



CHALMERS
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HMI Design for V2X Communication Technology

Refining Car Collision Warning with E-scooters to Improve User Experience

Master's thesis in Industrial Design Engineering

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DEPARTMENT OF INDUSTRIAL AND MATERIAL SCIENCE

CHALMERS UNIVERSITY OF TECHNOLOGY

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Ying Luo & Yifan Zhang

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Cover: The figure shows Vehicle-to-Everything technology integrated with the HMI
warning design.

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Abstract

Have you ever encountered a situation when an e-scooter suddenly appeared out of nowhere while driving? E-scooters are becoming increasingly popular, meanwhile, they present new safety challenges for urban transportation, especially for car drivers.

To address these challenges, this master's thesis project focused on developing a collision warning system for cars that integrated with Vehicle-to-Everything (V2X) technology and Human-Machine Interface (HMI) design principles. The objective is to increase the driver's awareness and experience, consequently reducing the risk of collisions between cars and E-scooters. Through three design iterations, the optimal parameters for modality, form, and timing of collision alerts were explored, leading to the development of a final multi-modality HMI concept and guidelines for V2X collision warning design.

Keywords: Vehicle to Everything, Warning Design, E-scooter, HMI design, Design Iteration, Usability Testing

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Ying Luo & Yifan Zhang, Gothenburg, May 2024

List of Terminology

Below is the list of terminology that have been used throughout this thesis listed in alphabetical order:

VANET	Vehicular ad-hoc network
HCD	Human-centered Design
HDD	Head-down Display
HMI	Human Machine Interface
HUD	Head-up Display
IC	Instrument Cluster
SA	Situation Awareness
V2X	Vehicle to Everything

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1

Introduction

1.1 Background

This thesis project aligns with the ongoing project “e-Safer”, responding to the increasing popularity of e-scooters in cities worldwide. While this vehicle brings many advantages, especially in terms of its ability to decrease emissions, congestion, and noise pollution, it also makes urban transportation more complex. Due to the scooter’s distinctive driving characteristics [1] compared to the traditional vehicles, given the smaller size, faster acceleration, and enhanced maneuverability, drivers face new challenges in detecting the blind spot and predicting its movement trajectory for decision-making. Furthermore, there are no established social norms, traffic regulations, or access to infrastructure for e-scooters [2], which makes it considered a more dangerous threat than bicycles. Thus, establishing a safety interaction between drivers and e-scooterists emerges as a crucial concern in this context. Thus, establishing a safety interaction between drivers and e-scooterists emerges as a crucial concern in this context.

To address these challenges, Vehicle to Everything (or V2X) technology with its potential to connect different devices seamlessly, opens up possibilities to solve the problem in new ways. With the application of this technology, the project can provide an improved Human-Machine Interface (HMI) that is displayed to car drivers, enhancing their ability to drive safely and make decisions more effectively.

The popularity of e-scooters [3] has made road conditions more complex, which makes it more difficult for drivers to make correct decisions. Therefore, the assistant information provided to drivers by HMI becomes more important. Relevant information such as the intention and movement of the e-scooter need to be conveyed to drivers to enhance their situational awareness and help them make informed decisions to avoid collision. The information can vary in type, sensory input, placements, as well as how it pops up.

1.2 Project Scope

1.2.1 Aim

This project aims to design a user-centric car HMI that is used in the cockpit to effectively convey information and reduce the risk of collisions between cars and e-scooters in possible scenarios.

1.2.2 Objectives

The project finally delivered several objectives as the expected results:

- High-fidelity HMI interfaces for specific situations.
- Suggestions regarding which elements (such as trajectory, direction, timing, criticality, vehicle type, etc.) should be used for an effective warning can significantly influence the requirements of V2X technology.
- Design guidelines for developing future V2X warning, mainly about how to convey the information, which includes appearance, position, modality, and stages.

1.2.3 Limitations

The study only focused on the communication between cars and e-scooters at the intersection and the on-road scenarios. The scenario we chose included only a blind spot warning and forward collision warning, however, in the real world the situation can be much more complex. This study didn't extend to discuss the relationship between e-scooters and other vehicles in other scenarios.

1.3 Collaborated Company

The collaborating company for this project is **Magna Electronics**, specifically aligned with Magna's Research and Innovation department's project called "e-safer." Magna's core value is "Think Big," and as one of the largest automotive suppliers globally, Magna has always focused on offering state-of-the-art solutions for customers. This project aims to provide guidelines for V2X warnings and explore potential radar technology solutions, which will greatly benefit future drivers in urban transportation.

1.4 Report Structure

This report are divided into 11 Chapters. The following is a brief capture of each Chapter.

1. **Introduction** - Introduced the background of this subject and the project scope.
2. **Theory** - Conducted literature research, and organized and summarized the theories related to this report.
3. **Methods** - The main methods used for the project are detail interpreted.
4. **Process** - This chapter introduced the preliminary preparation work, including literature inclusion, iteration plan, market research, and scenario choosing.
5. **Market Research and Foundations** - This chapter begins with a depiction of the market research that concluded the existing concepts from the benchmarking analysis. It then outlines the process of setting the default layout and selecting the scenario for the next phase.

6. **1st iteration** - This chapter compiled benchmarking results to create an information framework. Following this, implement the concepts (Demo A-G) into the default layout for initial usability testing. The results of it are moved to the 2nd iteration.
7. **2nd iteration** - This chapter introduces the second iteration of warning design and usability testing. Most warning features, except for placement, were identified as a result of this round of usability testing.
8. **3rd iteration** - This chapter introduces the third iteration of warning design and usability testing. The details of warning placement were thoroughly addressed.
9. **Final Solution and Guideline** - The results obtained from three rounds of iterations were summarized, and a comprehensive design plan and design guidance were proposed.
10. **Discussion** - In this chapter, the results are discussed together with limitations and future work.
11. **Conclusion** - This chapter reviews and summarizes the entire report.

2

Theory

This chapter addresses the theoretical aspects of this project. Related theories are discussed and compared. The theories cover V2X technology, staged warning, multi-modality situational awareness, car HMI warning design principles, and cognitive ergonomics-related theories.

2.1 V2X Technology

V2X (Vehicle-to-Everything) refers to the communication system that enables vehicles to exchange information with various entities in their environment, such as other vehicles (V2V), infrastructure (V2I), pedestrians (V2P), and networks (V2N). With the development of wireless communication, vehicular ad hoc networks (VANETs) can be achieved, where the vehicles act as nodes that broadcast different data (e.g., for safety or entertainment purposes)[4]. This technology allows vehicles to share their locations, speed, and travel directions in real time to improve road safety and traffic efficiency by wireless technology [5]. V2X technology brings increased awareness capabilities provided by the cooperative messages, unique HMI systems are required to present this information that goes beyond the scope of non-connected systems and clearly provided to drivers. To be mentioned, the realization of V2X functions mainly relies on the vehicle's existing wireless communication function, so there is no need to install additional hardware on the vehicle.

Advantages

V2X technology can significantly improve safety for drivers and pedestrians if it is properly applied, where the most common use case is in vehicle collision systems to predict its environment and avoid disaster. With V2X, collision warning systems can alert drivers to potential dangers even before critical objects come into view. This means that drivers may not have any visual cues about upcoming road hazards when they receive the warning. Instead, they rely on the system to provide detailed information about potential accidents, allowing them to react more quickly [6].

Furthermore, V2X technology can help create fuel-efficient vehicles. When cars can collect information about traffic jams, stoplights, and speed zones, they can translate this information into recommended routes. This increases fuel efficiency and avoids unnecessary stops.

Limitation

However, with the development of these information exchange technologies, car systems can provide an overwhelming amount of information, far exceeding what the human brain can process simultaneously. Therefore, if the information obtained through V2X is transmitted to the driver without proper processing, it is likely to cause driver distraction, thereby increasing the probability of driving accidents [4].

2.2 Staged Warning

The multi-staged warning system provides drivers with continuous and graded alerts based on the division of pre-crash warning scenarios, allowing them to take appropriate measures according to the urgency of the alert [7]. Designing staged warnings requires careful consideration of the warning's purpose and the criticality of the situation.

Single-stage warnings are effective in alerting drivers to imminent threats and minimizing the likelihood of false or nuisance alarms. In contrast, multi-stage warnings are beneficial for providing continuous information, such as a visual display of decreasing proximity to a lead vehicle in a forward collision warning system[8].

Numerous studies support the value of staged warnings, showing positive effects on driver performance, response to dangerous situations, and comprehension of system operation. Staged warnings may consist of two or more levels of cautionary information that increase in urgency proportionally to the criticality of the hazard situation, both in timing and modality. Normally, a single-stage warning provides only an imminent collision warning, requiring immediate corrective action. In contrast, a two-stage warning can also offer a cautionary collision warning before the imminent collision warning [8].

It should be noticed that although multi-staged warnings outperformed single-stage warnings in terms of objective utility and longitudinal car-following performance, the user experience, subjective utility, and trust in multi-staged warnings could be worse [7].

2.3 Multi-modality

Warnings can come in various forms. The way warnings are presented can affect driver responses and behavior. The appropriate type of warning modality depends on the driving environment (e.g., expected vehicle/cab noise and vibration, hazard scenarios), the criticality of the message (e.g., hazard versus non-hazard situations), the location of visual displays, and other factors [8].

Commonly used senses in car collision warning systems include sound, vision, and touch, shown in the Figure 2.1, which correspond to audio warning, visual warning, and haptic warning.

- **Visual messages** are best for presenting more complex information that is non-safety-critical and does not call for immediate action. Visual warning can be distracting when it is presented in a standard location inside of the vehicle (e.g. Cluster and infotainment) this is because it requires the driver to look away from the roadway to acquire the message.
- **Auditory warnings** can quickly capture the driver's attention and is suitable for presenting short, simple messages requiring quick or immediate action including high-priority alerts and warnings [8]. It can be particularly effective to get the driver's attention back to the situation when the driver is distracted or not looking at the roadway. Horberry et al. [9] found that tactile warnings were consistently preferred over visual and auditory warnings, the possible reason might be that tactile warnings are considered less likely to be confused with other similar types of stimuli in the cabin.
- **Haptic messages** are similar to auditory warnings, which are capable of quickly capturing the driver's attention and can be used if an auditory message is unlikely to be effective. Haptic messages can be divided into vibrotactile and kinesthetic. Vibrotactile interfaces provide information to the driver using vibrations and may be included in seat belts, seats, foot pedals, and the steering wheel. Kinesthetic interfaces provide information by causing limb or body motion. The review by Campbell [8] stated that haptic messages could be useful when drivers are engaged in secondary tasks or using portable services not under their control.

Multi-modal feedback is commonly recommended for car collision warnings. Many works of the literature suggest that combining **auditory and visual messages** when presenting warnings can improve performance compared to only utilizing visual warning systems [10] [8].

It is the same for the combination of **tactile and visual** warning. Researchers found that using the combination of tactile and visual warnings can also reduce users' reaction time compared to using only visual warnings.

However, combining **auditory and tactile** messages in the same warning will not improve users' reaction, however, it will reduce the drivers' effort [11].

It is important to notice that multi-modal warning can lead to an increase in driver subjective workload, the effort invested by humans into task performance, which in turn causes a decrease in the utility of the warning. Therefore, it is suggested that when evaluating different modalities, evaluate both objective indicators, such as usability, but also subjective indicators, such as mental workload and satisfaction [7].

