-fidelity mock-ups for the DECO PRO were developed, an evaluation was conducted to assess the effectiveness of the design. The purpose of the evaluation study lay in the following three aspects:

- To compare the DECO PRO with DECO in terms of motivation and user acceptance.
- To evaluate the usability of the DECO PRO user interfaces, identify the usability issues of the user interfaces and explore the way to solve them.

To achieve these objectives, the evaluation study was designed with the following

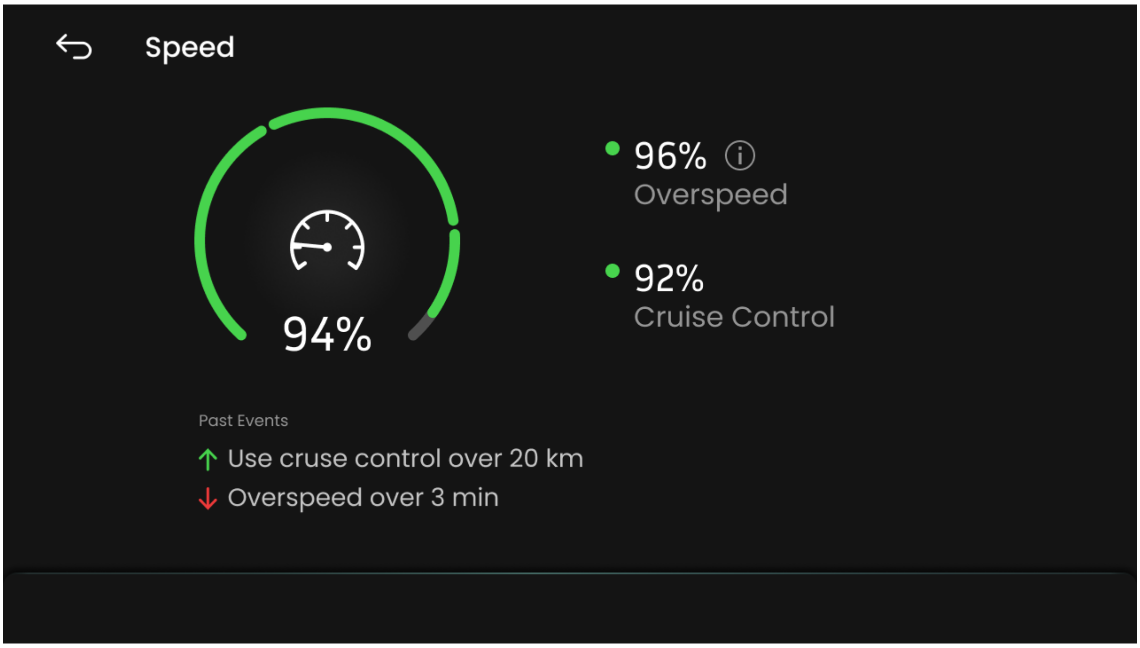


Figure 5.26: The screen of the KPI: Speed

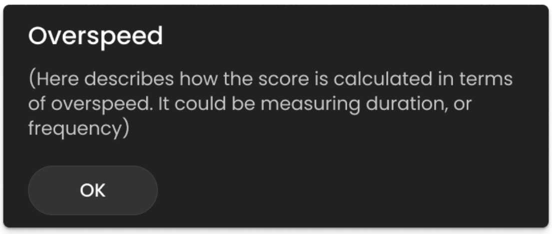


Figure 5.27: Dialogue to provide more information about the sub-KPI: Overspeed

research questions in mind:

- Which HMI solution is more motivating and acceptable to support drivers of eco-driving?
- What are the usability problems and better practices for DECO PRO?

Study Design

The evaluation was a mixed study, involving both quantitative and qualitative parts. The quantitative data was collected using scales to measure the users' motivation and acceptance with DECO PRO and DECO [26, 52]. The qualitative data was collected through observation, think-aloud protocol, and interviews. With the primary aim to determine the overall effectiveness of DECO PRO, this study also targeted to identify usability issues with the design and to provide insights on how to iterate it further, which made it both summative and formative.

In this study, the independent variable was the prototype version, with two conditions: DECO prototype walkthrough and DECO PRO prototype walkthrough. The dependent variables were the scores obtained in terms of motivation and acceptance.

Figure 5.28: Two types of real-time notifications on the IC: tip and feedback

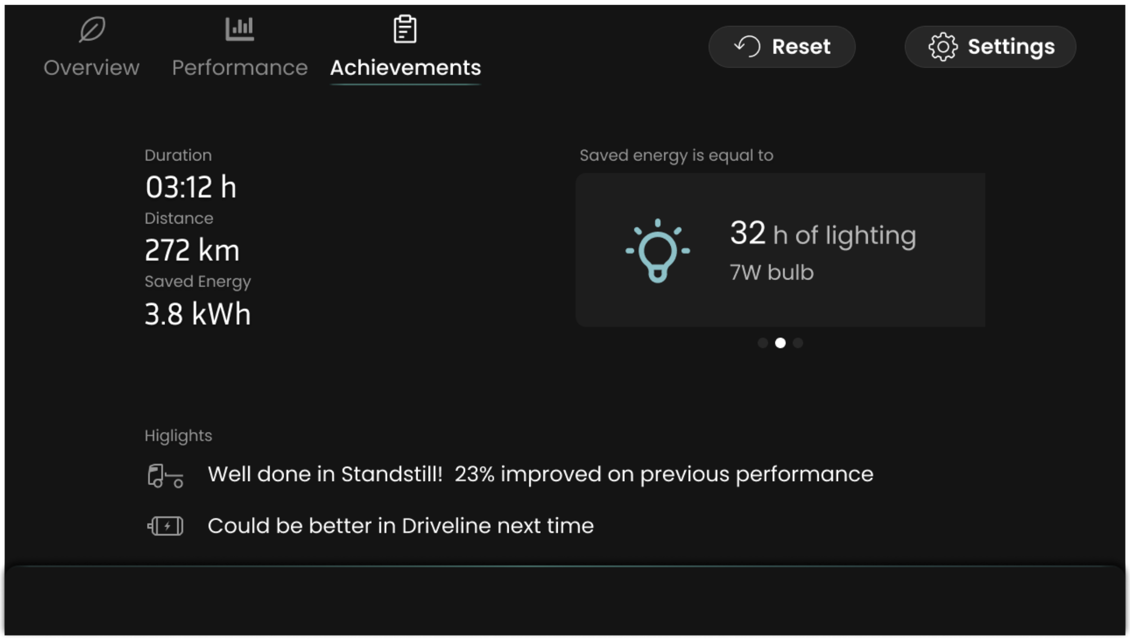


Figure 5.29: Achievement screen as an eco-driving summary of current trip

Additionally, a confounding variable was identified, namely, the participants' previous experience with DECO. A within-subject design was implemented to minimize potential biases, which means each participant experienced both prototype versions to ensure that the variations in the dependent variables could be attributed to the prototype itself rather than individual differences among participants. To control the order effects in the experiment, counterbalancing was applied by including all possible orders to present the independent variable, so half of the participants walked through DECO PRO prototype first, and the others were presented with DECO first.

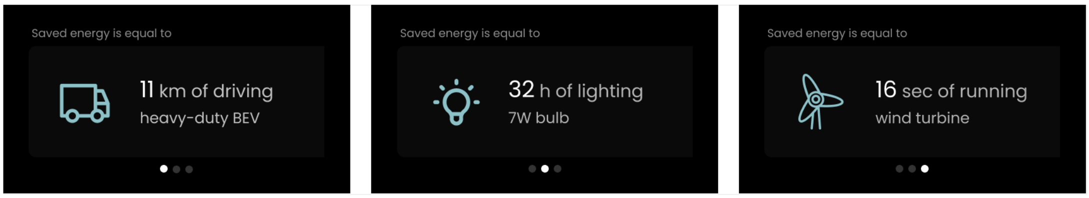


Figure 5.30: A carousel consisting of three *equivalence to saved energy*

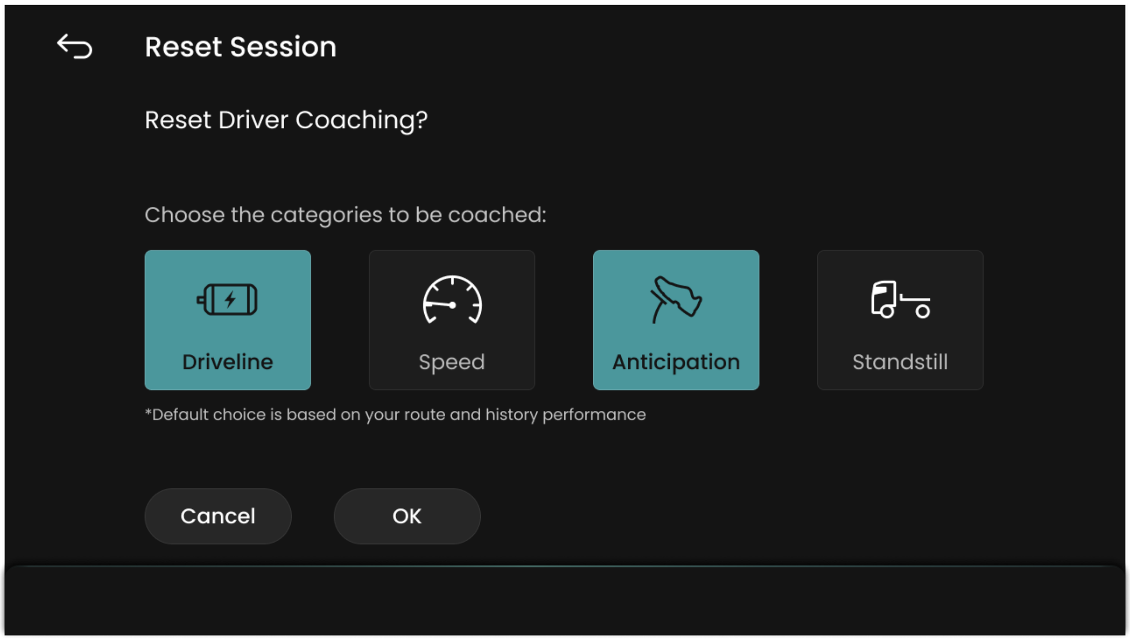


Figure 5.31: Selecting desirable coaching categories when resetting DECO PRO

Participants

11 people from The Company attended the testing. All of them have heard of DECO before, some of whom even worked with DECO. Their age ranged from 29 to 46, and some of them have truck driver's licenses. The participants were recruited through personal invitations in the company's network.

Procedure

The procedure of the study is presented in Figure 5.32. Before the study formally began, participants were provided with a consent form outlining the purpose of the study, which assured their privacy and confidentiality, as shown in Appendix E. After they signed the consent form, I gave them an instruction on the study's procedure. This included an explanation of how to perform the prototype walkthrough, what the think-aloud protocol is, and asking for their permission to record audio during the session.

The experiment started with either DECO PRO prototype or DECO, which were referred to as Prototype A or Prototype B in front of participants, and the order was

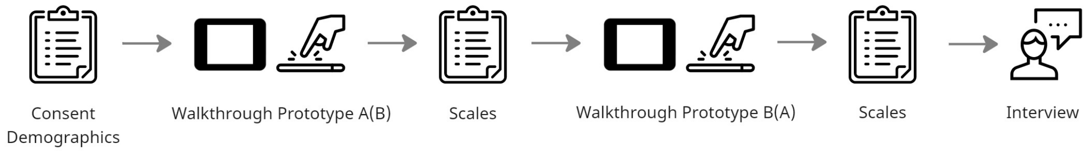


Figure 5.32: Procedure of the user test

counterbalanced. The participant performed the scenario-based walkthrough of the HMI mock-ups, exploring the functionalities and features. During this process, the participant was encouraged to think aloud, verbalizing their feelings, thoughts, and any difficulties they encountered. After each prototype walkthrough, the participant got the scales to fill in. When the walkthrough of two prototypes and the scales were all complete, I moderated a semi-structured interview with the participant based on his or her rating on the scales, talking about the reasons behind the scores, as well as his or her perceptions and preferences regarding the user interfaces.

Apparatus

During the experiment, there were two displayed in front of participants, as shown in Figure 5.33. The laptop in the center front was used to present the scenario description and the visualization of the instrument cluster, as well as running Microsoft Teams to record audio. The tablet on the right was to simulate the secondary information display, which was the main screen where the interactive prototype was based.

Figure 5.33: Setting of the user test

The prototype walkthrough was based on a series of possible scenarios during the driving, which I developed with the aim to present how DECO PRO and DECO responded to different driving situations and driver behaviors. The scenario-based walkthrough covered most features of DECO PRO and DECO, allowing participants to interact with the prototype comprehensively. The full scenario description can be found in Appendix D. The prototypes were interactive using Figma based on the user interface mock-ups, which are presented in Section 5.3.2.

The questionnaire used in the test included the consent form, demographic questions as well as scales after each prototype walkthrough, as Appendix E presented. A 7-point Likert scale consisting of four items was used to assess the striving self-determination index, which has been proven to be a motivational predictor of eco-driving [26]. To measure the acceptance of two prototypes, nine 5-point rating-scale items were referenced from Van Der Laan et al.'s research. These items are sensitive to differences in opinions regarding particular characteristics of the in-vehicle system. They fill out two scales: one measuring satisfaction with the system and the other measuring usefulness. In addition, SUS (System Usability Scale) was also used but only for DECO PRO prototype, as one of the aims of this study was to identify the usability issues for future iteration, and the previous user research reported in Section 5.2.2 has already investigated the usability of the DECO [7].

During the semi-structured interview, apart from the questions included in Appendix E, participants' thoughts and reasons for rating items on the scale were also asked by the facilitator reviewing the filled-in scales and asking questions such as "Why did you give [item X] a score of [Y]? ". Those open-ended interview questions were used to gather qualitative data to investigate the user experience of DECO PRO and DECO and explore potential usability issues or advice for improvement.

Results

Data collected from the user tests were analyzed using quantitative and qualitative methods. According to the scales, scores of striving self-determination index, satisfaction, and usefulness were calculated using the scale techniques instructed by previous studies [26, 52]. The descriptive statistics results were reported in Table 5.4. Three paired t-tests were conducted to compare the scores between the DECO prototype and DECO PRO prototype. The significance level is 0.05, and two-tailed were chosen. As a result, there were statistically significant differences between the two conditioners in terms of striving self-determination index ($t(10) = 3.56$, $p = .005$), usefulness ($t(10) = 2.99$, $p = .014$), and satisfaction ($t(10) = 4.84$, $p < .001$). The results indicated that participants believed DECO PRO was more motivating, useful, and satisfying compared to DECO.

To analyze the qualitative data from the observation and semi-structured interviews, thematic analysis was conducted and the results were presented in Figure 5.34, which were formulated into seven themes related to the primary improvements of the DECO PRO: *eco tree*, *notifications*, *past events*, *equivalence of saved energy*,

Table 5.4: Mean scores and SD (standard deviation) for DECO and DECO PRO

	Mean	SD
Striving self-determination index (DECO PRO)	4.09	2.43
Striving self-determination index (DECO)	2.55	2.30
Usefulness (DECO PRO)	0.95	0.74
Usefulness (DECO)	0.38	0.60
Satisfaction (DECO PRO)	1.25	0.65
Satisfaction (DECO)	0.45	0.74

highlights, *customizable coaching categories*, and *relative information*. The results covered the complementary comments (in green) and also feedback for potential improvements (in red) from participants, to serve both summative and formative purposes.

In general, when it comes to the DECO, it was subtle and had less clue to perceive the change when it comes to eco-performance feedback. While DECO PRO was believed as clearer and communicated better, and the overall design tone was calm and relaxing. However, there was an inconsistency of symbolic language and design patterns throughout the DECO PRO that could be improved, and the information conveyed by the eco tree was somehow redundant with the performance gauges.

Figure 5.34: Affinity diagram based on the interviews in user tests

6

Results

In this chapter, the primary results from this thesis are presented in two parts: the high-fidelity prototype and a series of design guidelines to answer the research question.