The modality for providing information can vary for different stages of a multi-stage warning system. In low-emergency situations, visual warnings are appropriate, as they are suitable for presenting non-safety-critical information that does not require immediate action. As the degree of emergency increases, a combination of visual and audio warnings or visual and haptic warnings can be used. The urgency can be escalated by increasing the intensity of the stimuli, for example, by increasing

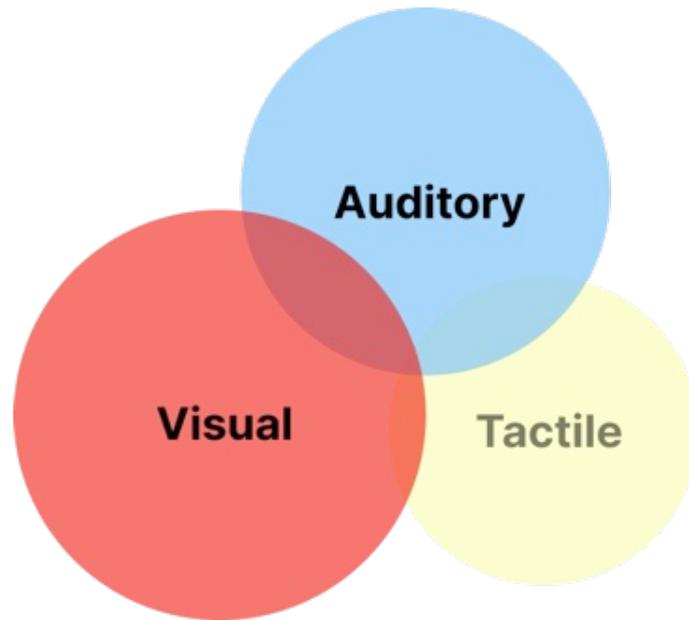


Figure 2.1: Multi-modality

the frequency and loudness of sounds. In extremely high-danger situations, highly stimulating haptic warnings can be applied at the last moment to prompt a quick response from drivers [8].

The appropriate warning modes can vary for different types of warnings, such as front collision, lateral collision, or rear-end collision. Zhao et al. [10] suggested that Human-Machine Interface (HMI) systems should provide only visual warnings for forward collisions but offer visual and auditory warnings for lateral and rear-end collisions.

Demographics such as the driver's age and years of driving experience can also affect drivers' responses to collision warnings. For example, experienced drivers are more sensitive to auditory warnings than new drivers so auditory warnings are particularly useful for them compared to new drivers [10].

2.4 Car HMI Design

Car HMI design involves various relevant factors. The following is a summary and comparison of these factors based on a review of the pertinent literature.

2.4.1 Placement

The placement of the warning is one of the key factors in car warning design. Campbell et al. [8] elaborate on some general design principles of placement in their article, suggesting that visual warnings should be presented on a single physical display rather than on separate displays. Driver responses are likely to be better if messages, even those from different devices, are shown on a single display.

The warning information should be separated according to its criticality before being displayed. When non-safety-critical information is presented inside the vehicle, it should be positioned near the periphery of the driver's field of view to avoid distracting from the immediate driving task. Three in-car displays that are commonly used to place warnings are introduced beneath, namely Instrument Cluster, HUD and Infotainment. The Figure 2.2 shows the common three in-car displays.

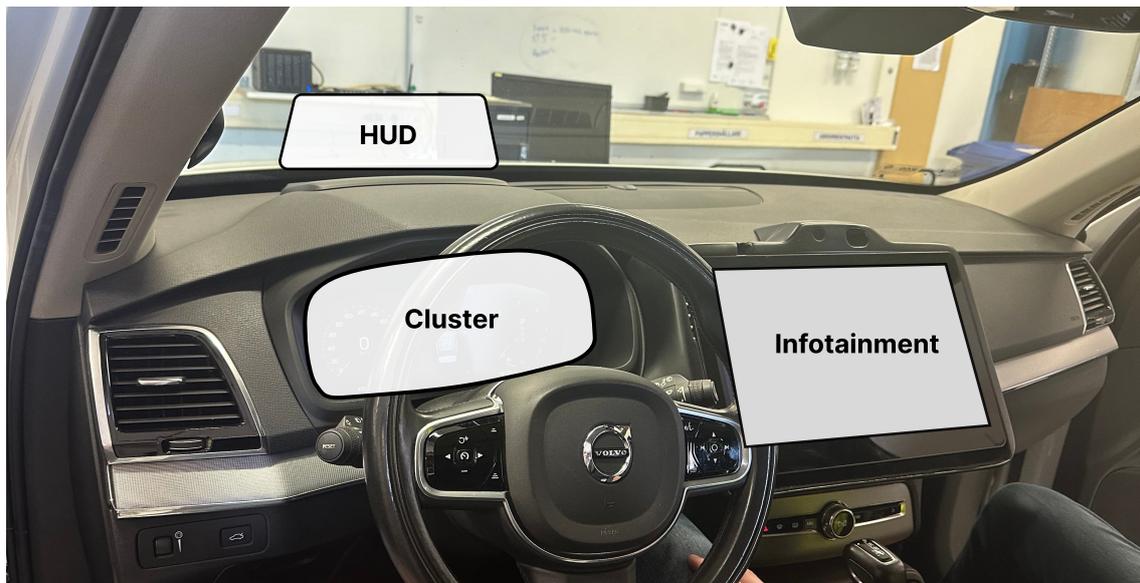


Figure 2.2: Three common In-car Displays

Instrument Cluster

Instrument Cluster, cluster, or information cluster is a specific part of the dashboard located directly in front of the driver, containing gauges and warning lights. It is designed to provide the driver with important information about the vehicle's status at a glance [4].

HUD

Head-UP display (HUD) is a small screen or image that appears as a floating, transparent display in the driver's foveal field of view. The standard size of the display is approximately 7 x 20 cm. Due to the short distance between the HUD and the driver's line of sight, the driver can quickly switch their focus between the road and the display.

Before, HUD presented information which almost exclusively devoted to the tasks critical for or related to driving [13]. However recently, with the popularization of HUD in passenger cars, they are adopted as an emerging device to not only provide drivers with driving aids but also reduce the visual workload caused by warning messages.

Although there are many literature reports on the advantages of HUD, such as that it causes minimal distraction compared to displays in other positions, there are also downsides that can cause driver distraction and confusion. Gerrit Meixner and Christian Müller [13] claim in their book that although HUD is located very close to the driver's sight while driving, they still need to focus on either one of them. They can not focus on both. Besides, although the display could be transparent, it could also partially occlude essential parts of the road scene.

Infotainment

Infotainment usually visualizes information about entertainment, communication, and office-related functions that are not directly related to the vehicle or road situation[4].

2.4.2 Warning Content

Although V2X technology can provide an abundance of information to drivers, designers must ensure that the information is sufficient but not excessive. Overloading drivers with too much information can cause distraction and increase their workload.

Another important rule is to avoid false and nuisance warnings, as they can cause driver distraction, lead to incorrect decisions and responses, and even increase the driver's reaction to true warnings. Nuisance alarms are alarms that convey the correct information but are not what the drivers need or want. The possible reason could be the drivers were already aware of the threats or believed that the threat would be resolved without driver intervention [8].

2.4.3 Timing

The criticality of situations for human drivers can be reduced when advisory warnings are given early. Galich's article [12] clearly shows that advisory warnings can enhance drivers' awareness, leading to earlier braking.

Several statements in the literature claim that the optimal warning time is 2 seconds before the latest possible moment. Therefore, warnings are typically shown to the driver 1-2 seconds before the last possible moment. This timing may maximize driver performance [12].

Generally, it is challenging to establish a universally optimal timing, as it must be tailored to different scenarios and integrated with various warning design factors, such as stimulus intensity, modality and so on.

Other literature explored the different timing requirements for Staged warnings. Ma et al. [7] separated warning into two stages: pre-warning and collision warning. The warning time for these two stages was different. The collision warning was triggered when the Time-To-Collision was less than 3s, while the Pre-warning was sent to the driver when the Time-To-Collision was greater than or equal to 3s and less than 5s.

2.4.4 Visual Warning Colors

Effective use of color can help drivers group and code information, attract their attention more quickly, and facilitate the interpretation of information, particularly for different levels of warning [4]. Cultural aspects should be taken into consideration when designing ergonomic warnings, as different cultures have different understandings of colors.

In a Western cultural context, red is associated with danger, amber or yellow with caution, and green with a problem-free state. Based on these assumptions, red should be used for high-priority warnings that demand immediate action from the driver. Amber or yellow should be used for less critical warnings, and green should indicate incident-free conditions or successfully executed actions, meaning it should not be used for warnings at all [4].

However, using red to display the highest level of danger on the instrument panel might be inappropriate. This is because the instrument cluster typically uses red for other warnings, such as car trouble alerts. In such cases, the high priority of the collision warning might not be perceived correctly, increasing the driver's cognitive load.

Color alone is not enough to convey a warning message; it always needs to cooperate with other kinds of information, such as icons or graphics [4] to correctly convey warning information.

2.4.5 Icon Message and Text Message

Icons are simple, minimalistic graphical representations that symbolize an object, action, situation, status, or idea. The condensed information they present makes them well suited to represent safety-related messages, thereby significantly speeding up drivers' processing steps compared to text-only [4].

In the design of warnings, text labels are often used together with graphic labels to convey warnings to drivers intuitively. Text warnings alone are less effective than graphic warnings or the combination of graphics and text. When using warnings in text form, it is essential to note that the longer the message, the lower the degree of urgency it can convey; the warning message should be within the length of two information units, such as "forward collision," to achieve an early warning effect [8] [4]. Rui et al. [44] article also stated that a short advice message is better than detailed instruction information.

2.4.6 Dynamic and Static Warning

Dynamic and static elements are commonly used in the warning design. Kraft et al. (2020) [14] claim that static symbolic warnings might be better than dynamic warnings. Firstly, a dynamic warning with its continuously changing feature may lead to more glances toward the display and cause distractions for the drivers. Moreover, static symbols can suffice to drive safely when the driver gets used to the system.

Kraft et al. [14] conclude that although dynamic warning can distract the driver to a significant level, it was highly accepted by the participants. It can hardly objectively increase usability or safety but subjectively increase driver's satisfaction. Static versions of warning are not subjectively preferred to the dynamics. With the context of the V2X technology and more information available to drivers, Kraft et al. [14] suggested adopting dynamic warnings to increase drivers' trust in the system.

2.4.7 Audio warning and format

Auditory information is also an important part of warning design. Researchers have shown that for experienced drivers, driving performance is better when the warnings are combined with visual and auditory messages. The possible reason could be that the eye-road time can be reduced when two of these modalities are adopted[10]. Rukonic et al. [9] reported a similar result: voice interaction with a car seems to be a novelty to older drivers.

Audio warnings can also be in various formats. Many studies have found that speech-based warnings are more effective and preferred by drivers. Rukonic et al.[9] conclude after a series of qualitative and quantitative data analyses that speech messages were more effective in conveying warning information than sound-based warnings to drivers. It is found that an auditory collision warning presented as a non-verbal 1,000 Hz tone or a verbal warning ('danger!') reduced crashes following task-induced fatigue. Gerrit Meixner and Christian Müller [13] concluded that natural speech interfaces provide the lowest cognitive load and highest user satisfaction among different modalities.

2.5 Cognitive Ergonomics

Car driving requires seamless interactions of multiple cognitive abilities. Here Situational awareness and cooperative perception are introduced.

2.5.1 Situation Awareness

Cognitive ergonomics emphasizes improving driver awareness by better expressing the system's contemporary state [15]. Drivers need this awareness to identify necessary actions and anticipate future developments based on their current understanding of the situation. Recognizing potential risks and connecting sensory cues is crucial for making informed decisions while driving [16]. Technologies such as advanced visualization tools and heads-up displays help drivers quickly comprehend complex scenarios. Effective human-machine interface (HMI) design improves situational awareness, enabling drivers to make contextually appropriate decisions in dynamic environments, ultimately enhancing performance and safety.

From Endsley's theory [15], situation awareness could be explained as "the perception of the elements in the environment within a volume of space and time, the

comprehension of their meaning, and the projection of their future status'. So it is typically divided into three levels: i) Perception, ii) Comprehension (understanding), iii) Projection. It also consists of various variables, such as individual, task, and environmental factors, that can influence the formation of awareness.

There are also guidelines for guiding the design practice, which is also aligned with the three levels [16].

1. Organize information around the goal.
2. Present level 2 information directly – support comprehension.
3. Provide assistance for projection.

The first guideline indicates that the user interface should convey important information in a way that is easy for drivers to integrate and process. Setting a clear goal and displaying information (e.g. progress) based on it can help users understand quickly. The second point is to simplify the user's comprehensive process and directly point out the prompt information that users can quickly understand based on their past long-term memory storage, consistent with previous research. The third point is to help the projection of the future state by changing assistance information. Another note that needs to be considered in subsequent designs is information overload, which may cause a high workload for the driver and affect SA. An underload that is in a loose state can also negatively affect SA.

2.5.2 Cooperative Perception

Cooperative Perception, which is also known as collective perception. The gathered information can form an understanding of the traffic and road conditions. V2X could enhance this process by gathering more information from other sensors (on infrastructure or other cars) to build the collective perception [12].

3

Methods

This chapter introduces the method used in this project to build a pragmatic design process and solve the problem of when, where, what, and how to deliver the information to drivers. Ultimately achieving the objectives stated in Chapter 1. The project involves an iterative design process, with three iterations following a similar structure. Therefore, the methods are presented here only once as a basic framework, with more detailed adjustments outlined in each iteration chapter.

3.1 Human-centered Design (HCD) Approach

Prioritizing the driver's needs is crucial to creating an effective driver interface for an in-vehicle warning system. Considering the organizational and environmental contexts in which driving tasks are performed, stakeholder involvement is also an essential part of the design [17]. While previous studies have used an HCD-type process for developing driver assistance [18] and driver fatigue warning systems [17], there has not been a specific focus on HMI design for warning e-scooters.

HCD is valued for its iterative nature, meaning the process involves constantly re-understanding needs, adjusting designs, testing and evaluating, and continuing to iterate. Horberry et al.[17] provide a reference framework with nine phases, however, due to time and resource limitations, we will base our project process on "ISO 9241: 210," [19] which outlines four fundamental HCD activities for the system's design: understanding and specifying the context of use, specifying user requirements, producing designs to meet these requirements, and evaluating the designs.

3.2 User Study

User studies are integral to all processes involving communication with users. Especially in the iterative process, interviews will be conducted in all three iterations to gather demographic information and guide free discussions to collect user insights. More specifically, the methods used include semi-structured interviews and KJ-analysis.

3.2.1 Interview

An interview is a qualitative research method used to collect primary data. Through interviews, a wealth of information about warning design and user needs can be obtained. In this project, semi-structured interviews are primarily applied. This method involves collecting data by asking predefined questions, but the questions are not asked in a set order or with fixed phrasing. It differs from structured interviews and open-ended questions, striking a balance between flexibility and ease of management.

3.2.2 KJ-analysis

KJ-analysis, also known as thematic analysis, is a bottom-up method used to analyze qualitative data [20]. This method involves marking common codes from the collected data to identify important themes in the feedback. An affinity map is typically used in this process to highlight, gather, code, and interpret these themes. In this project, both top-down and bottom-up analysis methods were used. Bottom-up analysis involves receiving information from the environment or context and processing it to build an understanding of the situation, while top-down analysis uses previous knowledge to interpret current input. Themes such as important factors influencing HMI design were categorized based on information from benchmarking. For analyzing qualitative data from interviews, the coding process was conducted in a bottom-up manner to identify new design issues.

3.3 Usability Testing

The primary method used for evaluation is usability testing, which generally involves testing the functionality of a prototype as users attempt to complete tasks related to it. In this project, more specifically, formative usability testing was employed.

3.3.1 Formative usability testing

This approach differs from summative usability measurement, which focuses on achieving overall task goals. Formative usability testing aims to identify usability issues and design interventions to improve or refine the system. It is closely related to iterative design practices, where the goal is to identify areas for improvement, make modifications, and then test again [21]. The project utilized empirical methods, including standard formative usability testing without the think-aloud protocol [22]. Although participants could voice their opinions if they felt strongly about something, it was not a mandatory requirement. This is because a questionnaire was provided to gather their comments on each aspect of the usability testing.

Nelsen 5 User Rules

The recruitment for testing followed the 5-user rule, which, as Nielsen stated, can uncover 85% of usability problems in a single test [23]. However, it is important to note that this does not mean five users are sufficient for the entire testing process—a

common misinterpretation. Instead, this rule is typically applied in an iterative design process with multiple rounds, allowing remaining usability issues to be identified in subsequent iterations [21]. Therefore, this project included five to six participants for each iteration, with a total of three iterations planned.

According to Lewis's research, although each iteration of small-sample-size formative usability testing may generate diverse user feedback addressing different aspects of the design, the process still contributes to a hill-climbing trajectory aimed at improving user experience and eventually reaching an optimal experience peak [21]. Additionally, the project limited the required actions for participants to manage task complexity, thereby reducing the influence of extraneous factors, as recommended by Lewis.

Post-task and Post-session Usability Testing

In usability testing, post-task and post-session questionnaires serve distinct purposes and are administered at different times. A post-task questionnaire is given immediately after a participant completes a specific task. Its primary goal is to capture the participant's immediate impressions and reactions to that particular task [24]. This type of questionnaire typically includes questions about the ease or difficulty of the task, any problems encountered, and the participant's satisfaction with their performance. By focusing on individual tasks, post-task questionnaires provide detailed insights into specific elements of the user experience.

On the other hand, a post-session questionnaire is administered after the participant has completed the entire usability testing session, which may include multiple tasks or interactions. The aim is to gather comprehensive feedback on the overall experience [24]. Participants are often asked to rank various aspects of the session, such as different demos or features, from most to least preferred. They may also provide overall ratings of usability, satisfaction, and any other general comments about the session. By asking participants to explain their rankings and choices, post-session questionnaires encourage deeper reflection on the features that influenced their overall experience.

Measuring Usability

As previously described, typical definitions of usability involve measurements of effectiveness, efficiency, and satisfaction (summative) or the identification and resolution of usability problems (formative). Following the Human-Centered Design (HCD) method, the project has created a use description 4.1, which defines how the final objectives should be used and guides the metric setting for questionnaire usage. Inspired by the System Usability Scale (SUS) [25], the project selected the clarity of warnings, ease of awareness of warnings, and satisfaction with the design as the main aspects for measurement. Additional specific questions will be addressed in the Iteration chapter.

3.3.2 Sensitizing

The sensitizing process triggers participants to think, reflect, and explore their personal context. Sensitizing concepts is foundational in qualitative research, offering a flexible starting point for interpretation and understanding complex phenomena. In this project, sensitizing storytelling is used to prepare participants for engaging with the driving simulator and interfaces. Before each session, a story is presented that sets the context of the driving scenario, immersing participants to focus on the safe driving process. This strategic use of sensitizing concepts enhanced the data collection by making the participants more aware of and reflective about their experiences, thereby enriching our insights into the objective.

3.3.3 Experience Prototype

Experience Prototyping creates realistic and immersive scenarios for participants. It allows researchers to build prototypes at any complexity level to imitate key features of the product, either simple or advanced, to evaluate and refine its user experiences. This method is valuable in three key activities within the design and development process: understanding existing user experiences and context, exploring and evaluating design ideas, and communicating ideas to an audience [26]. It enables users to provide feedback based on their interactions with the prototype and facilitates the exploration of new ideas.

In this project, the method is utilized by immersing participants in a simulated driving environment to test various driving interfaces and warning concepts. Initially, the environment was represented on a large screen with the addition of a car seat, a separate screen (instrument cluster), and a steering wheel in later iterations for enhanced realism. Another screen mimics the infotainment system and cluster, and lastly, the large screen also simulates the windshield.

3.4 Prototyping Method

Prototyping method is commonly used through the designer's working process. It equips designers to start from a simple and rough model to a completed functional product.

3.4.1 Video Prototyping

Video prototyping is a broadly employed technique [27] that enhances the design by incorporating scale scenarios, simple mock-ups, etc. Compared to field experiments, it allows for more collaborative and controlled experimentation. Designers can easily develop multiple alternatives and compare, categorize, and refine the concepts.

In this project, the Video prototype is also used to evaluate contextual elements such as different driving situations. Filmed videos offer factual context, which is important in scenario choosing, this has been tested in Rukonić's research [9]. This

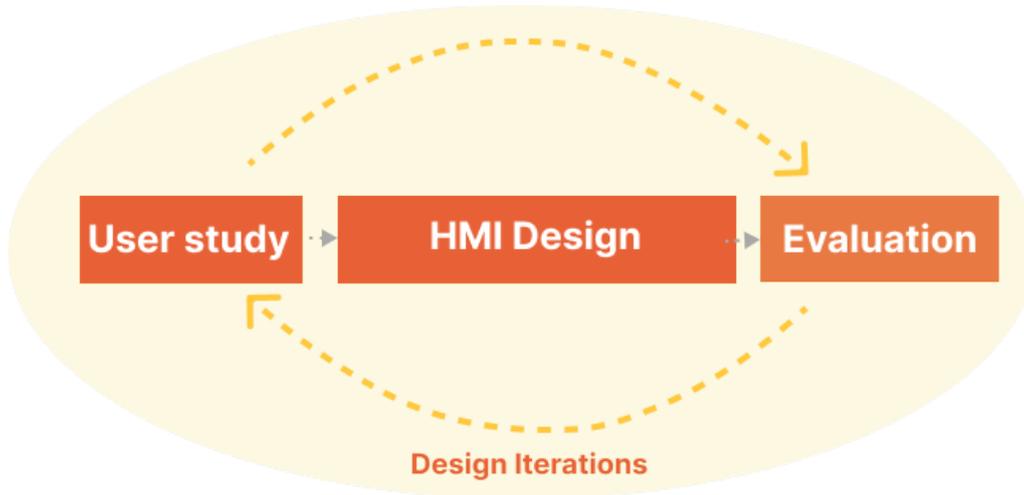


Figure 3.1: Design Iteration Process

method enables designers to ensure that multiple participants experience the exact same material with varying versions of interaction. Animation also allows the designer to facilitate the interaction and easily tweak it when needed.