6.1 Hi-Fidelity Prototype

This prototype of DECO PRO was built in Figma as the high-fidelity mock-ups, iterated from sketching, and low-fidelity wireframes to the final interactive prototype. As this project is based on the current DECO system which already has a user interface, I mainly focused on reporting the improved design solutions which were new or changed from DECO, instead of describing all the visual elements on the interface with equal richness of detail. Noticeably, the HMI presented in this section was slightly altered from the most recent design iteration in Section 5.3.2, as some particular components of the prototype underwent additional refinement based on the feedback provided by participants in the user tests.

Figure 6.1: The Overview screen

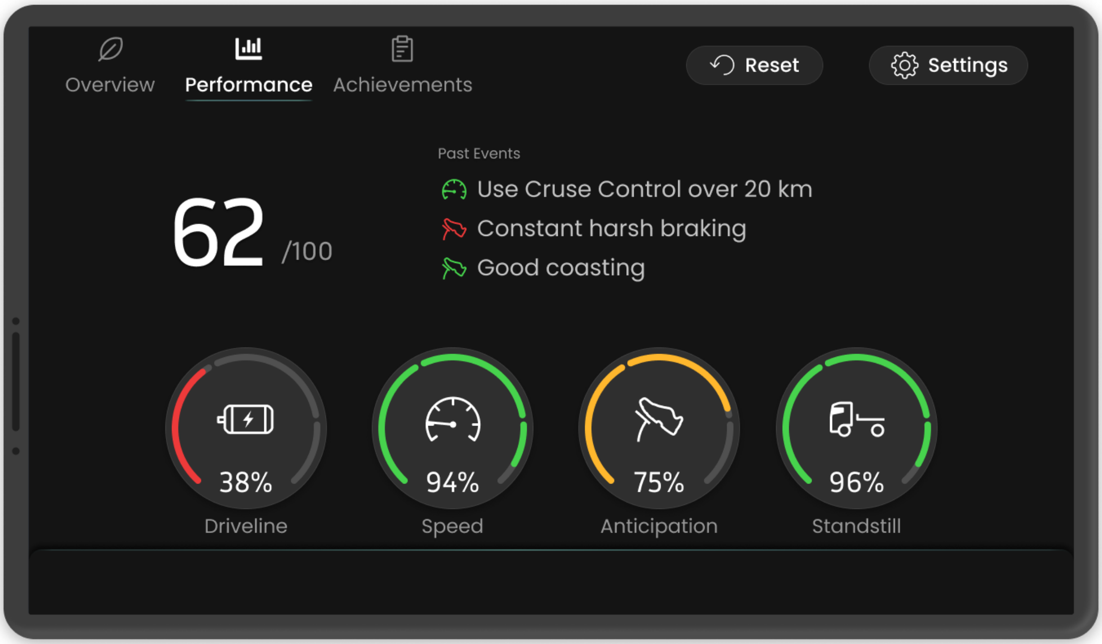


Figure 6.2: The Performance screen

6.1.1 Overview Screen

In the Overview screen, the tree metaphor is referred to and visualized as an *eco tree*, whose leaves grow or shrink along with the driver's eco-driving behaviors to reflect how much fuel or energy has been saved in the current trip (Figure 6.1). The tree is dynamically changed in real-time to give an overview for drivers to quickly grasp their eco-driving performance, as the Overview screen is the homepage of DECO PRO. The number shown in the lower right corner indicates how much energy has been saved during this trip. What is worth mentioning is that a design alternative being considered is to have the *eco tree* on the instrument cluster, with the assumption that it would be easier for drivers to monitor.

6.1.2 Performance Screen

The Performance screen adopted DECO PRO in general, with two elements being updated or added as follows. In this screen, *percentage values* were used to assess the eco-driving behavior. The *past events* account for users' scores, helping them to recall driving behaviors that contributed to eco-driving scores. Figure 6.2 shows the view.

6.1.3 Achievements Screen

The whole Achievements screen, as shown in Figure 6.3, is newly added and has the group of related parameters which were on the same screen with the KPI gauges before. Apart from that, the *energy equivalence* is introduced to make the term of saved energy tangible, and the *highlights* briefs which coaching category has im-

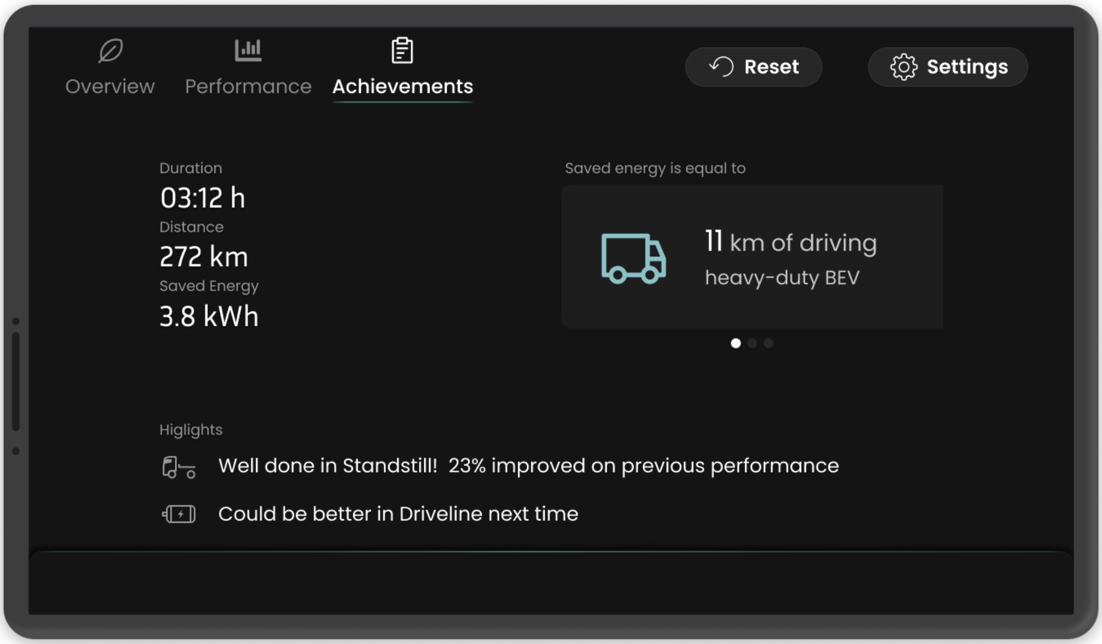


Figure 6.3: The Achievements screen

proved and which one to pay more attention to for potential future improvement.

6.1.4 Settings

In the settings, the driver can view the configurations of DECO PRO and change some of them. The Setting screen has been expanded from the DECO, with *vehicle profile*, *coaching category*, and *voice coaching* being added. Figure 6.4 presents the user interface. Drivers are able to see what vehicle profile set he or she got from the fleet manager, as there are different algorithms respectively when calculating the eco-driving scores. When it comes to customizable coaching categories, users can see what categories they have now, and they can alter the categories manually. Accordingly, the proactive notifications belonging to the deselected KPI(s) will be disabled from the pop-ups to decrease disruption to drivers. In addition, when the *driving coaching tips* is toggled on, users can choose to switch on *voice coaching* to get the verbal coaching notifications.

6.1.5 Notifications

Two types of notifications are presented as proactive interference at the instrument cluster during driving, as Figure 6.5 shows. One is the tip on how to drive in the following scenario to optimize fuel/energy consumption, and the other is giving feedback using a 5-leaf rating frame to visualize with a comment. The leaf metaphor is relevant to the tree, creating a coherent tone throughout the application even though they are split into two displays.

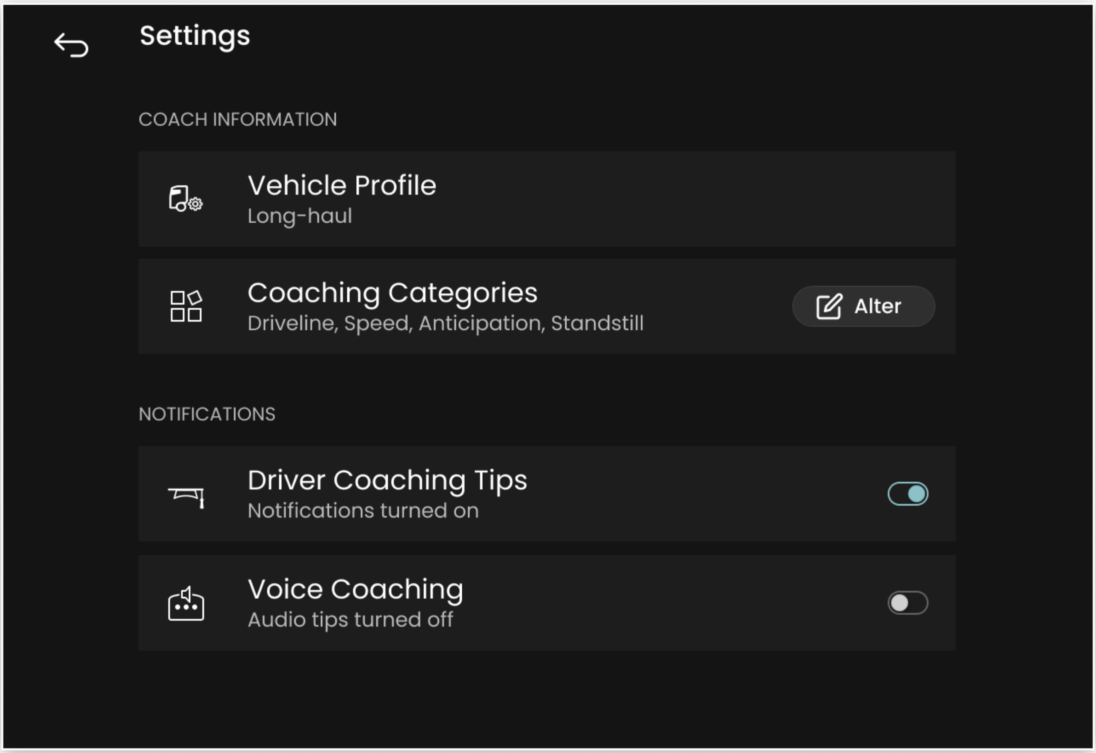


Figure 6.4: Settings of DECO PRO

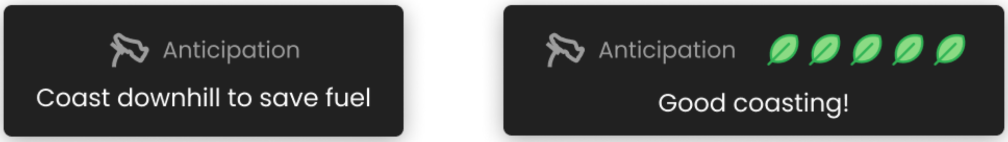


Figure 6.5: Two types of notifications on the IC

6.2 Guidelines

Below is a list of guidelines as the primary result of this project, which were formalized along with the design process by synthesizing the insights and findings from various design activities. For each of the 6 design guidelines, what I designed in this project as *Design Practices* are complemented as instances of the design strategies to support the understanding of the guidelines. As the user testing reported in Section 5.3.3 serves as an evaluation for my design work, some related comments from participants during the tests are quoted to complement the arguments.

G_1 Provide simple and abstract visualization to convey information during driving.

When driving eco-friendly, drivers experience a high workload and their adherence to eco-driving advice tends to be poor, especially in complex traffic conditions [21]. To address this, a clear and straightforward representation of HMI is helpful to facilitate self-monitoring, a common strategy employed in persuasive systems to nudge users of sustainable behavior and keep the distraction low in the meanwhile [1].

The degree of abstraction should be taken into account when designing eco-visualization. A simple and abstract visualization is considered effective in conveying overall performance information to drivers, particularly during driving [41]. By providing low-granularity feedback, drivers can easily perceive and track their eco-driving progress [12]. Furthermore, feedback designs that are abstract and symbolic have demonstrated greater effectiveness in reducing fuel consumption compared to concrete feedback like numerical scores [9, 10]. However, there should be a balance between abstraction and clearness of the interfaces that requires sufficient design consideration, to not cause confusion and misunderstanding to users [33].

Design Practices: The *eco tree*, as shown in Figure 6.1 is presented in informative art to support drivers keep track of their overall performance in terms of eco-driving, which leverages biophilic design in data visualization [43]. In the user test, participants generally recognized this feature as abstract, peaceful, calm, and relaxing, with some critiques that it could have been more dynamic and interactive.

"That is like a discreet way of showing it, but it's still quite obvious." (P1)

"It's always nice to have some graphical instead of only numbers." (P6)

"This is quite a calm view. I don't think this overview would be too distracting while driving." (P7)

"Now those are not clickable. I expect it could be something that you can click into to see more details regarding one specific KPI." (P2)

G_2 Apply Value Sensitive Design (VSD) to motivate behavior change by fostering a deep concern for sustainability.

As introduced in Chapter 3, Value Sensitive Design (VSD) is believed to foster a deep concern for sustainability and effectively promote drivers' intrinsic motivation to drive economically [25]. There are three strategies that I will discuss as follows on how to apply Value Sensitive Design (VSD) when designing an onboard system to support truck drivers of eco-driving behavior.

Firstly, activate values related to selflessness, peace, equality, and justice. It is vital to draw on broad self-transcendent values when developing interventions to encourage behavior change toward sustainability [40]. Individuals are more likely to continue engaging in similar or related behaviors when they adopt behaviors that are consistent with particular values [25]. Therefore, the HMI design should emphasize the positive effects of sustainable actions on well-being to activate and appeal to these values. For example, presented the carbon savings instead of monetary savings related to eco-driving, as it was proven to be more persuasive [27].

Secondly, facilitate reflection positively. The design should promote reflection on the value of environmental protection and highlight ways individuals can contribute to sustainability during their driving, rather than foster shame or guilt. In order to empower truck drivers to act and adjust their driving styles, encourage a sense of personal efficacy by providing them the chance to comprehend the broader effects of their actions and discover how small, individual actions could add up to significant efforts.

Thirdly, measure direct and indirect impacts for long-term behavior change. Direct impact indicates adjustments in specific behaviors related to sustainability, such as reduced energy consumption, and ups and downs of eco-driving score, which are commonly represented on HMI related to eco-driving. Meanwhile, reflecting indirect impact is also vital for the long-run behavior change. The indirect impact refers to both the overall contribution to a sustainable society as well as changes in people's attitudes, beliefs, and values regarding sustainability. For example, since emissions and energy are invisible and intangible, related information could be represented using more relatable terms, as understanding how one's actions might indirectly affect those concrete and well-known terms may result in more sustained behavior changes over time.

Design Practices: Overall, the design of DECO PRO stresses the positive valence by presenting how much energy is saved or could be potentially saved by eco-driving, to create the feeling to drivers that they are making impacts on sustainability transportation. The tree metaphor and green identity color used in the *eco tree* (in Figure 6.1) and the feedback *notification* (in Figure 6.5) can help to arouse drivers' self-transcendent values as well as a positive reflection on the environmental friendly behavior.

"I like the fact that it's a tree because it's a bit of a reminder of the ecosystem that we need to have. So I like that. So it's like in a sense, a subconscious way of showing the reason for saving fuel." (P2)

"This page is nice for the positive reinforcement. I was more like, intriguing to see what happens because it was clear that something would grow on the screen. So I thought it was engaging." (P5)

In addition, the *energy equivalence* presented in Figure 6.6 is also believed to provide positive feelings and tangible impacts for long-term behavior change, by concretizing the saved fuel or energy into the terms drivers are familiar with. During the user test, participants perceived it as fun and motivating, with the extendibility to design more relatable equivalent terms that have a high potential to raise truck drivers' awareness of environmental protection.

"It gets a bit more tangible. And you can instead of just having numbers, you

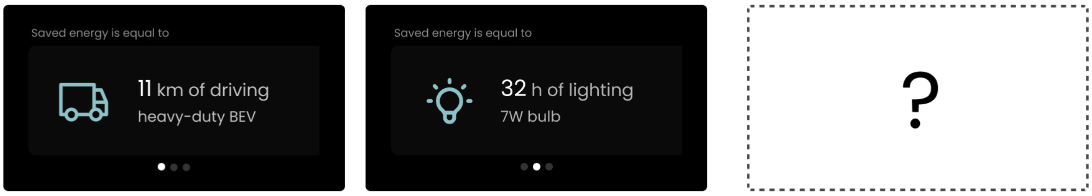


Figure 6.6: The *energy equivalence* relates energy with tangible terms, with possibility to extend

can actually understand how big of an impact it could have. [...] that could be quite a good way to motivate." (P7)

"How many kilometers of driving you have earned with saving energy is super good. This is a nice way of showing things. We need to raise the awareness and then make the people feel like their actions matter." (P11)

"This might be interesting. Uh, and especially if we can compare them to many things that you can select." (p2)

"Fun. Maybe there is something more related to the driver that we could have here instead of that [wind turbine]." (P8)

G_3 Consider the purpose of feedback when designing for temporal granularity.