3.5 Design Iteration & Project Management

Waterfall and Agile methods are used for project management, which keeps the project on track and provides flexibility. The Waterfall model helps determine the main phases: Understanding, Basic Settings, Design iterations, Final solution, and Documentation. Milestone meetings (dividing lines) are set to decide whether the process is sufficient to proceed to the next phase. The whole process is displayed in a Gantt Chart in Figure 3.3 to help the project with time management.

The Agile method is applied throughout the process, particularly in Design Iteration. By following Five User Rules [23](which recommend multiple iterations and at least five participants for each round), iterative HMI solutions are developed based on usability problems identified from feedback. Each iteration includes three main steps, shown in Figure 3.1: user study, HMI Design, and Evaluation. This iterative cycle allows the project to start with a broad scope of concepts and narrow it down after each iteration to arrive at the final demo. A robust framework for developing and refining design solutions can be established by combining these structured stages with iterative cycles.

Project Method

Horberry’s interpretation of the HCD process [17] underscores its iterative nature, beginning with a three-phase understanding stage. This stage involves a literature study, developing a context of use description, and interviewing end-users. These findings are then used to identify user needs and associated design requirements in the next stage. The subsequent stage comprises two design workshops to gather

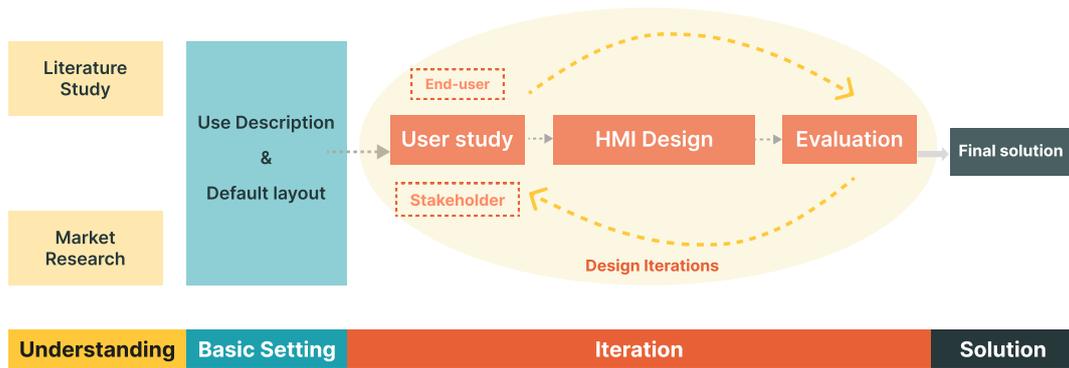


Figure 3.2: Project Human-centered Design Method

stakeholders’ input. The design is then operated, HMI evaluation studies are conducted, and the HMI concepts are finalized. Additionally, Lewis’s research [21] suggests that iterative usability testing alone may not guarantee a sufficiently usable design. Understanding the competitive design landscape is crucial when operating within an existing design space.

Therefore, inspired by the previous research, a unique and tailored Human-centered Design (HCD) was developed specifically for this project. The HCD method, a cornerstone of our approach, encompasses 6 distinct phases: literature study, market research, use description & basic setting, 1st iteration (industry interview with stakeholders), 2nd iteration (end-user), and 3rd iteration (stakeholder and end-user). Each iteration follows an iterative process, as previously outlined, demonstrating the method’s vital role in our project. The method is shown in the Figure 3.2.

A literature review could provide a theoretical foundation and guide the project’s direction, so it is good to conduct it early. Since the project focuses on V2X, which is a topic that has been discussed previously, some existing warning designs might work well. Thus, market research at the beginning could help the project capture the development in this field. Then, after gaining a fundamental understanding of the situation, a basic setting phase will apply to set the default interface used for further design development, choose the scenario for testing, and generate a use description as criteria for testing the questionnaire. When all the understanding and preparation work has been done, three design iterations will be conducted to generate the final solution. Each iteration will involve stakeholders and end-users to generate feedback to guide the design operation and then evaluate the adjustment effectiveness. To have a realistic starting point and shorten the process due to limitations, this HCD method combined interviews with usability testing: 1st iteration will test the existing V2X warning designs mainly with experts in the industry (stakeholders), 2nd iteration will evaluate the end-user, and the third iteration will involve the mix to finalize the concept.

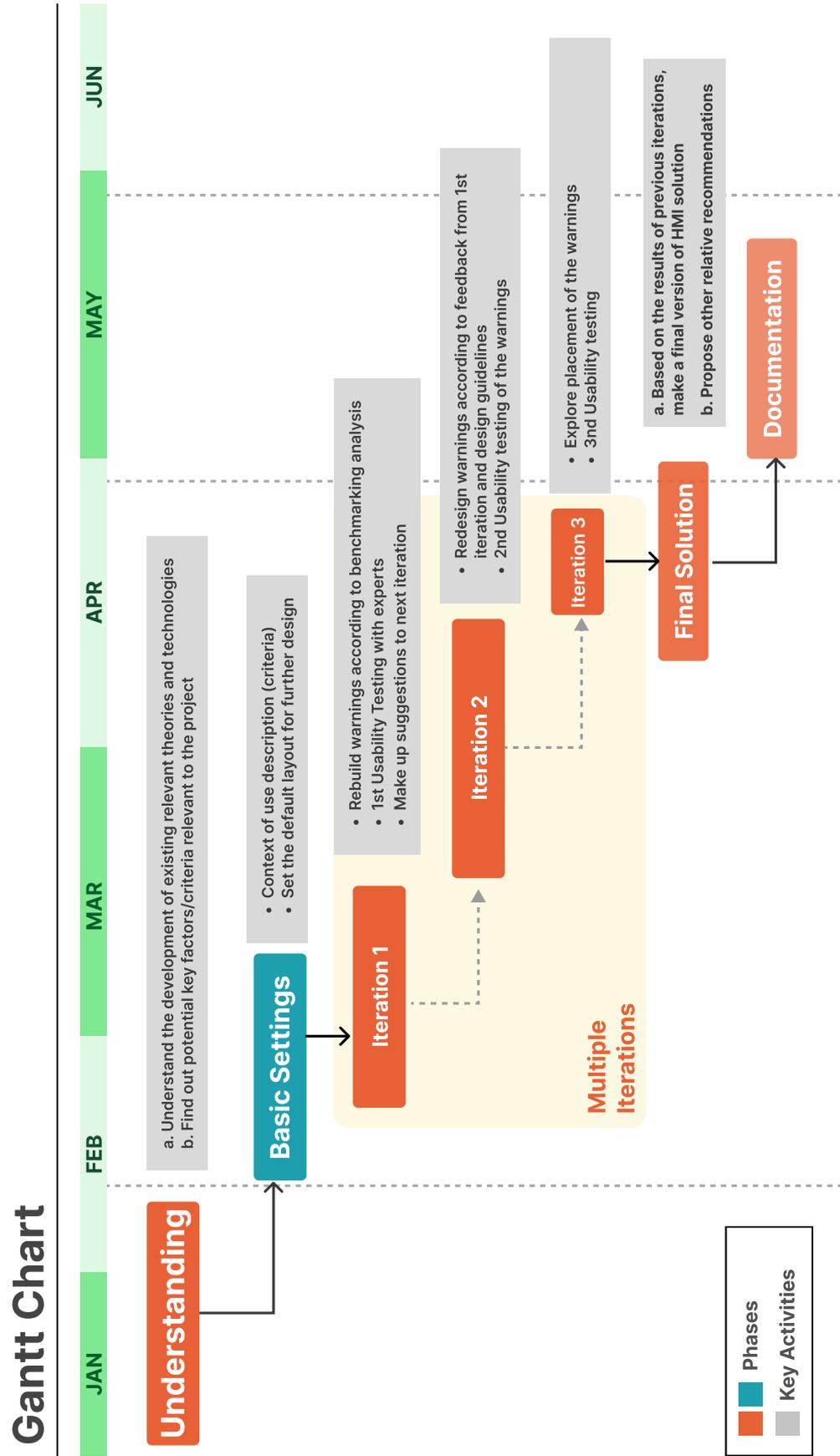


Figure 3.3: Gantt Chart for Project

4

Process

This chapter introduces the project process, presenting an iterative plan and objectives for each phase. It starts by showcasing the iterative plan, which demonstrates the strategic approach to planning phases to achieve the project's goals. Subsequent sections explore the process's design, outlining how ideation, evaluation, and analysis will be conducted to ultimately fulfill the project's aim.

4.1 Overall Plan

The process was initiated with a context study consisting of a literature review and benchmarking. This context study aimed to gain a basic understanding of V2X warning and the collision scenario for cars and e-scooters. Chapter 2 literature study aspired to provide knowledge of related fields, as well as contribute to the research criteria for Use Description 4.1. Benchmarking was instrumental in identifying research problems and exploring the potential of applying other existing warning designs to E-safer's focused testing scenario. The context study was significant in defining the scope and finding criteria/frameworks to guide the project's activity planning. Based on the context study, the project was followed with an iterative design process that was divided into three design iterations, illustrated in Appendix A. Each phase will have an understanding stage that depends on the findings from the previous one. The overall plan figure can be found in the Appendix A.

Context of Use Description - Criteria

From Kraft's research of trust and stress level [14] and Horberry's research [17], the interface design should give a clear warning to inform the driver easily to understand what's happening, and it is able to be aware the driver with the emergent situation. Additionally, drivers are satisfied with the design.

4.2 Literature Inclusion

To understand better the related theories and the cut-edge technology development, a literature review was first conducted. The process is shown in the Figure 4.1.

Google Scholar was chosen as our database. The following keywords were used, "car collision AND HMI AND user", "V2X AND HMI AND Situation Awareness", and "Driver Attention AND intersection AND warning AND human factors", as these

three keywords covered the directions that are related to our project. The literature searches were dynamic as the field of car HMI design integrated with V2X is new and emergent.

According to the order in which the articles appeared in the search, the title and abstract of each document were read in turn. By the end of the literature research stage, a total of 82 articles were included in the selection. The literature was moved to the software Zotero for further reading. Zotera is free and open-source reference management software that can manage bibliographic data and related research materials [28].

After further review of the 82 selected documents, the articles were scored on a scale from one to five based on their relevance to the research topic of the project, with five points indicating the highest relevance and one point indicating the lowest relevance

Finally, 15 pieces of literature were rated for 5 stars, 21 literature with 4 stars and 45 literature with 3 three stars. The most relevant articles rated 5 points were carefully studied and compared, and the articles rated 4 points and 3 points were stored for easy access when needed.

4.3 Market Research

Identifying the current V2X warning designs in the market is crucial as one of the project's initial stages. It can help find the current development frontier of V2X technology in HMI Design and understand the general rules for designing HMI warnings. It can help us target potential areas for changing the warning and collect compulsory information that needs to be shown to drivers.

The process began with general market research and was followed by benchmarking analysis, which aimed to identify current V2X Warning designs and draw concepts from them. Later, the Foundations section sets the default layout of the interfaces the project would use for further design implementation. Meanwhile, a scenario-choosing phase was also conducted to select the video used for the testing scene.