When designing the temporal granularity of the feedback, it is important to consider the purpose for which the feedback is provided. The temporal granularity can be categorized into two types: instantaneous (e.g. real-time feedback, momentary fuel efficiency) and accumulated over time (e.g. average scores of fuel efficiency, post-driving report) [43]. The purpose of the feedback can either be pedagogical, focused on facilitating learning and experimentation of eco-driving behavior, or assessment-oriented, aimed at assessing the overall performance and allowing goal-setting [49].

To design effective eco-feedback systems for truck driving, determine whether the feedback is intended for pedagogical or assessment purposes. If the goal is pedagogical, focus on providing instantaneous feedback that is momentary and real-time, which allows users to experiment with different driving styles and learn from the immediate consequences of their actions. This type of feedback is especially helpful for encouraging behavior change and promoting the adoption of new driving styles. If the purpose is assessment-oriented, consider the feedback that is accumulated over a duration, such as average fuel efficiency scores or post-driving summaries. Drivers can track progress, assess their overall performance over time, and set goals for their trip with this type of feedback, to be able to monitor their long-term performance and make improvements based on previous behaviors. Noticeably, one feedback can also be both pedagogical or assessment-oriented, with one purpose being prioritized when designing the features and interactions.

Design Practices: In DECO PRO, eco feedback for different purposes and temporal granularity are combined. The *eco tree* is both pedagogical and assessment-oriented, the real-time notifications in Figure 6.5 serve the purpose of pedagogy to provide coaching tips to the driver, and the Achievements screen mainly provides assessment feedback. The *highlights* presented in Figure 6.3 is the accumulated feedback that is expected to serve both pedagogy and assessment purposes. As the latest design prototype concluded the current trip of eco-driving, it would be better to provide more information regarding how to improve in terms of the weak categories, according to the participants' comments.

"This is really nice with some information that you could actually have a bit of a like retrospective." (P7)

"Would be good to have some tips on how to improve." (P6)

"The driver gets confirmation 'I have been working on this and the system confirms that I have improved'. But if you should have highlights, you should be precise here. No general texts, [...]what I would like to see is more details." (P8)

G_4 Utilize contextual information to make the coaching adaptive and customizable.

The system adapting to drivers' skills is important to the long-term success of the eco-driving practice [53]. It builds motivation toward continuous use of the HMI, and self-determination facilitates intrinsic motivation toward long-term eco-driving [40]. Therefore, leveraging contextual information and making the coaching customizable and personalized are believed to enhance the effectiveness and user experience of the eco-coaching system [14]. There is a variety of contextual information that can be cooperated by the system, such as historical self-comparisons, previous user configurations, routes, and traffic conditions. This information provides valuable insights into individual driving patterns, preferences, and environmental factors that could determine compatibility between the drivers and the HMI. By utilizing contextual information, the coaching system can tailor its instruction to better suit the particular needs of each user rather than providing generic guidance that might be repetitive and unnecessary in circumstances.

To personalize the guidance of eco-driving supportive HMI, customizable settings based on drivers' preference, creating user profiles, applying level design, and adaptive coaching techniques that adjust the level of sensitivity are possible ways to consider when designing the features. Also, by using machine learning algorithms and data analysis techniques to continuously learn from user interactions, it is promising to adapt the system's personalization capacities over time, which enables the system to adapt and enhance its coaching in response to user feedback and their driving styles.

Design Practices: In DECO PRO, the customizable coaching category is proposed as one of the configurations that the truck driver can adjust in the settings to prioritize the coaching categories he or she prefers to focus on and have more tips on. As shown in Figure 6.7, the initial coaching categories cover all of the four KPIs; as the driver is making progress in eco-driving, the adapted coaching category will be recommended based on the driver's skill level and route information, which allows the driver to prioritize specific eco-driving areas. From interviews during the user testing, some participants believed that it could increase the drivers' engagement by actively involving them in the learning mechanism adjustment.

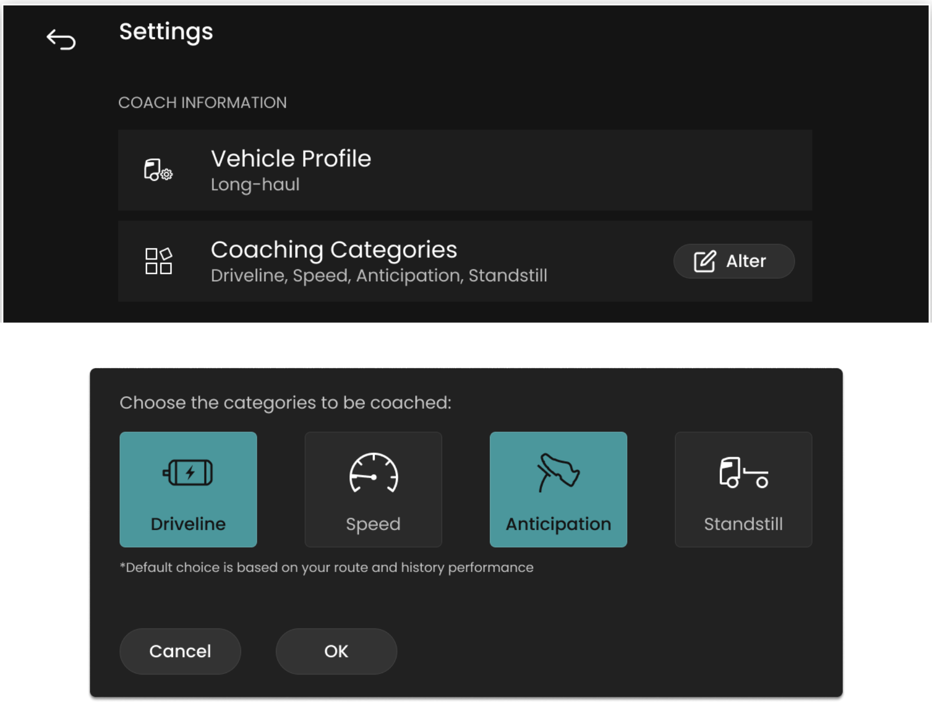


Figure 6.7: Customizable coaching category in DECO PRO

> *"If you (as a driver) decide actively to take the responsibility, then we offer you more information because hopefully that would create engagement and sort of internal motivation to do things.[...] I think if we can get the driver to do a learning agreement by actively choosing what they want to work with and sort of become part of the process without making them think that now somebody's from outside trying to change them, but 'I want to take this initiative to become better', then I think it should include some sort of customization."* (P11)

What is worth noticing is that information on the rest of the areas that are not prioritized should also be included in the HMI and visible to drivers, better being weakened visually, while the proactive interference such as notifications could show up in less frequency or low sensitivity level for less distraction. Accordingly, the chosen categories would be highlighted in different information channels to help the driver better focus.

"Because I assume that since I changed the categories, [...] maybe the other ones might be grayed out, but they are still there, they're still counting. And you need to be able to compare vehicles against vehicles." (P2)

"The selections are the ones that I want more feedback on. My expectation would be that I get the scores for everything but the push notifications for the things I have selected." (P4)

The system could even be more intelligent, to use the driver profiles to tailor the human-vehicle interactions according to their specific preferences and requirements, or automatically adapt to the driver without the input from the driver selecting categories manually.

"Personal settings should be automated and connected to the driver card or driver ID so that it gets the latest settings." (P8)

"I think it's too complicated. We already have your Information about the type of truck, route and stuff you driving so it should already be tailored to that. It should be kind of inbuilt into the system." (P9)

G_5 Display transparent and informative connections between offboard and onboard applications.

When designing a driver eco coaching system, it is common to have both onboard and back-office applications, each tailored to different target groups while sharing data and configurations. To guarantee a cohesive and transparent user experience for truck drivers, it is crucial to consider the connections between these two platforms and clearly communicate them to the drivers.

First, be explicit about how the data is used and synchronized between the two platforms to build trust. The relationship between the onboard and offboard applications should be clearly explained and illustrated on the HMI of the onboard system. Second, keep the truck drivers informed about the status updates and processes involving both the onboard and offboard applications. For example, when the fleet manager who uses the back-office application updates configurations to influence the algorithm of the onboard application, the synchronization should be updated to truck drivers so they could understand and anticipate the system's behavior. Third, provide accessible support resources, such as documentation, tutorial tooltips, or other contextual guidance to assist truck drivers in comprehending the connections between the onboard and offboard applications and utilizing the available features optimally.

Design Practices: As presented in Figure 6.8, in DECO PRO, the drivers can know the related settings they get from the back-offices by the fleet manager, for example, the *vehicle profile*, which will decide the algorithm of their eco-driving score. Besides, more information about the calculation of KPIs and sub-KPIs is also informed through the tooltips to make the system more transparent and understandable.

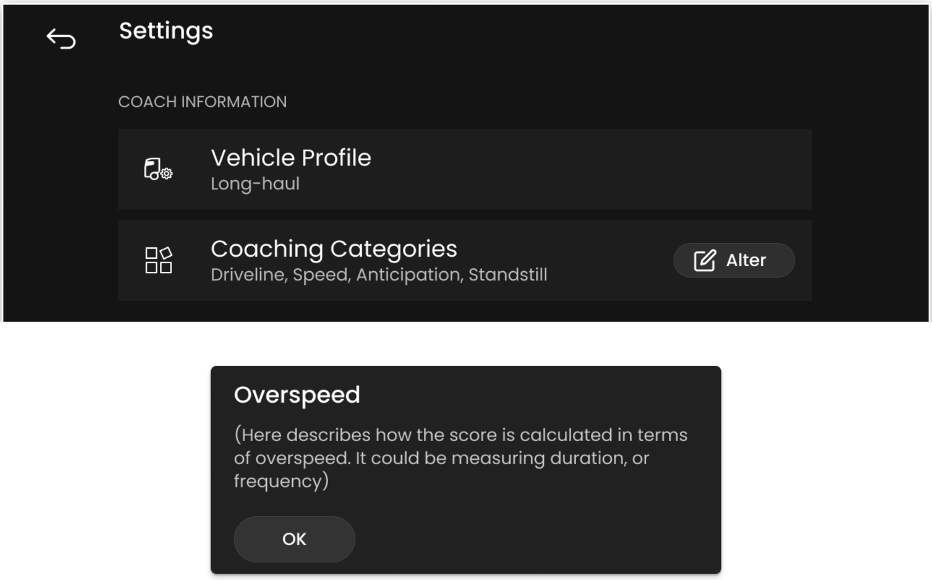


Figure 6.8: Users can see the *vehicle profile* in the settings (above) and the sub-KPI's explanation through the tooltip (below)

> *"It is needed for definition purposes, usually because in order to be better, you need to know what it's calculating. It's very useful to have it there."* (P2)
> *"We fill this in with relevant content so that we are more transparent, explaining where did you(drivers) get your score, and I think that will raise the user acceptance."* (P11)

G_6 Maintain consistent symbolic language to create a coherent tone.

Use particular visual metaphors or symbols that represent the concept being conveyed, and make sure that graphical components are consistently applied throughout the entire system, particularly across different parts of the interface. To develop a symbolic language to be meaningful for a memorable user experience, consider establishing an obvious association between the symbolic representative and the underlying system. Generally, when discussing eco-driving, the terms that come to mind are greenery, such as trees and plants. This connection reinforces the sense of continuity throughout the design. When an effective symbolic language is established, utilize it across different interaction channels within the system to create a cohesive and harmonious design that fosters drivers' comprehension and engagement, as well as to build an impressive brand identity.

Design Practices: In DECO PRO, I created the symbolic language of the tree and reused the visual metaphor in the *eco tree* and 5-leaf scale in notifications, as shown in Figure 6.9 to strengthen the overall design concept by reinforcing familiarity, which helps to create a memorable user experience according to the participants.

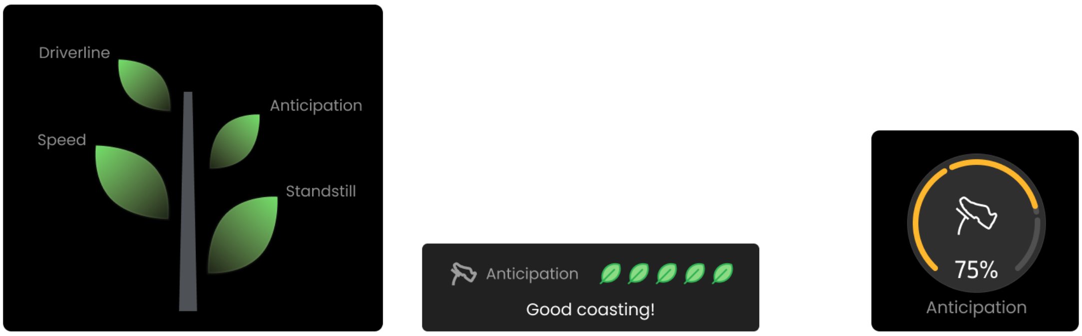


Figure 6.9: Eco tree, notification, and the KPI gauge (from left to right)

"I've seen you've been introducing in new concept which is this tree, and I can also see that you being consistent with it because it's also got shown in the IC, and that satisfied me.[...]. There was a clear integration there." (P5)

To reinforce the visual coherence of the interface and ensures a seamless transition for users, it is also important to extend the symbolic language to related views, which is a direction for DECO PRO to improve. The feedback from user tests pointed out that the symbolic language of the tree didn't fit the *KPI gauges* on the Performance screen in terms of visual language (Figure 6.9), which could hinder the unifying of a harmonious experience.

"So be consistent, if you go for the leaves, do it all the time. Don't change the symbolic language. Continue to work with the Leaf. You connect the leaf symbolic with the system and then you can reuse that communication method." (P8)

"[...] the other view should follow the same pattern of design. if the whole app should follow that design pattern of like calm, quiet view and soft-spoken, then maybe you should also be here." (P10)

7
Discussion

In this chapter, I discuss the process, the result, possible ethical issues, limitations, and future work of this thesis respectively. The discussion starts with the design process including the factors in methods and execution that may have affected the outcomes, followed by the interpretation and analysis of the results. Then, potential ethical issues are brought up. Finally, I reflect on the limitations of my work and discuss the directions for the next step to offer further exploration.

7.1 Process

There are considerations about the execution, especially when making design decisions. One is regarding the medium and location of the driver eco coaching. This project mainly explored the solution at the SID because of the consideration of realistic constraints in this project, like time and effort. From the competitor analysis in section 5.1.1, most of the competitor has their overview of eco-driving performance at IC. Therefore, in the first and second interactions, I had the initial idea in mind that the *eco tree* could be presented at the IC. However, when it was time to prototype in the third iteration, I chose to prototype the *eco tree* at the SID without exploring the possibility of putting it on the IC and comparing the two design alternatives, as the latter requires knowledge of the design guideline and design specification of the IC, as well as the comprehensive understanding of the ecosystem of The Company's applications. For example, if prototyping the user interfaces of the IC, all of The Company's other information that takes up the space of the IC needed to be considered to make the user interface of the IC compatible.

When it comes to the methods and tools applied during the design process, I had SUS scores of DECO and DECO PRO but from two studies with totally different settings: DECO was evaluated in the form of a questionnaire answered by the truck drivers reported in Section 5.2.2, and the SUS of DECO PRO was gathered in the user test in Section 5.3.3. Therefore, they were not directly comparable in statistics. However, the analysis based on scale items' scores could have been done to gain further insights into the usability and learnability of both designs, and benchmarks of SUS items could be referenced especially for DECO PRO prototype to better identify the aspects with possible usability issues [30, 29].

7.2 Results

This section discusses the results of this thesis project, respectively the prototype and design guidelines.

HMI Prototype

Although the fidelity of the prototype of DECO PRO appears to be high at first glance, there are still some features that are merely at a concept level and not visually sophisticated enough. When processing from the low-fidelity wireframes to the high-fidelity prototype, more time and effort could have been invested to elaborate on the concepts, and micro iterations could have happened by involving stakeholders and other designers in discussions and design reviews.

In the final prototype of DECO PRO, there are still some flaws and questions that remain to be solved. During the user tests, several usability or user experience issues were identified and many valuable insights were brought up by participants in the interviews. However, not all of them were implemented in the final prototype as some features need further investigation and ideation for better design solutions. For example, how to cooperate with the feature of resetting and configuring the coaching category properly on the user interface is one question that needs more consideration.

Design Strategies on Driver Eco Coaching

The set of guidelines produced from the research-through-design gives suggestions on the *information*, *display*, and *timing* of the eco-driving support provided by the in-vehicle system. What is worth mentioning is the frequency and timing of presenting the coaching interference were not thoroughly investigated in this project. Real-time notification is argued to be safer and more effective than continuous information in previous research, as the intermittent information leads to shorter dwell times, provided that the system presents information in strategically advantageous timing and locations that are not demanding for the driver [24]. In DECO PRO, the number of notification types was increased: there was only feedback before, but now there are both upfront tips and behavior feedback, as shown in Figure 6.5. There is a risk that it might result in more disruption to truck drivers and distract them from driving. Therefore, it is crucial to regulate the frequency and control the number of notifications when applying the guidelines. For example, when the driver has fair enough performance in anticipation, the system could decrease the pop-up tips under that category.

It has been proved there are variations in traffic culture and driving behavior in different countries and regions [11], and how my results might differ across cultures is a question. This project was conducted in Sweden and the company's target market of DECO is Europe, so the stakeholders involved in my design process mostly represent the voice based on the European traffic culture and regulations. As a result, it remains unclear whether the results especially the design guidelines can be validated and how much applicable they might be to encourage truck drivers in other regions which are different in their attitude and perception of eco-driving [18].

7.3 Ethical Implications

By encouraging eco-driving behaviors through the in-truck system, the project aims to reduce fuel and energy consumption and minimize emissions. This has a positive ethical impact on the environment, as it would contribute to reducing the environmental footprint of the transportation industry.

Another ethical Implication of the project lies in road safety. On the one hand, eco-driving techniques such as operating within safe speed limits and avoiding aggressive moves can lead to smoother driving and increase traffic safety. But at the same time, eco-driving behavior is not natural and needs the driver's additional mental workload to maintain, and the interference from the eco-driving supporting system can also distract drivers and therefore conflict with safety. When utilizing the guidelines from this project, it should be kept in mind that safety should be prioritized to ensure that eco-driving behaviors do not compromise the overall safety of the driver and other road users.

User autonomy and data privacy are also ethical considerations in this project. When implementing eco-driving support systems, the autonomy and consent of drivers ought to be respected to ensure they have control over their driving experiences. Drivers should be given the option to choose whether or not they want coaching system interference, and their preferences for the frequency and type of feedback should be considered. Additionally, the protection of personal data should be prioritized with the eco-driving systems' tendency to be adaptive and personalized. It should respect privacy regulations and make sure that any information gathered for eco-driving purposes is appropriately protected and only used to enhance the functionality of the system. It's important to note that since the back-office application and onboard system share data and configuration to a certain extent, it's crucial to be transparent when gathering data from truck drivers and to offer clear consent mechanisms when transferring data between platforms.

The HMI should be developed with equity and accessibility in mind. It should be usable by all drivers, regardless of their age, skill level, or technological literacy. As one of my discoveries while creating the personas in Section 5.1.1 indicated, taking into account a variety of user needs and offering inclusive design features can help ensure equitable access to the advantages of eco-driving support systems. Another concern is the accessibility of the HMI prototype as one of the results of this project, which can be further evaluated under the driving circumstances.

7.4 Limitations

There are several limitations to this project. One aspect fell in the final evaluation regarding the generalizability and robustness. The evaluation involved regular individuals without constraining their vocation as truck drivers, limiting the applicability of the findings to the specific truck driving context. Additionally, the study did not control for the confounding variable of participants' previous experience with DECO, so they might potentially have provided more positive feedback for the new design, introducing bias in their rating of the two HMI designs and skewing the results towards more favorable outcomes. Another aspect is that the project's scope focused on the HMI representation and how it affected eco-driving behavior, overlooking other factors like cultural and social influence, regional regulations, and financial incentives which are influential to eco-driving behavior as well.

7.5 Future Work

This section discussed which aspects could be expanded if this project were to be continued.

Iterating and Validating the HMI Prototype

If I were to improve the results of this thesis project, the next step could be to iterate the DECO PRO prototype based on the insights from the final evaluation. When the improvement is implemented, more advanced methods and experiment designs could be explored for the comparison between DECO and DECO PRO in terms of safety and user experience, to draw more rigor and replicable conclusions. In addition, if the new concept is later developed by the company, matrices such as NPS can be investigated and monitored to compare with the result of DECO that I got from the user questionnaire in the design process. Techniques such as driving simulator, VR/AR and Wizard of Oz method might also be utilized to validate the HMI concept [2, 32].

Gamification in Truck Driver Eco Coaching Scenarios

Gamification is the use of game design elements (e.g., points, levels, leaderboards, and badges) in non-game contexts to make real-world activities more engaging [28, 54]. From previous research, a positive effect has been found by utilizing gamification to facilitate sustainability and eco-driving behavior[54, 34]. Also, stakeholders from The Company brought this up during the stakeholders' meeting and co-design workshop. However, I didn't explore this direction deeply during my design practices. The main consideration was that many gamification ideas are based on the default and general mindset that the drivers are driving cars for themselves, but this project is targeted at designing for sustainability in trucks, which are commercial vehicles instead of private cars. Drivers use vehicles as a tool to do their work, which means their ultimate task is to complete the delivery mission and complete their work, making their mindset different: they might just want to finish their work efficiently without too much effort, especially when they don't need to pay for the fuel or electric bill by themselves. Besides, it is difficult to address learning and engagement outcomes simultaneously according to a previous study [44]. While gamification creates an enjoyable experience by engaging users, it might not be what truck drivers need or prefer in their driving context. It would be interesting to investigate this question in the future.

Differentiate Eco-Feedback in Multi-Modality

Another aspect that can be explored further is utilizing multi-modality user interfaces to provide various forms of coaching and feedback catering to different eco-driving behaviors. As mentioned in Chapter 3, visual, auditory, and haptic representations are possible in eco-driving coaching scenarios, each of which has advantages and drawbacks and can be complementary to each other. In this project, the visual display is still primary, with a rough concept that voice coaching is possible and can be toggled on or off by drivers in the settings. In addition, the forms of promoting all kinds of eco-driving behavior is unified in terms of HMI, by providing assessment results and interfering notifications in the same metrics and indicators.

In the future, the feedback design can differentiate for various eco-driving behavior leveraging multi-modality interface components. By defining behaviorally relevant attributes, behavior-specific feedback might be provided by means of the progress bar for each accelerating, cruising, and braking event; there are also on-market vehicles using the haptic pedal to teach the driver the most efficient throttle position during acceleration [42]. In addition, multisensor and vibrations can also be used based on the specific behaviors reflected to provide intuitive coaching variations for eco-driving [33]. In the co-design workshop, the idea of presenting how much distance one has been coasting was also mentioned.

8
Conclusion

The purpose of this thesis project was to answer the research question:

How to design for human-machine-interface (HMI) in the vehicle to support truck drivers of eco-driving?

In collaboration with The Company specializing in the automotive industry, which was interested in improving the User Interfaces of their onboard driver coaching system, this thesis followed an iterative design process instructed by research-through-design, aiming for a high-fidelity HMI prototype and design framework as the tool to guide researchers and designers in the sustainable mobility field, informing HMI design for commercial vehicles' eco-driving supportive application. The process included three design iterations, undergoing Sharp et al.'s life-cycle model of *discover*, *ideate*, *prototype*, and *evaluate*, As a result, based on the evaluation of the high-fidelity mock-ups, a set design guidelines were culminated as follows:

1. *Provide simple and abstract visualization to convey information during driving*
2. *Apply Value Sensitive Design (VSD) to motivate behavior change by fostering a deep concern for sustainability*
3. *Consider the purpose of feedback when designing for temporal granularity*
4. *Utilize contextual information to make the coaching adaptive and customizable*
5. *Display transparent and informative connections between offboard and onboard applications*
6. *Maintain consistent symbolic language to create a coherent tone*

To conclude, the research question may be answered through the design guidelines formalized from the design practice, documented in Chapter 6 as the deliverable of this project. The six guidelines together with the design examples are to provide insights to practitioners in the automotive and mobility context when designing applications to support sustainable driving.

Bibliography

[1] Ifeoma Adaji and Mikhail Adisa. A Review of the Use of Persuasive Technologies to Influence Sustainable Behaviour. In *Adjunct Proceedings of the 30th ACM Conference on User Modeling, Adaptation and Personalization*, UMAP '22 Adjunct, pages 317–325, New York, NY, USA, 2022. Association for Computing Machinery. ISBN 9781450392327. doi: 10.1145/3511047.3537653. URL `https://doi.org/10.1145/3511047.3537653`.

[2] Craig K Allison, James M Fleming, Xingda Yan, Roberto Lot, and Neville A Stanton. *Assisted Eco-driving: A Practical Guide to the Design and Testing of an Eco-driving Assistance System (EDAS)*. CRC Press, 2021. ISBN 1000473481.

[3] Craig K. Allison, Neville A. Stanton, James M. Fleming, Xingda Yan, and Roberto Lot. How does eco-driving make us feel? Considering the psychological effects of eco-driving. *Applied Ergonomics*, 101:103680, 5 2022. ISSN 0003-6870. doi: 10.1016/J.APERGO.2022.103680.

[4] Matthias G. Arend and Thomas Franke. The role of interaction patterns with hybrid electric vehicle eco-features for drivers' eco-driving performance. *Human Factors*, 59(2):314–327, 3 2017. ISSN 15478181. doi: 10.1177/0018720816670819. URL `https://journals.sagepub.com/doi/abs/10.1177/0018720816670819`.

[5] Aurora Harley. UX Expert Reviews, 2 2018. URL `https://www.nngroup.com/articles/ux-expert-reviews/`.

[6] Ann Blandford, Dominic Furniss, and Stephann Makri. Qualitative HCI research: Going behind the scenes. *Synthesis lectures on human-centered informatics*, 9(1):1–115, 2016. ISSN 1946-7680.

[7] John Brooke. SUS-A quick and dirty usability scale. *Usability evaluation in industry*, 189(194):4–7, 1996.

[8] Hronn Brynjarsdottir, Maria Håkansson, James Pierce, Eric Baumer, Carl DiSalvo, and Phoebe Sengers. Sustainably unpersuaded: how persuasion narrows our vision of sustainability. In *Proceedings of the sigchi conference on human factors in computing systems*, pages 947–956, 2012.

[9] Andre Dahlinger, Verena Tiefenbeck, Benjamin Ryder, Bernhard Gahr, Elgar Fleisch, and Felix Wortmann. The impact of numerical vs. symbolic eco-driving feedback on fuel consumption – A randomized control field trial. *Trans-*

portation Research Part D: Transport and Environment, 65:375–386, 2018. ISSN 1361-9209. doi: https://doi.org/10.1016/j.trd.2018.09.013. URL https://www.sciencedirect.com/science/article/pii/S1361920918302359.

[10] André Dahlinger, Felix Wortmann, Benjamin Ryder, and Bernhard Gahr. The impact of abstract vs. concrete feedback design on behavior insights from a large eco-driving field experiment. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*, pages 1–11, 2018.

[11] Panagiotis Fafoutellis, Eleni G Mantouka, and Eleni I Vlahogianni. Eco-driving and its impacts on fuel efficiency: An overview of technologies and data-driven methods. *Sustainability*, 13(1):226, 2020. ISSN 2071-1050.

[12] Thomas Franke, Matthias Georg Arend, Rich C. McIlroy, and Neville A. Stanton. Ecodriving in hybrid electric vehicles – Exploring challenges for user-energy interaction. *Applied Ergonomics*, 55:33–45, 7 2016. ISSN 0003-6870. doi: 10.1016/J.APERGO.2016.01.007.

[13] William Gaver. What should we expect from research through design? In *Proceedings of the SIGCHI conference on human factors in computing systems*, pages 937–946, 2012.

[14] Ekaterina Gilman, Georgi V Georgiev, Piiastiina Tikka, Susanna Pirttikangas, and Jukka Riekki. How to support fuel-efficient driving? *IET Intelligent Transport Systems*, 12(7):631–641, 2018. ISSN 1751-956X.

[15] Jenny Gunnarsson, Veronica Jansson, and Katerina Cerná. A Qualitative User Experience Evaluation of Volvo Trucks' On-Board Driver Coaching System. Technical report. URL https://gupea.ub.gu.se/handle/2077/72434.

[16] Madlen Günther, Nadine Rauh, and Josef F. Krems. How driving experience and consumption related information influences eco-driving with battery electric vehicles – Results from a field study. *Transportation Research Part F: Traffic Psychology and Behaviour*, 62:435–450, 4 2019. ISSN 1369-8478. doi: 10.1016/J.TRF.2019.01.016.

[17] Madlen Günther, Celina Kacperski, and Josef F Krems. Can electric vehicle drivers be persuaded to eco-drive? A field study of feedback, gamification and financial rewards in Germany. *Energy Research & Social Science*, 63:101407, 2020. ISSN 2214-6296. doi: https://doi.org/10.1016/j.erss.2019.101407. URL https://www.sciencedirect.com/science/article/pii/S2214629619305183.

[18] Joan Harvey, Neil Thorpe, and Richard Fairchild. Attitudes towards and perceptions of eco-driving and the role of feedback systems. *Ergonomics*, 56(3):507–521, 2013. ISSN 0014-0139.

[19] IDEO.org. Rapid Prototyping. URL https://www.designkit.org/methods/rapid-prototyping.

[20] Jakob Nielsen. Thinking Aloud: The #1 Usability Tool, 1 2012. URL https://www.nngroup.com/articles/thinking-aloud-the-1-usability-tool/.

[21] Samantha L. Jamson, Daryl L. Hibberd, and A. Hamish Jamson. Drivers' ability to learn eco-driving skills; effects on fuel efficient and safe driving behaviour. *Transportation Research Part C: Emerging Technologies*, 58(PD):657–668, 9 2015. ISSN 0968-090X. doi: 10.1016/J.TRC.2015.02.004.

[22] Jeff Sauro. Measuring Usability with the System Usability Scale (SUS), 2 2011. URL `https://measuringu.com/sus/`.

[23] John Chris Jones. *Design methods*. John Wiley & Sons, 1992. ISBN 0471284963.

[24] Katja Kircher, Carina Fors, and Christer Ahlstrom. Continuous versus intermittent presentation of visual eco-driving advice. *Transportation Research Part F: Traffic Psychology and Behaviour*, 24:27–38, 2014. ISSN 1369-8478. doi: https://doi.org/10.1016/j.trf.2014.02.007. URL `https://www.sciencedirect.com/science/article/pii/S1369847814000217`.

[25] Bran Knowles, Lynne Blair, Stuart Walker, Paul Coulton, Lisa Thomas, and Louise Mullagh. Patterns of Persuasion for Sustainability. In *Proceedings of the 2014 Conference on Designing Interactive Systems*, DIS '14, pages 1035–1044, New York, NY, USA, 2014. Association for Computing Machinery. ISBN 9781450329026. doi: 10.1145/2598510.2598536. URL `https://doi.org/10.1145/2598510.2598536`.

[26] Jule Kramer and Tibor Petzoldt. The role of self-concordance for self-reported strategic, tactical, and operational eco-driving. *Transportation Research Part F: Traffic Psychology and Behaviour*, 84:83–98, 1 2022. ISSN 1369-8478. doi: 10.1016/J.TRF.2021.11.005.

[27] Kenneth S Kurani, Tai Stillwater, Matt Jones, and Nicolette Caperello. Ecodrive I-80: A Large Sample Fuel Economy Feedback Field Test Final Report. *Institute of Transportation Studies Report ITS-RR-13-15, University of California, Davis*, 2013.

[28] Kristi Larson. Serious games and gamification in the corporate training environment: A literature review. *TechTrends*, 64(2):319–328, 2020. ISSN 1559-7075.