4.4 Scenario Choosing

There are numerous collision situations between bicycles and vehicles at urban intersections, which is a similar scenario for e-scooters and vehicles as well [29]. Due to time constraints, this project will focus on scenarios currently being addressed in the "E-safer" project, specifically the blind spot warning and forward collision warning. Figure 4.2 illustrates these two scenarios: the blind spot warning occurs when an e-scooter approaches from a car's blind spot, and the forward collision warning describes a situation where a car intends to go straight while an e-scooter suddenly turns into the car's path.

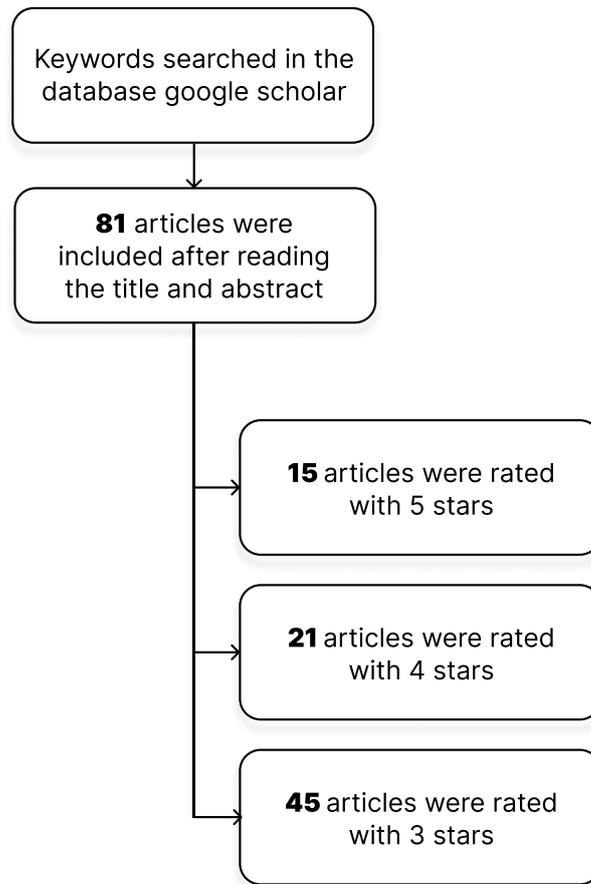


Figure 4.1: The Processes and Results of Literature Inclusion and Rating

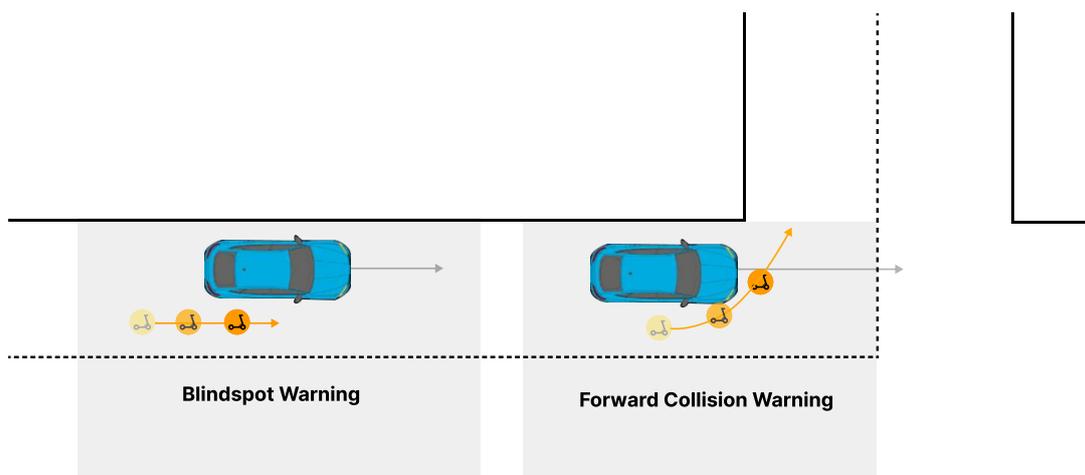


Figure 4.2: Two Scenarios in this Project

To manage the testing, the group decide to use the Dynamic Video Method to build the scenario. Thus, finding driving videos online and clipping the appropriate part from it are being conducted. We have started by searching the driving video in Sweden and clipping some relevant scenarios. Then, the group discussed with the company experts and chose the ideal one as a reference to search for more videos in Europe. Finally, one of the clips from Britain was chosen as the scenario video we would like to work with. Several related scenarios and the final chosen one can be seen in Appendix A, which has a link to the video clip and video reference. More detailed information will be stated in Chapter 6.

4.5 Iterative Design

After the market research and scenario selection, a three-stage iterative design was embarked upon to generate a desired solution for the project objectives. Each iteration was accompanied by a procedure corresponding to the design methodology, including a User Study, HMI Redesign, and Evaluation. The detailed plan was shown in the **Appendix A**.

The first iteration has substituted the user study phase with benchmarking to gain some insights from experts about the current V2X warning designs. Since there are rare data and examples available, the industry interview aims to map out user needs and issues arising from their immersion into the given scenario, which will be used to gain a foundational understanding of the redesign cues in the next iteration. Finding the most fitting design(s) currently available in the market is another purpose that could remain and be applied as a framework for the second iteration. A benchmarking analysis, redesign implementation, and usability testing are planned in this iteration to set the design framework and evaluate the prototypes applied from market research.

The second iteration will explore further with the selected demos from the 1st iteration. In this iteration, participants' feedback and guidelines based on research findings from the literature review were applied to develop new concepts. Through several brainstorming sessions, new concepts are generated regarding the feedback and guidelines to improve the ideas in the first iteration. Concepts are then discussed and regrouped into categories related to the benchmarking analysis in Figure 5.1. Then, each category was finally implemented into a prototype that was shown as a demo video. The remaining ideas from the first iteration are then tested with those new concepts. Six concepts in total were created that aimed to improve the driver's user experience within the scenario. The final concept was formed by combining the highest score demo with well-received elements from each category. And then, it was used in the 3rd iteration to conduct a final evaluation.

The third iteration aimed to focus on identifying the optimal warning placement by conducting randomized position usability tests. Additionally, the secondary goal was to conclude and generate design guidelines for future V2X warning design. The process includes testing all three positions with the concept from the second iteration result and evaluation from physical and cognitive ergonomics expectations. Then

after that, the final overall best warning design and guideline of placement has been concluded.

4.6 Final Solution and Design Suggestion

Finally, after the three iterations, the final solution will be concluded by combining the third iteration result with the demo used for testing, which has a multi-modality prototype and specific placement.

Meanwhile, design suggestions are generated as a guideline according to the results of each iteration and theory verification. The guideline is developed following the framework set during the first iteration and updated based on the findings during testing, which contains a staged warning strategy, modalities, and elements. The suggestion involves the project scenario's best practice, findings that align or contrast with theory, and more specific indications for the scenario situation.

5

Market Research & Foundations

This chapter introduces market research about V2X warning designs, including general market research to find resources and benchmarking analysis to identify concepts. Then, in the Foundations section, it builds the default interface and chooses the scenario for the following iterative process.

5.1 Market Research

Market research involves understanding the context of the project's target group. It is typically divided into primary research and secondary research [33]. In this project, secondary research was primarily used by researchers to evaluate the current V2X warning designs and gather market information to support further redesign efforts.

5.1.1 Market Research

Identify Existing Designs

General market research has been conducted to gain insights into how other companies in the mobility industry have solved similar problems and the recent trend of applying this technology since Vehicle-to-Everything was not a new topic.

A keyword browsing method was used to start with identifying the current designs. As mentioned before, there have been very limited studies or data about e-scooter accidents [3], and so have specific studies about related warnings on cars. As the E-scooters are classified as bicycles in Sweden and e-scooter riders are subject to the same rules as cyclists [1], the project would also search the warnings for cyclists or related collision warnings as part of the benchmarking. The keywords were: "V2X warning", "cyclist warning," and "e-scooter collision warning" and were searched for on both Google and YouTube.

Design Profiles

Finally, several V2X warning designs are identified, including BMW, Audi, Samsung and Bosch, etc. The relevant information is collected from their official websites, videos for concepts, and the manual book, which is shown in Table 5.1 below. Then, the features of their solutions were documented and categorized by functionality, type of information, modality, and design specifications. The result was shown in the 1st iteration and was analyzed as a base for the following design and test phase.

Table 5.1: Existing V2X warning designs List

Company	Solution	Additional Info
Samsung	CES2020: 5G and V2X (Vehicle-to-Everything)	https://www.youtube.com/watch?v=-feixG1u178
Applied Information Inc & Qualcomm	C-V2X Alerts Powered by AI & Qualcomm	https://www.youtube.com/watch?v=UByB50HD00o
ASTRI	Demonstration on Internet of Vehicles (C-V2X) technology	https://www.youtube.com/watch?v=IsCVSK5DVEw
Commsignia Qualcomm	C-V2X CES 2023	https://www.youtube.com/watch?v=LpVo9KPZ3Fc
Commsignia with support from Volkswagen, Bosch and Autotalks	Cooperation to pilot eBike safety improvements with V2X	https://www.youtube.com/watch?v=I84V6S830TM
BMW	Live Demonstration C-V2X: BMW i3 Urban Suite im autonomen Einsatz	https://www.youtube.com/watch?v=t7wRxq-0wbY
Audi	C-V2X technology demonstration	https://media.audiusa.com/en-us/releases/550#gallery
Volkswagen	Car2X in the new Golf: A “technological milestone”	https://www.volkswagen-newsroom.com/en

5.1.2 Benchmarking Analysis

Benchmarking started with concluding the concept from solution videos. After extracting relevant elements from each concept and categorizing them into different groups, all concepts were differentiated from each other for testing. Analysis was conducted to categorize the elements and build a framework for future warning design.

The analysis was conducted with a depth that yielded comprehensive findings covering various aspects. These elements were identified based on an extensive literature study, from a high level to a detailed bottom level, as depicted in Figure 5.1. The analysis delved into the nature of the concept, whether it is a staged warning that has a changing effect due to situation severity or just the sample single warning. It also considered the modality factor, for instance, whether it is a multi-modality warning or a single-modality one. Usually, it could have “visual” and “visual with audio.” The timing was also counted based on the video’s editing software.

Then, the concept could break down into different modalities, for example, at the audio level, whether it is a voice or sound warning, and if the sounds are changed or directional due to the situation; at the visual level, how the changing effect of the warning showing the difference. The final part is the content level, which type of information is displayed (e.g., direction, trajectory, distance), in which way (graphic or text) it was delivered, and whether the content is static or dynamic. A more structural framework will be given in the section 6.1.

Differentiate Various Concepts

Each solution has its own visual and audio feature for developing the V2X warning that could remind the driver from an early stage but not cause any distractions [8]. After collecting enough information, differentiated elements are mapped out and used to generate the HMI concepts for 1st iteration testing. The analysis’s findings are below.

It is interesting to find most of the solutions have used a staged warning strategy for V2X warning; only ASTRI had a simple one-stage warning but had an animation to indicate what’s happened. Besides, Applied Information Inc. & Qualcomm, Volkswagen, Audi, Samsung, and Commsignia all used color changes to indicate different severity. Audi used the colors yellow and orange; others used yellow and red; Volkswagen and Commsignia also have some decoration elements to distinguish the notification, for example, a bottom border or a shining ambiance light. BMW’s concept doesn’t have a color chain but has a shining ring instead. When it came to the content level, the icon and text usage would be considered. As the warning might be dynamic, elements “Direction and Trajectory” are identified as the same group [34], followed by distance information and icon type.