[29] James R. Lewis and Jeff Sauro. The factor structure of the system usability scale. *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, 5619 LNCS:94–103, 2009. ISSN 03029743. doi: 10.1007/978-3-642-02806-9{_}12/COVER. URL `https://link.springer.com/chapter/10.1007/978-3-642-02806-9_12`.

[30] James R Lewis and Jeff Sauro. Item benchmarks for the system usability scale. *Journal of Usability Studies*, 13(3), 2018. ISSN 1931-3357.

[31] Maria Rosala. How to Analyze Qualitative Data from UX Research: Thematic Analysis, 8 2022. URL `https://www.nngroup.com/articles/thematic-analysis/`.

[32] B Martin, B Hanington, and B M Hanington. *Universal Methods of Design: 100 Ways to Research Complex Problems, Develop Innovative Ideas, and Design*

Effective Solutions. Rockport Publishers, 2012. ISBN 9781592537563. URL https://books.google.se/books?id=uZ8uzWAcdxEC.

[33] Rich C Mcllroy and Neville A Stanton. *Eco-driving: from strategies to interfaces*. CRC Press, 2017. ISBN 1351400673.

[34] Stavros Nousias, Christos Tselios, Dimitris Bitzas, Dimitris Amaxilatis, Javier Montesa, Aris S Lalos, Konstantinos Moustakas, and Ioannis Chatzigiannakis. Exploiting Gamification to Improve Eco-driving Behaviour: The GamECAR Approach. *Electronic Notes in Theoretical Computer Science*, 343:103–116, 2019. ISSN 1571-0661. doi: https://doi.org/10.1016/j.entcs.2019.04.013. URL https://www.sciencedirect.com/science/article/pii/S1571066119300167.

[35] Page Laubheimer. Beyond the NPS: Measuring Perceived Usability with the SUS, NASA-TLX, and the Single Ease Question After Tasks and Usability Tests, 2 2018. URL https://www.nngroup.com/articles/measuring-perceived-usability/.

[36] Sanna M. Pampel, Samantha L. Jamson, Daryl L. Hibberd, and Yvonne Barnard. How I reduce fuel consumption: An experimental study on mental models of eco-driving. *Transportation Research Part C: Emerging Technologies*, 58(PD):669–680, 9 2015. ISSN 0968-090X. doi: 10.1016/J.TRC.2015.02.005.

[37] Sanna M. Pampel, Samantha L. Jamson, Daryl L. Hibberd, and Yvonne Barnard. Old habits die hard? The fragility of eco-driving mental models and why green driving behaviour is difficult to sustain. *Transportation Research Part F: Traffic Psychology and Behaviour*, 57:139–150, 8 2018. ISSN 1369-8478. doi: 10.1016/J.TRF.2018.01.005.

[38] Irina Paraschivoiu, Alexander Meschtscherjakov, and Manfred Tscheligi. Persuading the Driver: A Literature Review to Identify Blind Spots, 2019. URL https://doi.org/10.1145/3290607.3312841.

[39] Hannah Park, Angela Sanguinetti, and Gabriel Castillo Cortes. EcoTrips. In *International Conference of Design, User Experience, and Usability*, pages 60–76. Springer, 2017.

[40] Richard M Ryan and Edward L Deci. Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. *American psychologist*, 55(1):68, 2000. ISSN 1557987041.

[41] Angela Sanguinetti. Onboard Feedback to Promote Eco-Driving: Average Impact and Important Features. Technical report, 2018.

[42] Angela Sanguinetti, Hannah Park, Suhaila Sikand, and Ken Kurani. A typology of in-vehicle eco-driving feedback. *Advances in Intelligent Systems and Computing*, 484:979–992, 2017. ISSN 21945357. doi: 10.1007/978-3-319-41682-3{_}80/COVER. URL https://link.springer.com/chapter/10.1007/978-3-319-41682-3_80.

[43] Angela Sanguinetti, Kelsea Dombrovski, and Suhaila Sikand. Information, timing, and display: A design-behavior framework for improving the effectiveness of eco-feedback. *Energy Research & Social Science*, 39:55–68, 2018. ISSN 2214-6296.

[44] Radhika Santhanam, De Liu, and Wei-Cheng Milton Shen. Research Note—Gamification of technology-mediated training: Not all competitions are the same. *Information systems research*, 27(2):453–465, 2016. ISSN 1047-7047.

[45] Sarah Gibbons. Journey Mapping 101, 12 2018. URL `https://www.nngroup.com/articles/journey-mapping-101/`.

[46] Sarah Gibbons. Using Prioritization Matrices to Inform UX Decisions, 5 2018. URL `https://www.nngroup.com/articles/prioritization-matrices/`.

[47] Helen Sharp, Jennifer Preece, and Yvonne Rogers. *Interaction Design : Beyond Human-Computer Interaction*, volume Fifth edition. Wiley, Indianapolis, IN, 2019. ISBN 9781119547259. URL `https://search.ebscohost.com/login.aspx?direct=true&db=edsebk&AN=2097340&site=eds-live&scope=site&authtype=guest&custid=s3911979&groupid=main&profile=eds`.

[48] Michael Sivak and Brandon Schoettle. Eco-driving: Strategic, tactical, and operational decisions of the driver that influence vehicle fuel economy. *Transport Policy*, 22:96–99, 7 2012. ISSN 0967-070X. doi: 10.1016/J.TRANPOL.2012.05.010.

[49] Tai Stillwater and Kenneth S Kurani. Drivers discuss ecodriving feedback: Goal setting, framing, and anchoring motivate new behaviors. *Transportation Research Part F: Traffic Psychology and Behaviour*, 19:85–96, 2013. ISSN 1369-8478. doi: https://doi.org/10.1016/j.trf.2013.03.007. URL `https://www.sciencedirect.com/science/article/pii/S1369847813000314`.

[50] Therese Fessenden. Net Promoter Score: What a Customer-Relations Metric Can Tell You About Your User Experience, 10 2016. URL `https://www.nngroup.com/articles/nps-ux/`.

[51] Ran Tu and Junshi Xu. Effective and Acceptable Eco-Driving Guidance for Human-Driving Vehicles: A Review. 2022.

[52] Jinke D. Van Der Laan, Adriaan Heino, and Dick De Waard. A simple procedure for the assessment of acceptance of advanced transport telematics. *Transportation Research Part C: Emerging Technologies*, 5(1):1–10, 2 1997. ISSN 0968-090X. doi: 10.1016/S0968-090X(96)00025-3.

[53] Takahiro Wada, Koki Yoshimura, Shun Ichi Doi, Hironori Youhata, and Koichi Tomiyama. Proposal of an eco-driving assist system adaptive to driver's skill. *IEEE Conference on Intelligent Transportation Systems, Proceedings, ITSC*, pages 1880–1885, 2011. doi: 10.1109/ITSC.2011.6083034.

[54] Siaw-Chui Wee and Weng-Wai Choong. Gamification: Predicting the effectiveness of variety game design elements to intrinsically motivate users' energy conservation behaviour. *Journal of Environmental Management*, 233:

97–106, 2019. ISSN 0301-4797. doi: https://doi.org/10.1016/j.jenvman.2018.11.127. URL https://www.sciencedirect.com/science/article/pii/S0301479718313926.

[55] Nan Xu, Xiaohan Li, Qiao Liu, and Di Zhao. An Overview of Eco-Driving Theory, Capability Evaluation, and Training Applications. *Sensors*, 21(19), 2021. ISSN 1424-8220. doi: 10.3390/s21196547. URL https://www.mdpi.com/1424-8220/21/19/6547.

A

Co-Design Workshop

Below are the slides to instruct the co-design workshop for ideation, as described in Section 5.2.1.

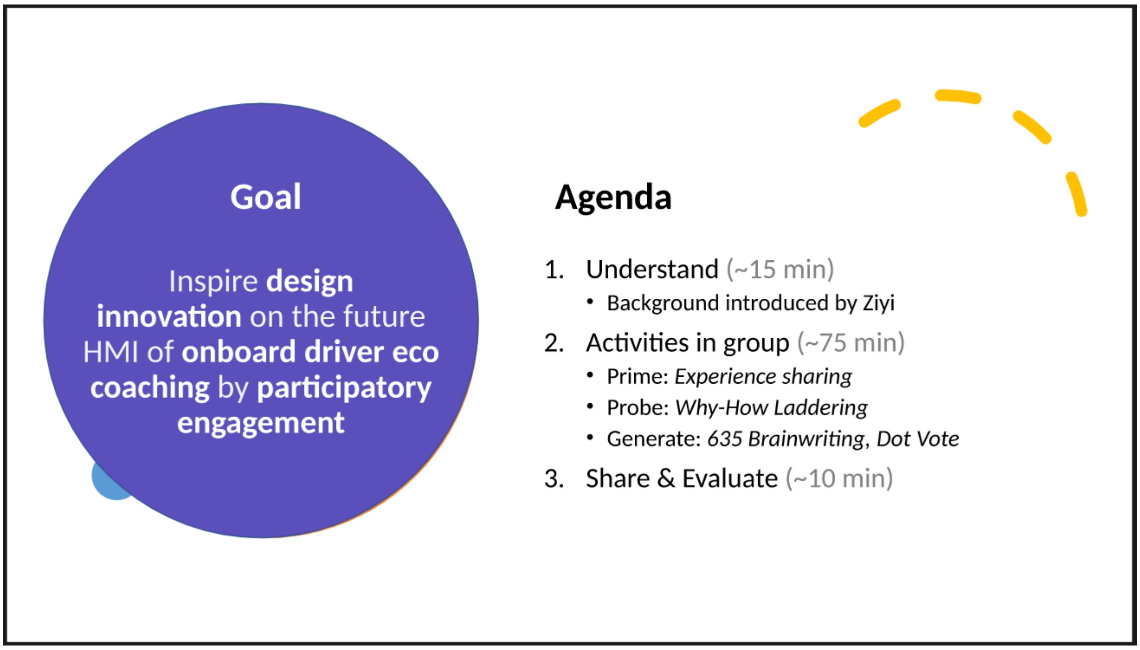


Figure A.1: Co-design workshop: the agenda

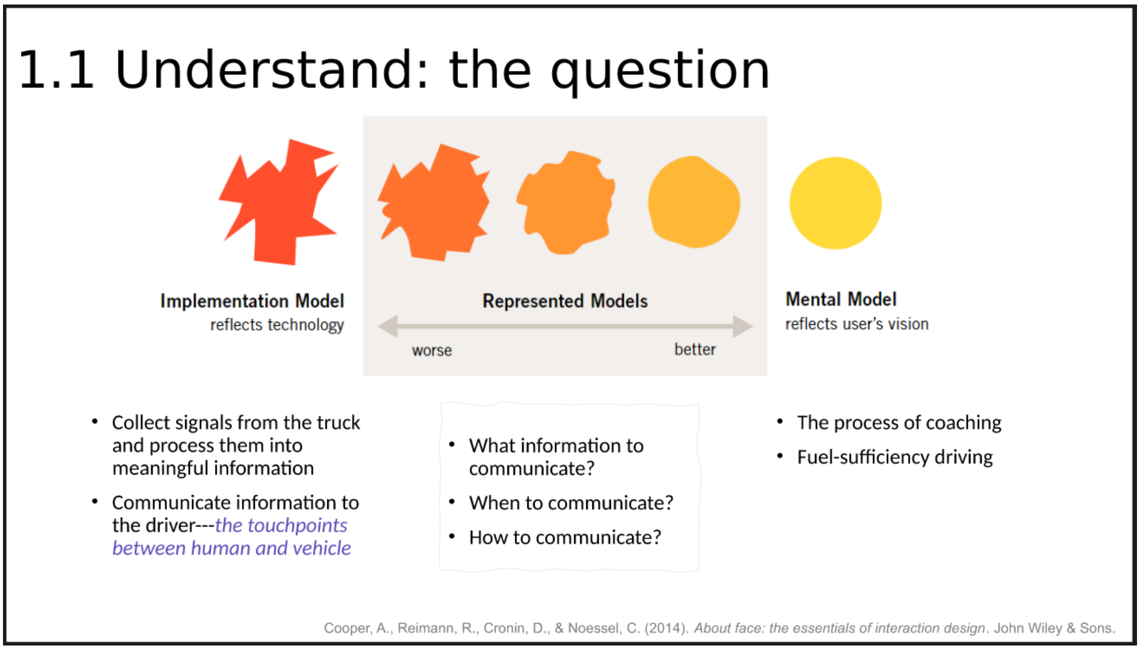


Figure A.2: Co-design workshop: understand the design challenge (a)

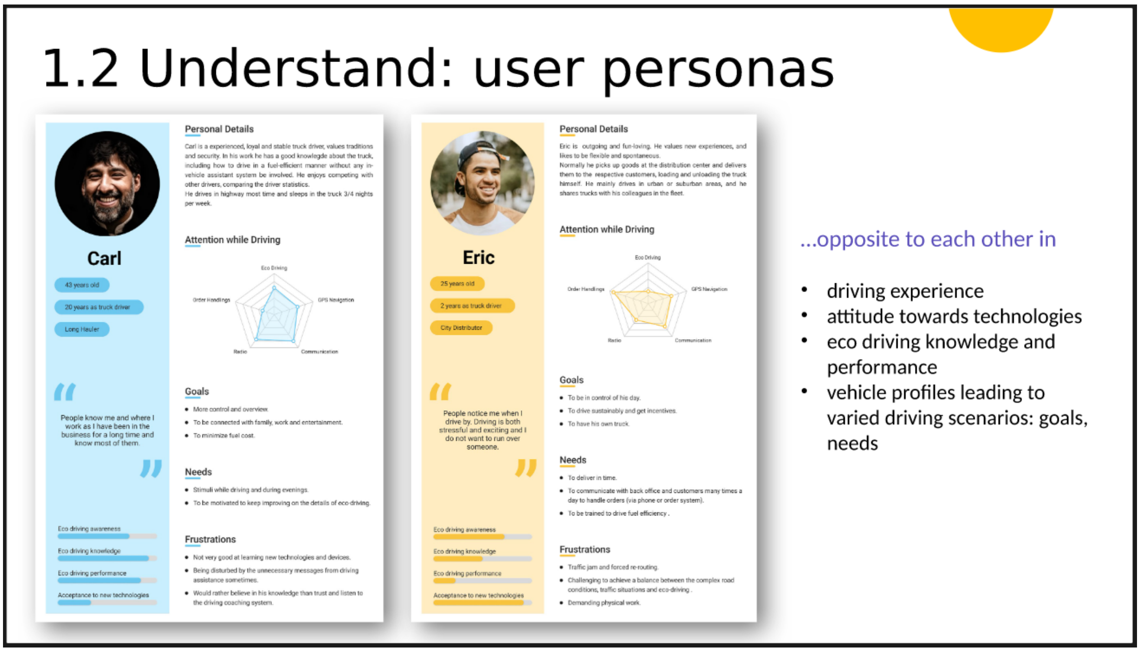


Figure A.3: Co-design workshop: understand the design challenge (b)