AI & Qualcomm use warning sign and “vehicle” text, Volkswagen used risk sign and longer text to indicate type of risk, they didn’t show any direction or trajectory for the further information ; ASTRI used a car animation instead of static text which is

	A	B	C	D	E	F	G
	Applied Information & Outcom	Volkswagen	ASTRI 香港應用科技研究院	Audi	Samsung CES2020	Bosch,continental, autodrive, Volkswagen	BMW i3 Urban Suite
Criticality	Y	Y	N	Y	Y	Y	Y
Periodic Changes	Color	Icon+color	Animation	Color	Color	Color and zoom in, full screen shining	Shining
Trajectory/ Distance	N	N	N	Y, no distance	Y	Y, real-time position	Y, real-time position
Icon type	Warning sign	Sign, text	text + warning sign + car	Bike sign + Arrow	Warning sign + risk trajectory	E-bike sign + Route	Pedestrian sign
Direction	N	N	Y	Y	Y	Y	Y
Timing/once	2+ 2 =4s	4s	5 + 3s	3+ 2 s	3+ 2 s	3+ 3 =6s	7s
Modality	V	V	V+A	V+A(bling)	V	V+A (bling twice, repeat)	V

Figure 5.1: Concepts Features

clear to show the direction and lively inform the driver what's going on, but might require a longer time for reading the how animation; Audi used a "vehicle icon" to show the risk vehicle and graphic to inform driver about the direction or the future trajectory, however, it is not a real-time relative position; Samsung used a similar icon with Volkswargen's concept, but have a red zone on map to indicate the trajectory and have text to show distance; Bosch and commsignia have used an ADAS map to display the situation, and have used the vehicle icon indicating the trajectory, criticality, distance and direction, which is a real time position; Last one was BMW's concept, it used a pedestrian icon to show the warning with a color blue and green. It also showed the real-time position but used a blinking ring to represent the severity.

As highlighted, the existing warning designs have interpreted the situation differently, but most have used a proactive notification strategy [12], which is the biggest strength of V2X technology as it can alert drivers earlier. However, as mentioned in the article [8], proactive notifications can capture drivers' attention earlier but may also distract them in certain ways. Therefore, all these solutions need to be tested to determine which type of information is most important for safe driving, especially in situations involving e-scooters.

5.2 Foundations

The foundation section is aimed to clarify the basic settings that used for the testing and design. It involved the information displayed on the default layout, which will remain the same in all testing demo, and the scenario video used for immerse participants.

5.2.1 Default Layout

After discovering existing V2X warning designs, the next step was to set the interface's layout for further demo development.

Screens and Layout

The project started by choosing the instrument cluster as the screen to test the warning since it is mostly used, especially since not all cars have a head-up display, and solutions found in the benchmarking mostly used clusters as their displaying screen Table 5.1. Although there are several pieces of literature [8][12][14] mentioned that the Head-up Display is the best position to show the warning. Since currently, HUD isn't commonly equipped for most cars, the project decided to continue with the instrument cluster for warning to gain a more general result and finally test the placement in the 3rd Iteration.

The company primarily has customers from mobility industry. [31], So, the project's objective is to design a warning that fits both electric and petrol car displays, and the basic layout should be carefully chosen as the testing framework.

As Volvo is one of Sweden's representative customers for the company, the project group decided to use Volvo's map display and layout. The project will modify the instrument clusters refer to the instrument cluster (driver display) on Polestar 2 and Volvo XC to avoid infringement and establish the project's own basic layout. Choosing these two series of cars as the model is because they are the most selling cars in Sweden during 2023 in their own brand [32]. The layout will follow the dimensions of the Polestar 2 [35], which uses a 12 ' 3-inch driver display that has an 8:3 ratio. However, although Volvo XC used a 12-inch driver display [36][39] which is stated on the official website, from the Volvo accessory website [41] it seems it also had the option to upgrade to a 12'3 inch display from 8 inches one, therefore, the information displayed on the official website may be an abbreviation. So the project will continue with a 1920x720 (8:3) pixels dimension as the default layout. Specific interface could be found here [42][40][43].

Compulsory Information

Since the information displayed is rigorously regulated, the research started by finding the requirement of showing compulsory information. From Kraft's research [14], there are several pieces of information that should show on the cluster to reflect the car's performance, which could be either static or dynamic. Static information typically includes the power gauge, speed limit, and drive mode (parking, reverse, neutral, drive). Dynamic information consists of a speedometer and warning lights.

Warning lights, also known as indicator lights in the instrument cluster, demonstrate the operation of a function or show errors [47]. Their color indicates the priority of the warning. Red means an error that requires immediate action, while yellow means that the journey can be continued, but a safety function may be out of operation [37]. There is also an orange which means slow down. Automobile safety standards worldwide regulate indicator lights. In Europe, ECE Regulations [48] and the "United Nations (UN) Vehicle Regulations—1958 Agreement" have been applied. Our basic layout will also follow these rules. It is also good to compare the location and information shown on both instrument clusters of Polestar 2 and Volvo XC, shown in the Table 5.2 and the Table 5.3.

Table 5.2: Polestar 2 Driver Display Manual [49]

Polestar 2		
On the Left	In the Middle	On the Right
Indicator and warning symbols	Temperature	Indicator and warning symbols
Speedometer	Messages, in some cases with graphics	Battery meter
Driving direction selected	Door and seatbelt information	Power meter
Cruise control and speed limiter information	Driver support functions	Trip meter
Odometer		Distance to empty battery
		App menu

Table 5.3: Volvo XC60 Driver Display Support [50]

Volvo XC(60)		
On the Left	In the Middle	On the Right
Indicator and warning symbols	Indicator and warning symbols	Indicator and warning symbols
Speedometer	Temperature	Tachometer
Cruise control and speed limiter information	Messages, in some cases with graphics	Drive mode
Trip meter	Door and seatbelt information	Driving direction selected
	Driver support functions	Regenerative braking
	App menu	Fuel guage

5.2.2 Default Interface

After preliminary research, two versions of the basic layout were designed, mainly to lay out and design the information mentioned above. After discussion, the project chose the flat map navigation version and chose dark colors based on the Volvo interface design model and to further simplify the information. Finally, the basic information layout of the test interface is shown in the Figure 5.2.

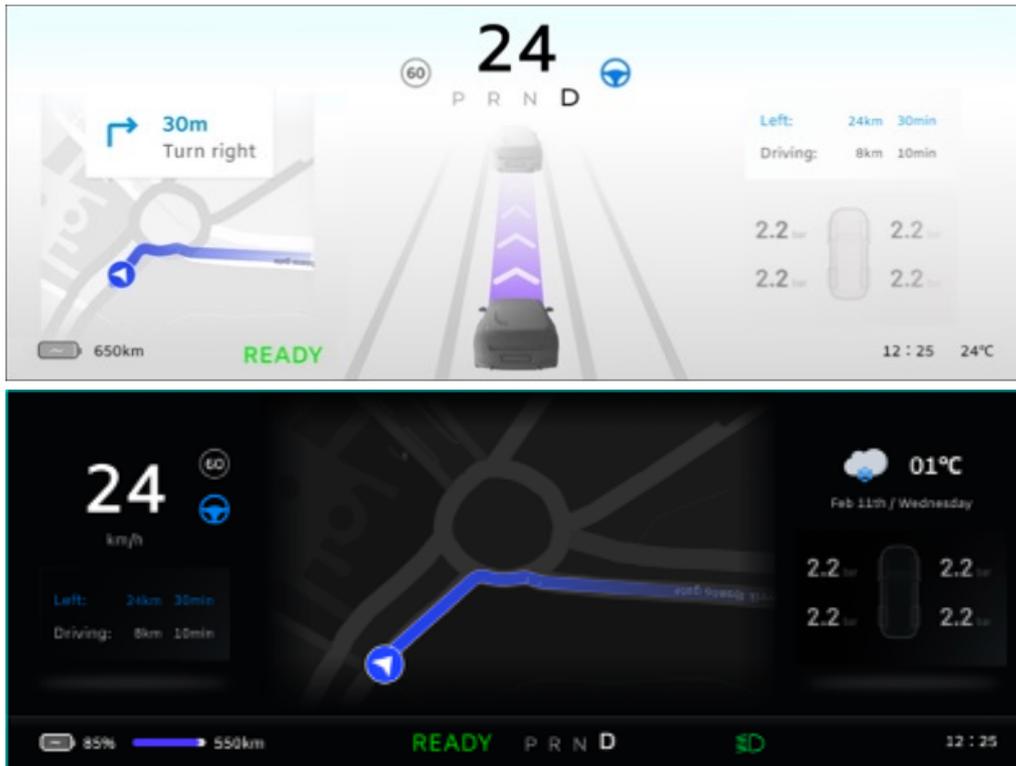


Figure 5.2: Two Versions of the Layout

The left shows the speed meter and the power gauge, displayed with the available driving distance. A 2-Demisenion map is shown in the middle, which has the navigation route and the arrow representing the vehicle itself. On the right side is the drive mode and navigation planning information.

The new layouts have been modified in several aspects, shown in the Figure 5.3. Firstly, unnecessary information will be hidden, and weather information and tier conditions will not show on the default layout. A bottom bar was also added to divide the information more specifically, which helps drivers more easily focus on the relevant information. Secondly, the indicator lights have been moved to the middle of the bottom bar, and the drive mode moved to the right side and has a bigger size that would be clearer for drivers. Here is the final manual of the default layout for testing interfaces.

Besides, the color of the default interfaces has been changed. As our study primarily worked with the navigation mode to give warnings while driving, Volvo has used a

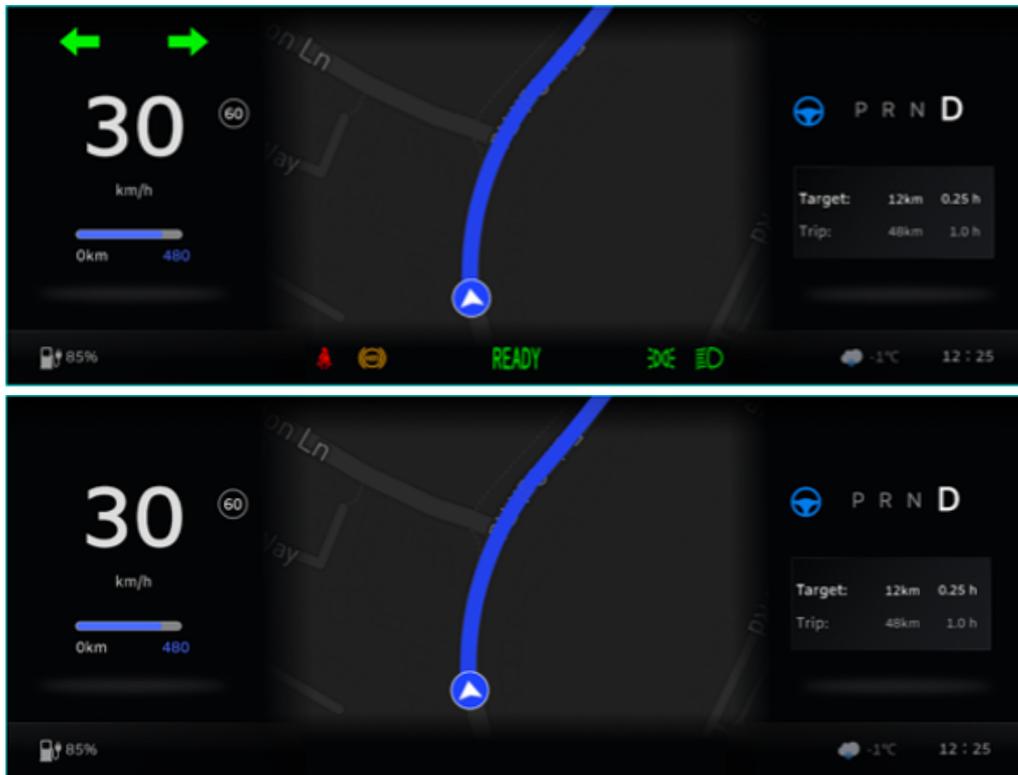


Figure 5.3: Modified Layouts (unnecessary information has been removed)