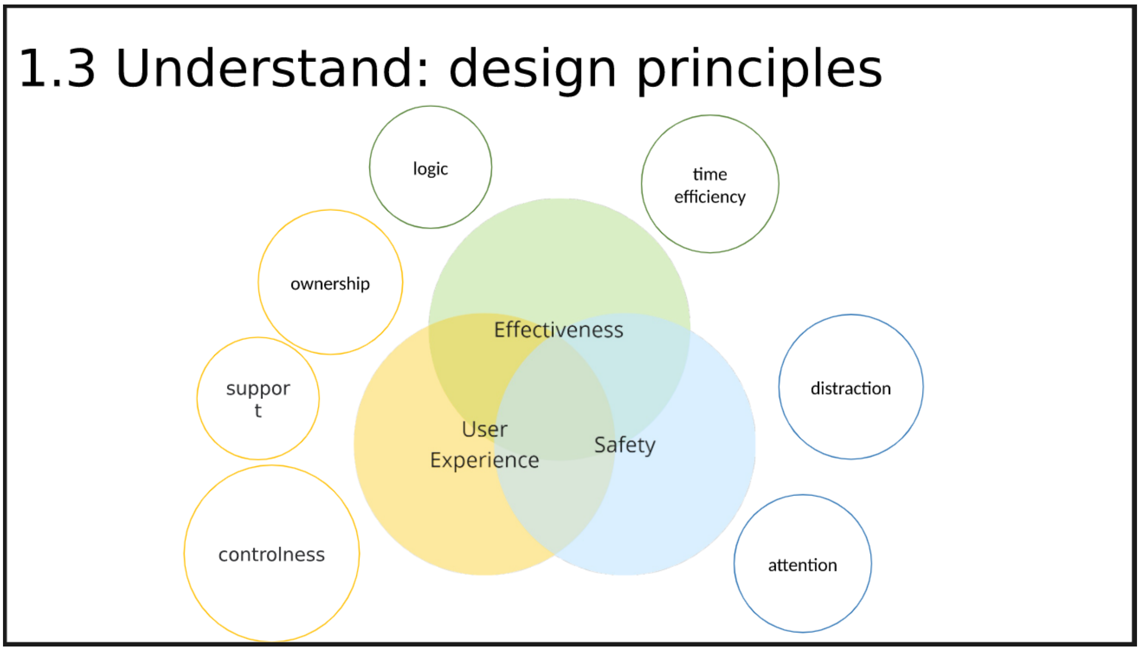


Figure A.4: Co-design workshop: understand the design challenge (c)

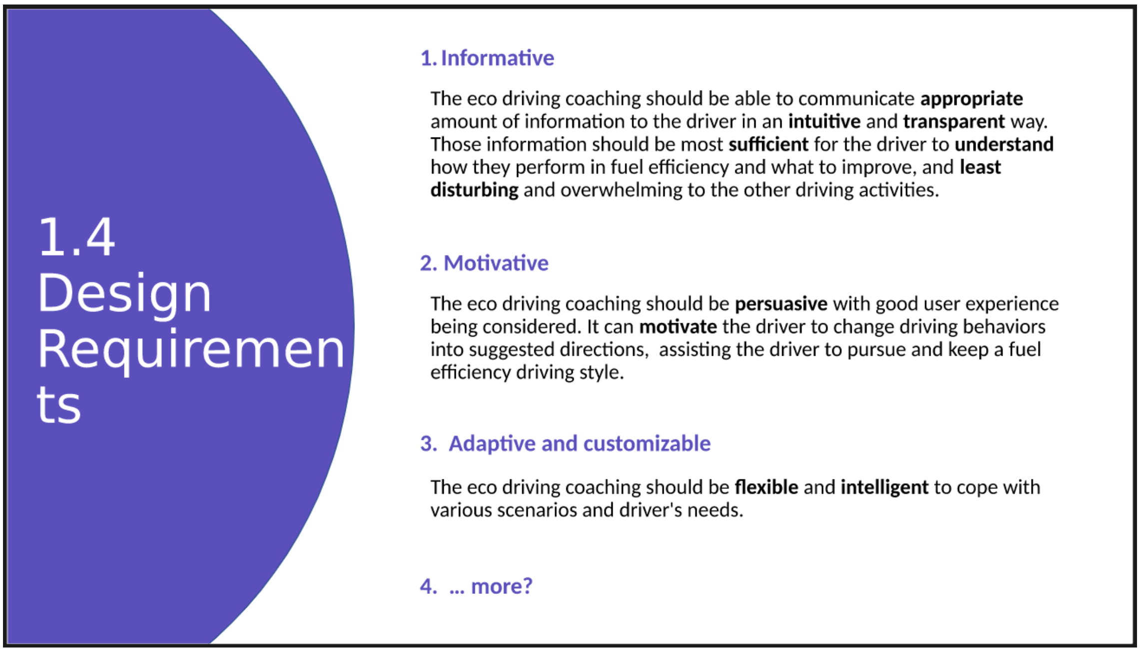


Figure A.5: Co-design workshop: understand the design challenge (d)

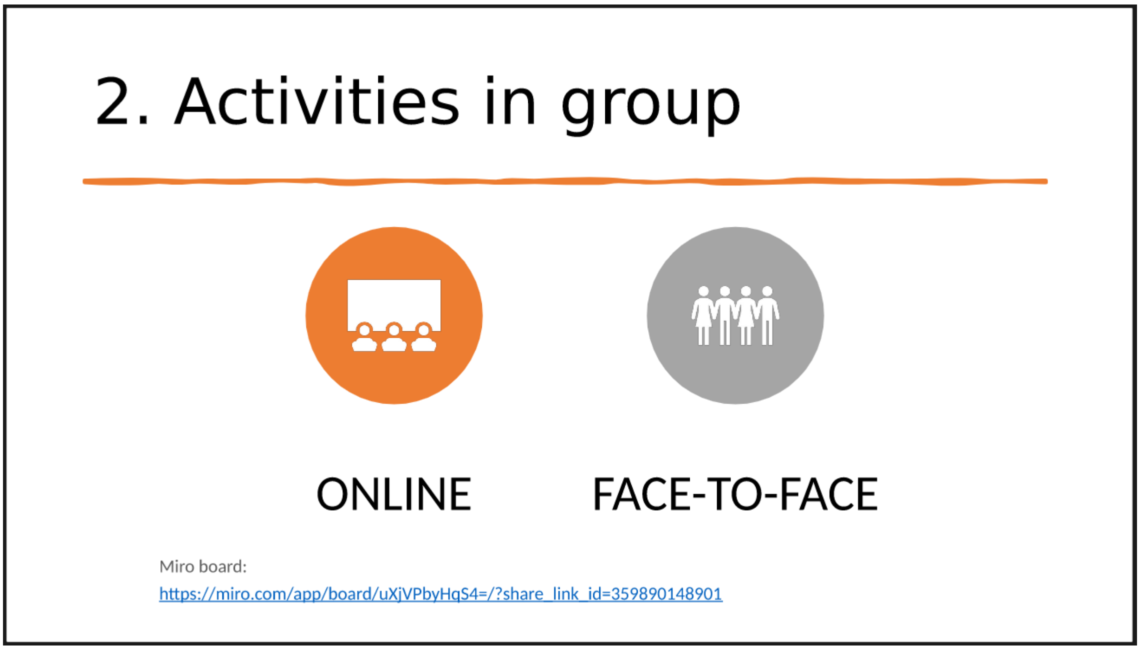


Figure A.6: Co-design workshop: activities in groups

Figure A.7: Co-design workshop: Prime

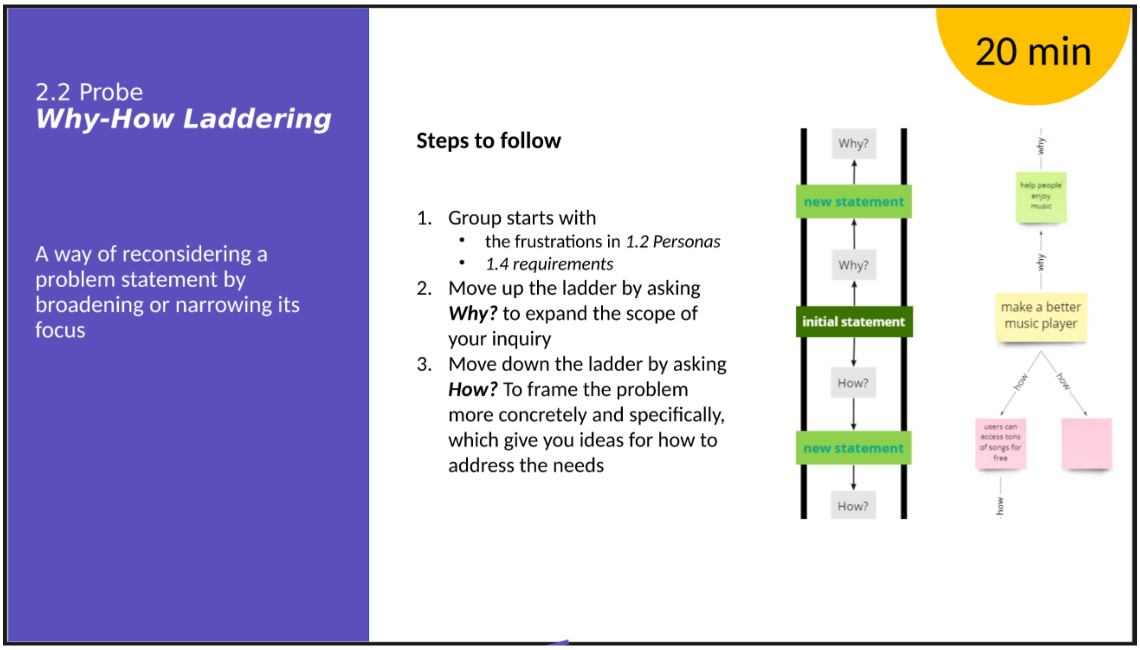


Figure A.8: Co-design workshop: Probe

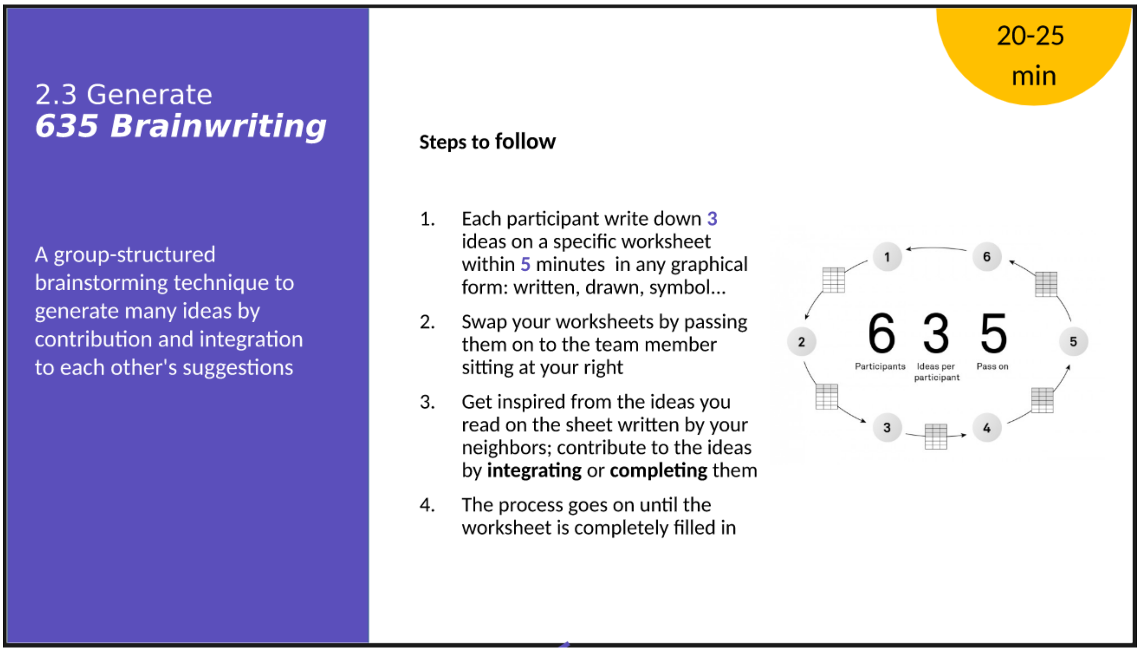


Figure A.9: Co-design workshop: Generate (a)

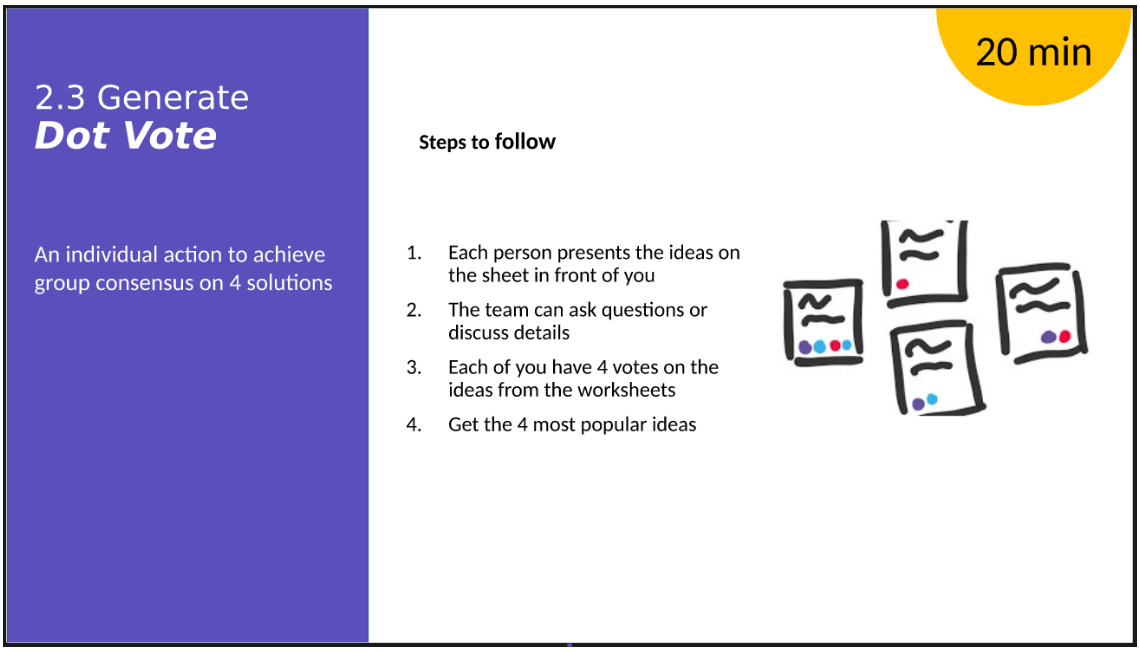


Figure A.10: Co-design workshop: Generate (b)

Figure A.11: Co-design workshop: Share and evaluate (a)

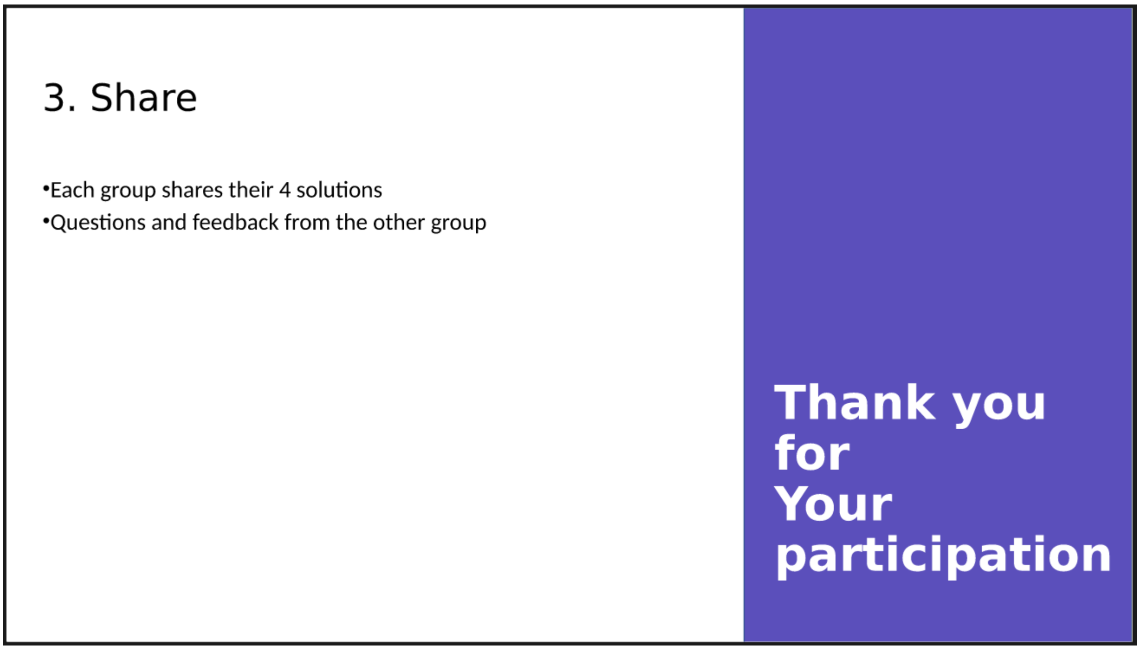


Figure A.12: Co-design workshop: Share and evaluate (b)

B

User Questionnaire

User Interface Improvement for Onboard Driver Eco Coaching (DECO)- INSTANCE 1

Consent

Welcome to our research study!

The survey is part of a master's thesis from Chalmers University of Technology collaborated with Volvo Group Truck Technology. We would like to hear your voice, as a truck driver, to help us improve the user interface of Volvo Truck's Onboard Driver Eco Coaching (DECO) system.

In this survey, you will respond based on your reflection on fuel/energy efficiency in your daily mission, your needs for the eco-driving coaching system, and your experience of DECO (if you have any). Please be assured that your responses will be anonymised.

The survey should take you 6 10 min to complete. Your participation in this research is voluntary. You have the right to withdraw at any point during the study.

By clicking the button below, you acknowledge that your participation in the study is voluntary, you are 18 years of age, and that you are aware that you may choose to terminate your participation in the study at any time and for any reason.

We appreciate your time and insight.

`[I consent. Begin the study]` or `[I do not consent. Terminate the study]`

Demographic

- *What is your age? (18-24, 25-34, 35-44, 45-54, 55-64, 65 years or older)* `[Single choice]`
- *How many years have you driven trucks? (0-5, 6-10, 11-15, 16-20, 21-25, 26-30, more than 30)* `[Single choice]`
- *What is your most common type of driving? (Distribution, Long-haul, Construction, Other)* `[Single choice]`
- Do you pay for the truck's fuel/electricity bills by yourself? `[Yes or No]`

Figure B.1: Representative picture from The Company's onboard DECO

Eco-Driving Experience

Where do you position yourself in terms of your levels of motivation, knowledge, awareness, and performance of fuel/energy efficiency driving?

- *How motivated are you to drive fuel/energy efficiently?* `[5-point Likert scale: 1 is very low, 5 is very high]`
- *How much knowledge do you have with driving fuel/energy efficiently? (Knowledge refers that you know what to do and how to do in terms of eco-driving)* `[5-point Likert scale: 1 is very little, 5 is very much]`
- *How aware are you of fuel/energy efficiency when driving the truck? (Awareness refers that you can think of fuel/energy efficiency and/or understand it exists)* `[5-point Likert scale: 1 is very low, 5 is very high]`
- *Rate your performance of eco-driving in your daily mission.* `[5-point Likert scale: 1 is very low, 5 is very high]`

The Company's Onboard Driver Eco Coaching (DECO)

Please answer the questions based on your experience of using The Company's onboard Driver Eco Coaching.

- *Have you used The Company's onboard Driver Eco Coaching (DECO) system shown in Figure B.1?* [if Yes, continue; if No, jump to the question in Section B]

Figure B.2 to B.5 are given to help you recall how the DECO system works, as well as the primary features the system has.

How frequently do you use the following features in your daily mission? (Please use the above pictures as references in terms of each feature)

1. *View the overall accumulated score of eco-driving.* `[5-point Likert scale: 1 is never, 5 is always]`

Figure B.2: View the overall accumulated score of eco-driving, and view of key performance indicator's (KPI's) gauges

Figure B.3: View of sub-KPI's gauges

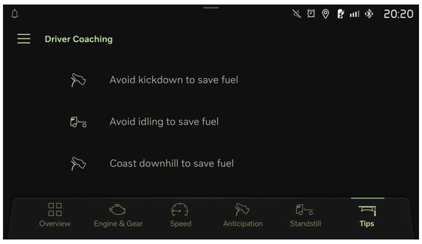


Figure B.4: View of sub-KPI's gauges

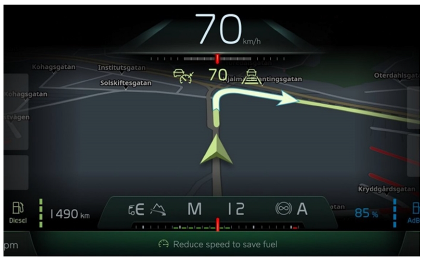


Figure B.5: Receive real-time coach notifications as toasts (on the instrument cluster)

2. *View of key performance indicator's (KPI's) gauges.* `[5-point Likert scale: 1 is never, 5 is always]`
3. *View of sub-KPI's gauges.* `[5-point Likert scale: 1 is never, 5 is always]`
4. *View the list of coach notifications.* `[5-point Likert scale: 1 is never, 5 is always]`
5. *Receive real-time coach notifications as toasts (on the instrument cluster).* `[5-point Likert scale: 1 is never, 5 is always]`

How useful do you think the following features will help you to perform better in your eco-driving? (Please use the above pictures as references in terms of each feature)

1. *View the overall accumulated score of eco-driving.* `[5-point Likert scale: 1 is not at all useful, 5 is extremely useful]`
2. *View of key performance indicator's (KPI's) gauges.* `[5-point Likert scale: 1 is not at all useful, 5 is extremely useful]`
3. *View of sub-KPI's gauges.* `[5-point Likert scale: 1 is not at all useful, 5 is extremely useful]`
4. *View the list of coach notifications.* `[5-point Likert scale: 1 is not at all useful, 5 is extremely useful]`

5. *Receive real-time coach notifications as toasts (on the instrument cluster).* `[5-point Likert scale: 1 is not at all useful, 5 is extremely useful]`

- *How likely would you recommend Volvo Driver Eco Coaching to a friend or colleague?* `[10-point scale: 1 is not at all likely, 10 is extremely likely]`
- *Any opinion about DECO? Leave it here!* `[Text field]`

Rate Concept Features

The following are new concepts that we are considering to design for the future onboard eco-driving coaching system. Please state how much appealing you think they are to help you drive fuel/energy efficiently.

- *For each trip, focus on a limited number of categories/KPIs (eg. anticipation and standstill) to be trained based on your historical performance.* `[5-point Likert scale: 1 is not at all appealing, 5 is very appealing]`
- *For each trip, focus on a limited number of categories/KPIs (eg. anticipation and standstill) to be trained based on your route.* `[5-point Likert scale: 1 is not at all appealing, 5 is very appealing]`
- *Be able to set eco-driving goal(s) for a specific trip (scenario: When starting the Driver Eco Coaching, set a target/goal for eco-driving, eg. how much fuel/energy you want to save).* `[5-point Likert scale: 1 is not at all appealing, 5 is very appealing]`
- *Receive eco-driving tips in advance before a situation happens (scenario: when Carl is approximating a downhill, he gets a notification "coasting downhill to save fuel").* `[5-point Likert scale: 1 is not at all appealing, 5 is very appealing]`
- *Receive instant feedback (good/bad action) on your behavior related to eco-driving (scenario: the system gives a hint to Carl to indicate how properly he coasted downhill).*`[5-point Likert scale: 1 is not at all appealing, 5 is very appealing]`
- *Have an overview on Instrument Cluster to track your progress.* `[5-point Likert scale: 1 is not at all appealing, 5 is very appealing]`
- *Route fuel/energy map: view eco-driving feedback or tips visualized on a route map.* `[5-point Likert scale: 1 is not at all appealing, 5 is very appealing]`
- *View your achievement: how much fuel/energy you have saved from eco-driving.* `[5-point Likert scale: 1 is not at all appealing, 5 is very appealing]`
- *Public Leaderboard: view your colleagues' scores and compare to them publicly (driving similar truck on similar route).* `[5-point Likert scale: 1 is not at all appealing, 5 is very appealing]`
- *Anonymous Leaderboard: view your colleagues' scores and compare to them anonymously (driving similar truck on similar route).* `[5-point Likert scale: 1 is not at all appealing, 5 is very appealing]`

- *Get a post-trip summary including your weaknesses and where to improve in terms of eco-driving.* `[5-point Likert scale: 1 is not at all appealing, 5 is very appealing]`
- *Get a post-trip summary including what you have improved compared to your historical records.* `[5-point Likert scale: 1 is not at all appealing, 5 is very appealing]`
- *Any other idea to create a better driver eco coaching system? Leave it here!* `[Text field]`

User Interface Improvement for Onboard Driver Eco Coaching (DECO)- INSTANCE 2

Consent

Welcome to our research study!

The survey is part of a master's thesis from Chalmers University of Technology collaborated with Volvo Group Truck Technology. We would like to hear your voice, as a truck driver, to help us improve the user interface of Volvo Truck's Onboard Driver Eco Coaching (DECO) system.

In this survey, you will respond based on your reflection on fuel/energy efficiency in your daily mission, your needs for the eco-driving coaching system, and your experience of DECO (if you have any). Please be assured that your responses will be anonymised.

The survey should take you 6 10 min to complete. Your participation in this research is voluntary. You have the right to withdraw at any point during the study.

By clicking the button below, you acknowledge that your participation in the study is voluntary, you are 18 years of age, and that you are aware that you may choose to terminate your participation in the study at any time and for any reason.

We appreciate your time and insight.

`[I consent. Begin the study]` or `[I do not consent. Terminate the study]`

Demographic

- *What is your age? (18-24, 25-34, 35-44, 45-54, 55-64, 65 years or older)* `[Single choice]`
- *How many years have you driven trucks? (0-5, 6-10, 11-15, 16-20, 21-25, 26-30, more than 30)* `[Single choice]`
- *What is your most common type of driving? (Distribution, Long-haul, Construction, Other)* `[Single choice]`

Figure B.6: Representative picture from The Company's onboard DECO

- Do you pay for the truck's fuel/electricity bills by yourself? `[Yes or No]`

Eco-Driving Experience

Where do you position yourself in terms of your levels of motivation, knowledge, awareness, and performance of fuel/energy efficiency driving?

- *How motivated are you to drive fuel/energy efficiently?* `[5-point Likert scale: 1 is very low, 5 is very high]`
- *How much knowledge do you have with driving fuel/energy efficiently? (Knowledge refers that you know what to do and how to do in terms of eco-driving)* `[5-point Likert scale: 1 is very little, 5 is very much]`
- *How aware are you of fuel/energy efficiency when driving the truck? (Awareness refers that you can think of fuel/energy efficiency and/or understand it exists)* `[5-point Likert scale: 1 is very low, 5 is very high]`
- *Rate your performance of eco-driving in your daily mission.* `[5-point Likert scale: 1 is very low, 5 is very high]`

Usability Of The Company's Onboard Driver Eco Coaching (DECO)

Please answer the questions based on your experience of using The Company's onboard Driver Eco Coaching.

- *Have you used The Company's onboard Driver Eco Coaching (DECO) system shown in Figure B.6?* [if Yes, continue; if No, jump to the question in Section B]

Figure B.7 to B.10 are given to help you recall how the DECO system works.

- *I think that I would like to use this system frequently.* `[5-point Likert scale: 1 is strongly disagree, 5 is strongly agree]`

Figure B.7: Picture of DECO (a)

Figure B.8: Picture of DECO (b)

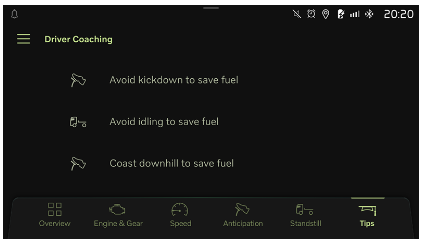


Figure B.9: Picture of DECO (c)

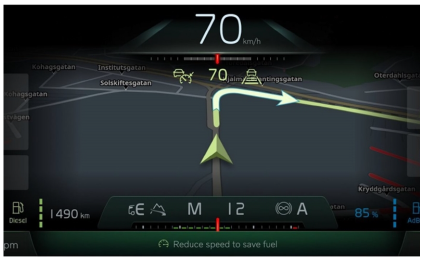


Figure B.10: Picture of DECO (d)

- *I found the system unnecessarily complex.* [5-point Likert scale: 1 is strongly disagree, 5 is strongly agree]
- *I thought the system was easy to use.* [5-point Likert scale: 1 is strongly disagree, 5 is strongly agree]
- *I think that I would need the support of a technical person to be able to use this system.* [5-point Likert scale: 1 is strongly disagree, 5 is strongly agree]
- *I found the various functions in this system were well integrated.* [5-point Likert scale: 1 is strongly disagree, 5 is strongly agree]
- *I thought there was too much inconsistency in this system.* [5-point Likert scale: 1 is strongly disagree, 5 is strongly agree]
- *I would imagine that most people would learn to use this system very quickly.* [5-point Likert scale: 1 is strongly disagree, 5 is strongly agree]
- *I found the system very cumbersome to use. (cumbersome: awkward because of being large, heavy, or not effective)* [5-point Likert scale: 1 is strongly disagree, 5 is strongly agree]
- *I felt very confident using the system.* [5-point Likert scale: 1 is strongly disagree, 5 is strongly agree]
- *I needed to learn a lot of things before I could get going with this system.* [5-point Likert scale: 1 is strongly disagree, 5 is strongly agree]

- *How likely would you recommend Volvo Driver Eco Coaching to a friend or colleague?* [10-point scale: 1 is not at all likely, 10 is extremely likely]
- *What do you like most about DECO?* [Text field]
- *What do you like least about DECO?* [Text field]

Rate Concept Features

The following are new concepts that we are considering to design for the future onboard eco-driving coaching system. Please state how much appealing you think they are to help you drive fuel/energy efficiently.

- *For each trip, focus on a limited number of categories/KPIs (eg. anticipation and standstill) to be trained based on your historical performance.* [5-point Likert scale: 1 is not at all appealing, 5 is very appealing]
- *For each trip, focus on a limited number of categories/KPIs (eg. anticipation and standstill) to be trained based on your route.* [5-point Likert scale: 1 is not at all appealing, 5 is very appealing]
- *Be able to set eco-driving goal(s) for a specific trip (scenario: When starting the Driver Eco Coaching, set a target/goal for eco-driving, eg. how much fuel/energy you want to save).* [5-point Likert scale: 1 is not at all appealing, 5 is very appealing]
- *Receive eco-driving tips in advance before a situation happens (scenario: when Carl is approximating a downhill, he gets a notification "coasting downhill to save fuel").* [5-point Likert scale: 1 is not at all appealing, 5 is very appealing]
- *Receive instant feedback (good/bad action) on your behavior related to eco-driving (scenario: the system gives a hint to Carl to indicate how properly he coasted downhill).*[5-point Likert scale: 1 is not at all appealing, 5 is very appealing]
- *Have an overview on Instrument Cluster to track your progress.* [5-point Likert scale: 1 is not at all appealing, 5 is very appealing]
- *Route fuel/energy map: view eco-driving feedback or tips visualized on a route map.* [5-point Likert scale: 1 is not at all appealing, 5 is very appealing]
- *View your achievement: how much fuel/energy you have saved from eco-driving.* [5-point Likert scale: 1 is not at all appealing, 5 is very appealing]
- *Public Leaderboard: view your colleagues' scores and compare to them publicly (driving similar truck on similar route).* [5-point Likert scale: 1 is not at all appealing, 5 is very appealing]
- *Anonymous Leaderboard: view your colleagues' scores and compare to them anonymously (driving similar truck on similar route).* [5-point Likert scale: 1 is not at all appealing, 5 is very appealing]
- *Get a post-trip summary including your weaknesses and where to improve in terms of eco-driving.* [5-point Likert scale: 1 is not at all appealing, 5 is very appealing]
- *Get a post-trip summary including what you have improved compared to your historical records.* [5-point Likert scale: 1 is not at all appealing, 5 is very appealing]
- *Any other idea to create a better driver eco coaching system? Leave it here!* [Text field]