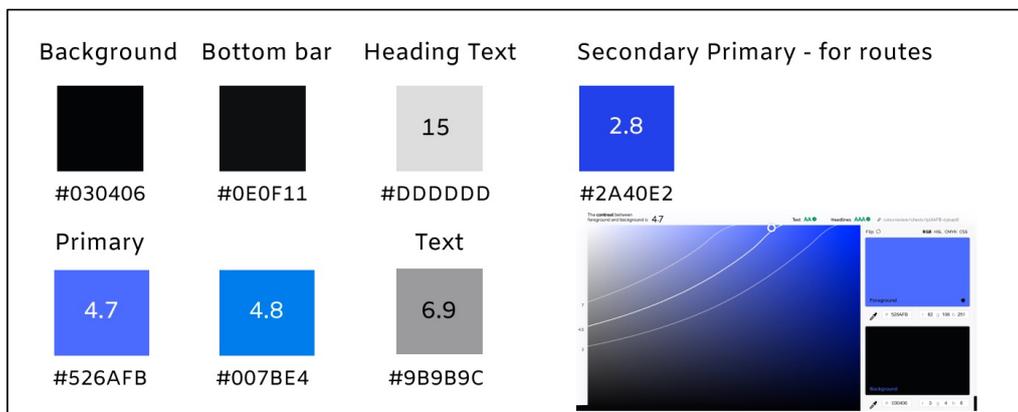


Figure 5.4: Color Usage of the interface

Google built-in for their car play [51]. Google Automotive OS [52] recommended that the contrast ratio between text and base image be at least 4.5:1. And basing interface colors on black mode could lead to a more consistent user experience, with no drastic change between day and night themes. So, the primary color is modified to fit these requirements, detailed information is showed in the Figure 5.4. But to highlight the important information, the guideline also mentioned using a secondary color or dark variants of your primary colors [53]. So, the highlighted text will still use quite a bright color. Last but not least, the route that has a gradient color will start with a high-brightness color and end with the primary color that is 100% transparent. Since it is only used slightly, the route will not make the driver feel much visual fatigue.

Here is the table about the layout information in Table 5.4.

Table 5.4: Default Layout Information

Default Layout		
On the Left	In the Middle	On the Right
Indicator and warning symbols	Indicator and warning symbols	Indicator and warning symbols
Speedometer	Messages, in some cases with graphics	Driving direction selected
Cruise control and speed limiter information	Driver support functions (navigation)	Drive mode
Distance to empty power		Trip meter
Bottom Bar		
Power meter	Driver support functions	Temperature
	Door and seatbelt information	

5.2.3 Scenario Choosing

Continuing with the statement from Chapter Process, the project has used the Dynamic Video method to simulate the driving situation for testing. While playing a scene video, an interactive interface for warnings will be added to the driving scene through video editing software to show it simultaneously as the video. The project completed several rounds of screening video clips to select the best possible scenarios.

In the first round, the group selected Nordic countries and e-scooters as keywords for search. Because of their geographical closeness, the driving habits and people's driving behavior in these countries are similar, which could broaden our scope of source searching. Eight related first-person driving clips were found on YouTube, including typical scenes of V2X: an e-scooter appears from a blind spot and comes

across the road; two e-scooters are driving in the opposite direction of the car but are blocked by a turning bus, then they suddenly appeared; the e-scooter overtook the car from behind and was overtaken again; the car approached the e-scooter, and then the electric scooter suddenly turned. The group, together with the company's expert, have selected three scenarios as fundamental references for the second round of screening. At the same time, a preliminary demo template design was completed for three videos to verify whether their functions meet the testing requirements.

In the second round, we expanded the scope to first-person driving videos across Europe. Then, we conducted further research on the keywords "e-scooter collision," "risk e-scooter," "e-scooter bad drive," and "why I hate e-scooter" video search and scene filtering.

The ideal scenario provided by the project can be described as "a scooter come from behind that overtakes the car and goes straight; the car overtakes back later and intends to turn right, so the driver needs to know the scooter's position." We filter based on this when retrieving videos. In the second round of searches, a newly discovered scene was in the UK where an E-scooter came from behind and cut into the route to take a turn, but the car still went straight. And a conflict scene in Gothenburg where a car turns right and an e-scooter turns right simultaneously. The UK scenario perfectly reflects the company's needs, but the drawback is that they drive on the left and are inconsistent with Swedish driving habits. Fortunately, left-hand drive is legal in the UK [46], and the car in the video is left-hand drive so it can be entirely consistent with the usage habits of our testers. Since the scene is relatively short and there are only two approaching cars (otherwise, it can be considered a one-way road), we think this scene was the best choice at that time. Meanwhile, further searches are conducted based on this scenario to complete the final third round of screening.

The third round found eight more scenes: one in Belgium, where an e-scooter suddenly ran a red light; two in Stockholm, together with one in Madrid, where the car followed the e-scooter and overtook to turn; two in Rome, where the e-scooter suddenly appeared on the road; and another two that met the e-scooter at the intersection in Switzerland. However, except for the scene in Belgium, which has a sudden awakening, the definition needs to be higher and meet the usage requirements. Other scenes have bicycle lanes, slow-moving signs, or sufficient distance and vision to ensure safe driving, which does not meet the project's scene requirements. In the end, although the British driving scene has the disadvantage of driving on the left, we still decided to develop the design based on this scene. All the related videos are shown in the Appendix A Video Resource.

6

1st Iteration

The 1st iteration seeks to gain insight into current V2X warning designs from the expert(stakeholder) perspective and information about the user needs. The process begins with the phase of concluding a framework from solutions in benchmarking to categorized interface information. Followed by the redesigning of high-fidelity warning interfaces that are used for testing the demo. Finally, the first iteration of usability testing is conducted, and the result will be analyzed.

More specifically, to assess user experience with existing warning designs and understand users' habits and motivations regarding different elements, the project first categorized solutions into three groups (static warning, staged static warning, and stated dynamic warning) with seven total concepts 7.2. Following this, concepts were broken down due to a framework that could interpret all elements 6.1. Based on the breaking down feature system, the warning design for testing demos is generated with the same features as the original solution. After conducting tests and analyzing results, the project identified which elements in the framework should be retained, which performed poorly, and which should be discarded. Finally, the selected concept and the updated framework will be used in the second iteration.

6.1 Concept Redesign

Seven concepts were concluded from the benchmarking analysis. To implement the concept with our default layouts, a framework was made (Figure 6.1) based on the elements categorization in benchmarking and literature review about staged warning [8][7] and information displayed on cluster [10].

6.1.1 The Framework

From all the results of the benchmarking analysis, the group has concluded which type of information could be delivered to the driver: criticality (severity), trajectory, distance, direction, warning sign, and vehicle type. Each piece of information will use one or multiple methods to deliver. How the warning is offered during the process will also be different since the same information could have various expressions or motion effects. To be mentioned the staged warning means multiple stages in one warning; use Commingsigni's solution as a case (Figure 6.3): it will be a yellow "remind" level warning when the bike is still far away. The bike will change to the more critical red "warn" warning when it approaches.

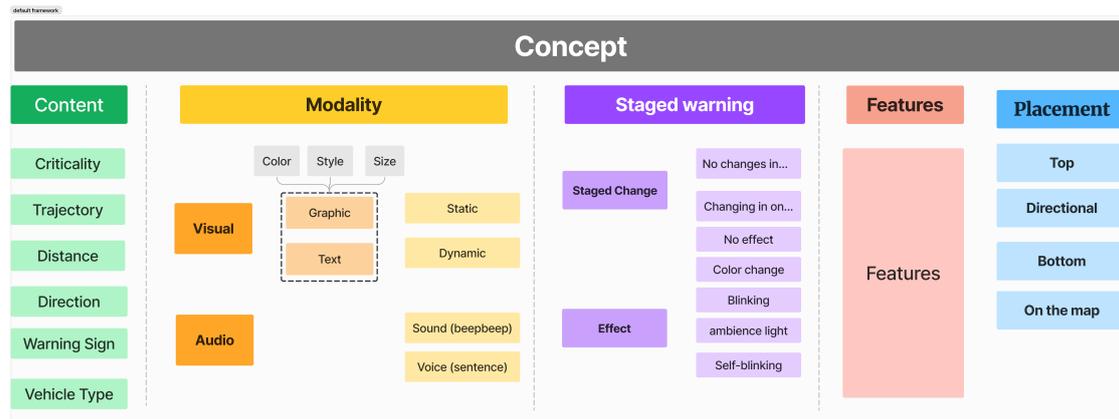


Figure 6.1: Framework of Warning Design

Then, each chain will result in a feature of the warning. All features shown on the set placement will finally combine into a warning concept. The reason for establishing this framework is that the concepts concluded from benchmarking have diverse layouts and are used on different devices. Since keeping all the factors the same is challenging, it is a straightforward way to break down the solution to the information level and assemble it as originally as possible. Here is an example (Figure 6.2) of how the features of a concept are defined:

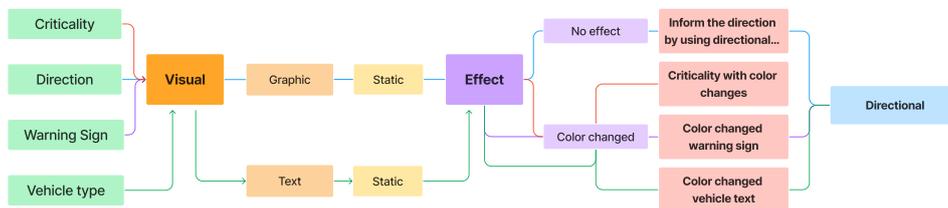


Figure 6.2: Features Chain for Demo A

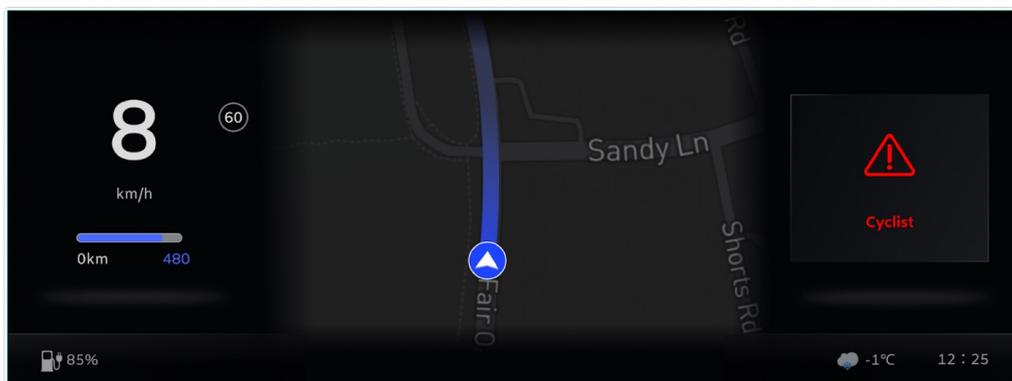


Figure 6.3: Features Chain for Demo A

The warning shows a warning sign and a text indicating the vehicle type of the risk.