C

Results of User Questionnaire

Demographic Information

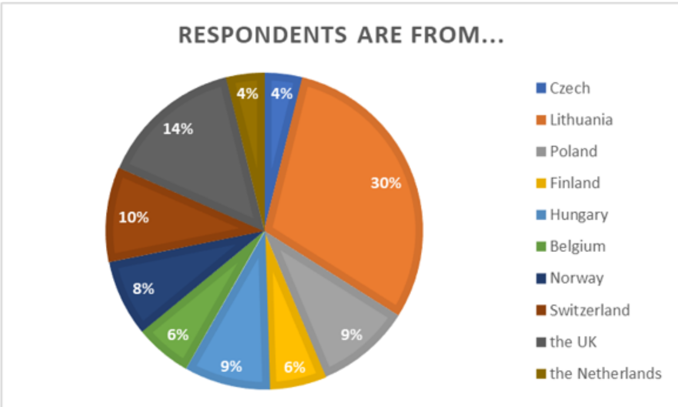


Figure C.1: Regions where participants were from

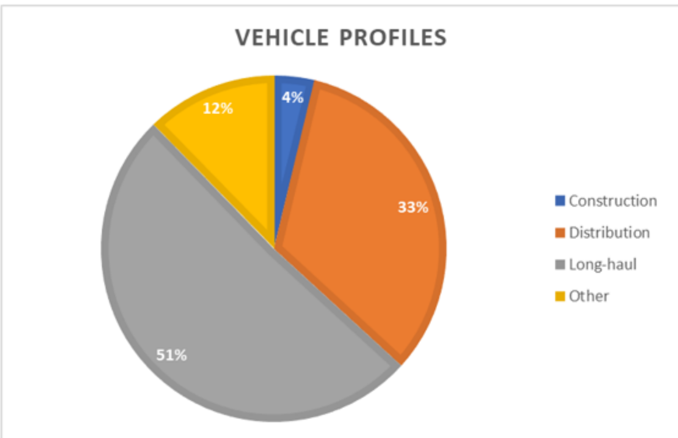


Figure C.2: Distribution of the participants' vehicle profiles

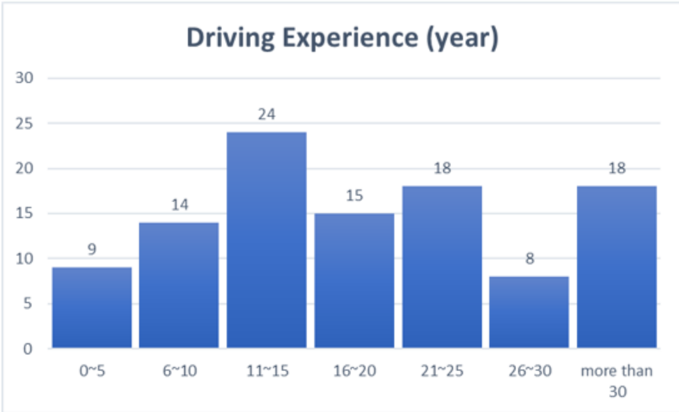
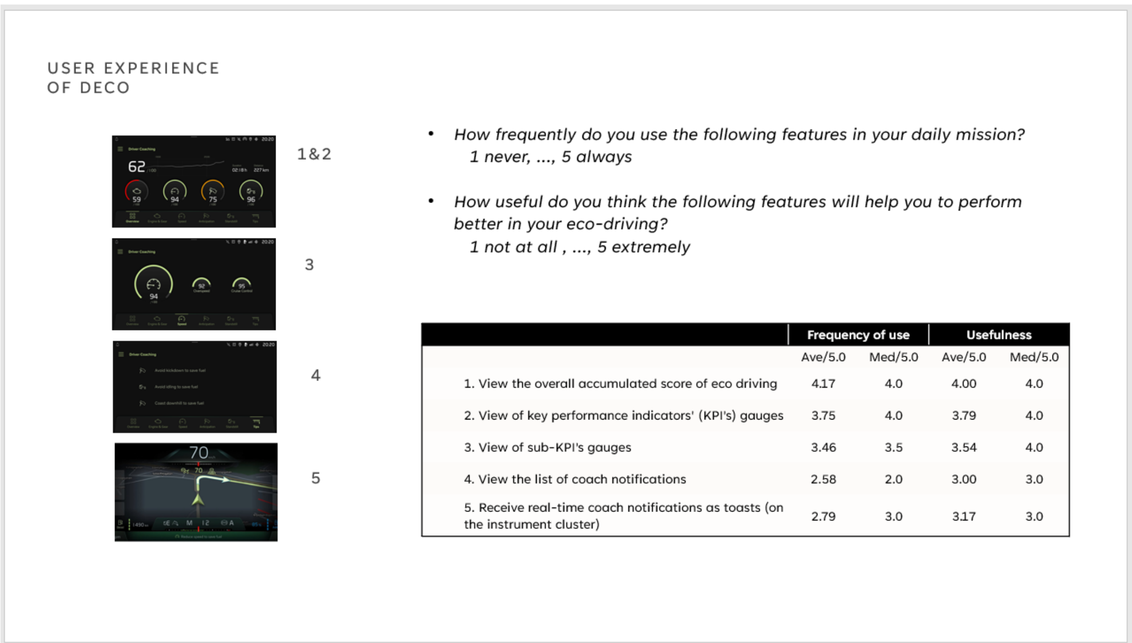


Figure C.3: Years of driving trucks of participants

DECO: Frequency of Use and Usefulness



	Frequency of use		Usefulness	
	Ave/5.0	Med/5.0	Ave/5.0	Med/5.0
1. View the overall accumulated score of eco driving	4.17	4.0	4.00	4.0
2. View of key performance indicators' (KPI's) gauges	3.75	4.0	3.79	4.0
3. View of sub-KPI's gauges	3.46	3.5	3.54	4.0
4. View the list of coach notifications	2.58	2.0	3.00	3.0
5. Receive real-time coach notifications as toasts (on the instrument cluster)	2.79	3.0	3.17	3.0

Figure C.4: Scores for frequency of use and usefulness of 5 key features

Concepts Evaluation

FUTURE CONCEPTS EVALUATION

how much appealing you think they are to help you drive fuel/energy-efficiently?

(1 not at all appealing ,..., 5 very appealing)

Concept	Ave/5.0	Med/5.0
Have an overview on Instrument Cluster to track your progress	4.25	5.0
View your achievement: how much fuel/energy you have saved from eco-driving	4.17	5.0
Get a post trip summary including your weaknesses and where to improve in terms of eco-driving	4.17	4.0
Get a post trip summary including what you have improved compared to your historical records	4.11	4.0
Receive instant feedback (good/bad action) on your behavior related to eco-driving	3.95	4.0
Receive eco-driving tips in advance before a situation happens	3.93	4.0
Route fuel/energy map: view eco-driving feedback or tips visualized on a route map	3.93	4.0
For each trip, focus on a limited number of categories/KPIs (eg. anticipation and standstill) to be trained based on your historical performance	3.82	4.0
For each trip, focus on a limited number of categories/KPIs (eg. anticipation and standstill) to be trained based on your route	3.82	4.0
Be able to set eco-driving goal(s) for a specific trip	3.69	4.0
Anonymous Leaderboard: view your colleagues' scores and compare to them anonymously (driving similar truck on similar route)	3.61	4.0
Public Leaderboard: view your colleagues' scores and compare to them publicly (driving similar truck on similar route)	3.48	4.0

Figure C.5: Scores for appealingness of 12 concept features

D

Prototype Walkthrough

Scenarios

Below is the description of 8 scenarios for Prototype A.

1. You get on the truck and prepare to start your trip. Feel free to check around.
    - Interact with DECO on the SID (Secondary Information Display)
2. Now you are driving on the road. Based on the route of this trip, you are about to go downhill.
    - Take a look at the IC (Instrument Cluster)
3. You followed the tip by coasting downhill.
    - Take a look at the IC
    - Take a look at the SID
4. Now you are driving on the highway. You have been using Cruise Control for a while as you know it can help save energy.
    - Take a look at the SID (Secondary Information Display)
5. You are still driving on a highway with high speed. You were distracted a little bit so you didn't notice the car in front of you has been reducing speed. When you realized that you need to do something, you did a series of harsh braking.
    - Take a look at the IC (Instrument Cluster)
    - Take a look at the SID
6. After a while, here comes a short break when waiting for a red light, so you have a moment to interact with the SID (Secondary Information Display).
    - Interact with the SID
7. Now it's the end of the trip. You pulled over the truck and now you are able to interact with the SID (Secondary Information Display) as much as you want.
    - Interact with the SID
8. The other day, you started a new trip.
    - Reset DECO

Below is the description of 7 scenarios for Prototype B.

1. You get on the truck and prepare to start your trip. Feel free to check around.
    - Interact with DECO on the SID (Secondary Information Display)
2. Now you are driving on the road. Based on the route of this trip, you are about to go downhill.
3. You coasted downhill.
    - Take a look at the SID

4. Now you are driving on the highway. You have been using Cruise Control for a while as you know it can help save energy.
    - Take a look at the SID (Secondary Information Display)
5. You are still driving on a highway with high speed. You were distracted a little bit so you didn't notice the car in front of you has been reducing speed. When you realized that you need to do something, you did a series of harsh braking.
    - Take a look at the IC (Instrument Cluster)
6. Now it's the end of the trip. You pulled over the truck and now you are able to interact with the SID (Secondary Information Display) as much as you want.
    - Interact with the SID
7. The other day, you started a new trip.
    - Reset DECO

Instruction on Walkthrough

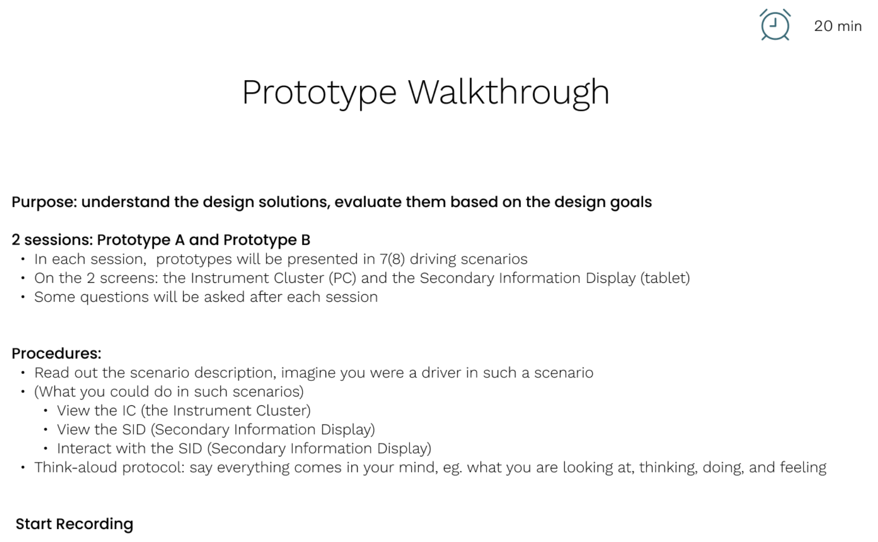


Figure D.1: Instruction on the prototype walkthrough during the user test

E

Questionnaire and Interview Questions in User Testing

Questionnaire

Consent

Welcome to our research study! The survey is part of a master's thesis from Chalmers

University of Technology collaborated with Volvo Group Truck Technology to improve the User Interfaces of the onboard Driver Eco Coaching (DECO). In this study,

you will be presented the HMI prototypes of DECO and asked to answer a series of questions on the survey, followed by a semi-structured interview. More instructions will be given before the study starts. Please be assured that all your responses will be anonymized. The study should take you approximately 50 minutes to complete.

Your participation in this research is voluntary. You have the right to withdraw at any point during the study. By clicking the button below, you acknowledge that

your participation in the study is voluntary, you are 18 years of age, and that you are aware that you may choose to terminate your participation in the study at any time and for any reason.

`[I consent. Begin the study]` or `[I do not consent. Terminate the study]`

Demographic

- *What is your age? (male, female, prefer not to say)* `[Single choice]`
- *What is your age? (The value must be a number)* `[Text field]`
- *What is your profession/role?* `[Text field]`

Prototype A

Motivation

if I were a driver using DECO with this HMI, I would like to pursue eco-driving because...

- *Somebody else wants me to do it or because I get something out of it.* [7-point Likert scale: 1 is not at all for this reason, 7 is completely for this reason]
- *I would feel ashamed, guilty, or anxious if I did not.* [7-point Likert scale: 1 is not at all for this reason, 7 is completely for this reason]
- *I really believe it is an important goal to have.* [7-point Likert scale: 1 is not at all for this reason, 7 is completely for this reason]
- *Of the fun and enjoyment that it provides me.* [7-point Likert scale: 1 is not at all for this reason, 7 is completely for this reason]

Acceptance

- *I think DECO with this HMI is* [5-point Likert scale: 1 is useful, 5 is useless]
- *I think DECO with this HMI is* [5-point Likert scale: 1 is pleasant, 5 is unpleasant]
- *I think DECO with this HMI is* [5-point Likert scale: 1 is bad, 5 is good]
- *I think DECO with this HMI is* [5-point Likert scale: 1 is nice, 5 is annoying]
- *I think DECO with this HMI is* [5-point Likert scale: 1 is effective, 5 is superfluous]
- *I think DECO with this HMI is* [5-point Likert scale: 1 is irritating, 5 is likable]
- *I think DECO with this HMI is* [5-point Likert scale: 1 is assisting, 5 is worthless]
- *I think DECO with this HMI is* [5-point Likert scale: 1 is undesirable, 5 is desirable]
- *I think DECO with this HMI is* [5-point Likert scale: 1 is sing alert, 5 is sleep-inducing]

System Usability Scale (SUS)

- *I think that I would like to use this system frequently.* [5-point Likert scale: 1 is strongly disagree, 5 is strongly agree]
- *I found the system unnecessarily complex.* [5-point Likert scale: 1 is strongly disagree, 5 is strongly agree]
- *I thought the system was easy to use.* [5-point Likert scale: 1 is strongly disagree, 5 is strongly agree]
- *I think that I would need the support of a technical person to be able to use this system.* [5-point Likert scale: 1 is strongly disagree, 5 is strongly agree]
- *I found the various functions in this system were well integrated.* [5-point Likert scale: 1 is strongly disagree, 5 is strongly agree]
- *I thought there was too much inconsistency in this system.* [5-point Likert scale: 1 is strongly disagree, 5 is strongly agree]

- *I would imagine that most people would learn to use this system very quickly.* [5-point Likert scale: 1 is strongly disagree, 5 is strongly agree]
- *I found the system very cumbersome to use. (cumbersome: awkward because of being large, heavy, or not effective)* [5-point Likert scale: 1 is strongly disagree, 5 is strongly agree]
- *I felt very confident using the system.* [5-point Likert scale: 1 is strongly disagree, 5 is strongly agree]
- *I needed to learn a lot of things before I could get going with this system.* [5-point Likert scale: 1 is strongly disagree, 5 is strongly agree]

Prototype B

Motivation

if I were a driver using DECO with this HMI, I would like to pursue eco-driving because...

- *Somebody else wants me to do it or because I get something out of it.* [7-point Likert scale: 1 is not at all for this reason, 7 is completely for this reason]
- *I would feel ashamed, guilty, or anxious if I did not.* [7-point Likert scale: 1 is not at all for this reason, 7 is completely for this reason]
- *I really believe it is an important goal to have.* [7-point Likert scale: 1 is not at all for this reason, 7 is completely for this reason]
- *Of the fun and enjoyment that it provides me.* [7-point Likert scale: 1 is not at all for this reason, 7 is completely for this reason]

Acceptance

- *I think DECO with this HMI is* [5-point Likert scale: 1 is useful, 5 is useless]
- *I think DECO with this HMI is* [5-point Likert scale: 1 is pleasant, 5 is unpleasant]
- *I think DECO with this HMI is* [5-point Likert scale: 1 is bad, 5 is good]
- *I think DECO with this HMI is* [5-point Likert scale: 1 is nice, 5 is annoying]
- *I think DECO with this HMI is* [5-point Likert scale: 1 is effective, 5 is superfluous]
- *I think DECO with this HMI is* [5-point Likert scale: 1 is irritating, 5 is likable]
- *I think DECO with this HMI is* [5-point Likert scale: 1 is assisting, 5 is worthless]
- *I think DECO with this HMI is* [5-point Likert scale: 1 is undesirable, 5 is desirable]

- *I think DECO with this HMI is* `[5-point Likert scale: 1 is sing alert, 5 is sleep-inducing]`

Interview Questions

The following questions were specifically targeted to Prototype A, the NEW prototype.

- *How do you understand the eco tree?*
- *How do you understand those notifications?*
- *How do you understand the list of past events?*
- *Did you notice there is more information of subKPIs?What do you think of it?*
- *Do you think Duration and Distance are in a proper place? Or should they be displayed on the Performance screen?*
- *When do you think the drivers are likely to view the Achievements screen? In which kind of driving scenario?*
- *What do you think of the customizable coaching categories?*
- *if there is voice coaching, do you think it should be solely broadcast or given along with the text notifications?*

The last two questions were only for experts in UX design or research.

- *Is there any Usability problem you identified but we haven't talked about?*
- *Any suggestions for improvements?*