It shows on the right side in the same direction from which the risk comes. It has no audio but uses a color change effect to represent the criticality. This concept was interpreted from the Applied Information Inc & Qualcomm solution. Using this framework, all existing concepts from benchmarking could be interpreted and then implemented with the same type of features into the default layout.

6.1.2 High-fidelity Design

Based on the framework, here are all the final concepts that were interpreted from benchmarking Table 5.1 and applied in our default layout, which is showed in the Figure 6.4. Demo B refers to Volkswagen solution; Demo C refers to ASTRI; Demo D refers to Audi; Demo E refers to Samsung; Demo F refers to Bosch, Commsignia, Autotalks, and Volkswagen solution; Demo G refers to BMW. Most of the demos are quite aligned with the original solutions; however, since Demo F was shown in an ADAS mode, the features are applied to a flat map view to fit with the default layout, which is not highly consistent with the original solution. This could be discussed further in the Chapter Discussion.



Figure 6.4: All Demos of the 1st Iteration, detailed in Appendix C

6.1.3 Demos Making

All demos are implemented with a layout that has scenarios on the top and HMI information at the bottom. The scenario video is 33 seconds. The timing “22s when the e-scooter appears from the scene”, “26.5s when the e-scooterist shows a pronounced tendency to turn”, and “29.5s when the e-scooter is most likely to collide” are identified as the study’s crucial time points. The first scene is set so the warning disappears at 23s, one second after it appears. The warning of the second scene is also set to disappear at 30.5s. Based on these two points, a warning in the demo video is set according to the timing of different solutions in the benchmarking.

The software used in this iteration were Figma, Protopie, and Adobe AfterEffects to modify the demo video and animation of the interactive prototype. A transition animation to help the participants get prepared for is also added in each demo.

6.2 1st Usability Testing

To detect user needs and null current V2X warning designs, each warning concept concluded from benchmarking is going to be tested with users. Concepts consist of different stages, modalities, design, and timing elements; the criteria to evaluate would be the overall user experience, which is stated in Chapter Methodology. Following the procedure of usability testing [24], a series of participatory activities were planned to ask participants for feedback, report issues, and suggest design improvements.

6.2.1 Recruitment

Five participants were recruited for the usability testing workshop. They held diverse roles in the Research department, such as assistant, patent administrator, research engineer, and director. The group's demographic was balanced, with two females and three males aged 33 to 57. All of them had more than 6 years of driving experience and drove every day.

Overall, all the participants had a natural attitude toward their interactions with e-scooters. Only one participant reported that she had once experienced a risk of incident against e-scooters. The possible reason is that the e-scooter is much faster than pedestrians and bikes, as the answer stated.

6.2.2 Configuration

In this iteration, testing was conducted using a computer screen to display both scenarios and interfaces. The screen was connected to a laptop via an HDMI cable as an extended screen, where the demo (a combined video showcasing the scenario and interface) was played. Another laptop was provided for participants to grade their experience and type their feedback. Based on insights from the pilot study, headphones were added to help participants immerse themselves more easily into the situation. The setting is showed in the Figure 6.5.

There were three roles in the project usability testing: participant, moderator, and facilitator. The moderator was responsible for informing the participants about the context and offering necessary guidance at each step. The presence of a moderator helped avoid bias and ensured participants felt comfortable during the test. The facilitator primarily set up the testing scenario and observed the participants during the test. They also interpreted participants' actions and statements during discussions, encouraging them to provide further feedback.

This role change was inspired by Sanders' research [38] on the evolving roles of designers in the co-creation process. However, it was impractical to have all partic-

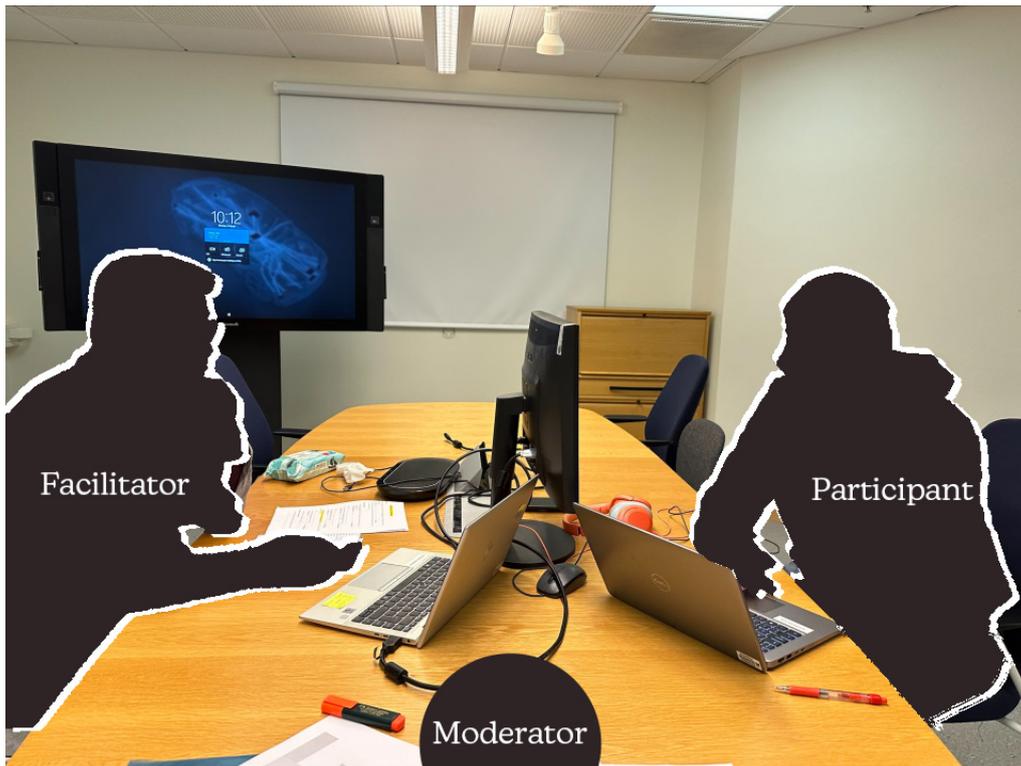


Figure 6.5: 1st Iteration Testing Configuration

Participants watch every demo and collaborate in generating ideas together. Instead, the questionnaire asked participants to provide ideas for improvements for each demo and included a free discussion section after the questionnaire to gather their opinions and expectations about the warnings.

6.2.3 Process

The usability testing was divided into three phases: Pre-testing, Testing, and post-testing, which was based on a typical usability testing procedure [24].

Pre-testing

In the pre-testing phase, the moderator concisely introduced the project's theme, aim, and the stage of this usability testing process. A slide presentation was shown on the extended screen for participants to follow along. Regarding GDPR regulations, since all participants were internal, the only requirement was to confirm that the project would not publish their personal information. If a persona was needed, a virtual one would be used as a representation. After the introduction, participants completed a basic information survey while the facilitator set up the demo.

Next, the moderator introduced the experiment settings in the Figure 6.6, including the layout of the demo and the equipment, to help them get familiar with the experiment settings. Then, the participants were informed about how many demos they would test, and the testing processes include watching demos and answering

after-demo & after-session questionnaires.

To help participants better immerse themselves in the car driving, the moderator described a scene and asked participants to imagine themselves in it. The following is the scene described by the host:

“Now, imagine you are driving back home from grocery shopping on a sunny Sunday. Picture yourself as a driver behind the wheel, observing the view through the windshield along with a dashboard that displays essential driving information.”

Testing

This phase can also be explained as the Post-demo testing [24] in this project. There were 7 formal rounds of testing in total, corresponding to 7 demos. The scenarios were all the same in the formal rounds. More specifically, 3 of them have audio sounds, and the other only have visual elements. After viewing each demo, participants were asked to complete a questionnaire about their experiences with warnings.

Post-testing

After the participants viewed all seven warning design demos, they were asked to sort the seven demos based on how much they liked them. The moderator would ask about the reason for the sorting and other related questions due to their feedback. The participant was encouraged to give any other suggestions and comments after the questions.



Figure 6.6: Sorting and Layout of the Demo

6.2.4 Questionnaire

Post-demo

After viewing each demo, participants were asked to complete the post-demo questionnaire. The questionnaire consisted of Likert 7-point questions and open-ended questions. The open-ended questions were follow-up questionnaires about the reason they rated on the 7-point Likert questionnaires, in which they could talk about

any thoughts they have on the demo but not need to specify all the aspects related to it, for instance, "Why do you like the audio of this demo?".

The post-demo questionnaire questions covered the overall ease of use and experience, satisfaction with design elements, timing, and auditory information of the warning design. If there isn't audio in the demo, the question would be, "to what extent do you think adding audio would be better?" The full questionnaire is in the Appendix D.

Post-session

After experiencing all the demos, the participants were asked to sort the 7 demos from the most and the least favorite based on their overall experience and given a reason for their choosing. Then, participants need to grade the importance of elements, which include timing, appearance, form of risk information, auditory warning, effects, trajectory, and others.

6.3 Result and Analysis

This section discusses the results of first iteration testing. Both qualitative and quantitative analysis are involved for two questionnaires.

For the 7-point Likert scale questions and sorting questions, primarily quantitative analysis was employed. As stated in the Chapter Methodology, the average score is commonly used across many fields, with the median serving as a good alternative if the average score is unavailable [21]. Since these two measurements can reflect tendencies, the quantitative analysis calculated both for thorough analysis. Additionally, a top-box scoring method was also utilized in the analysis [24].

For qualitative data, KJ-analysis was used, and an affinity diagram was drawn so that Participants' insights and feedback for each demo were concluded. The codes or common opinions that concluded from the result would be used for analysis.

6.3.1 Post-demo

Participants were asked to complete the post-demo questionnaire immediately after experiencing each demo when they had first impressions. This post-demo analysis focused more on specific features, such as participants' comments on specific design elements, if they get confused about some features.

Quantitative Analysis

The Single Ease Question (SEQ) is a usability metric used in user experience research. It's a 7-point rating scale that assesses how difficult users find a task after attempting it in a usability test. The complete results are displayed in the Appendix E. Below is an example of the SEQ question showed in the Figure 6.7.

Overall clearness								
	01	02	03	04	05	median	mean	Top 2
Demo A	4	4	4	5	4	4	4.2	0
Demo B	3	5	6	6	5	5	5.0	2
Demo C	5	7	7	7	7	7	6.6	4
Demo D	6	6	7	7	6	6	6.4	5
Demo E	5	3	6	2	1	3	3.4	1
Demo F	4	4	7	5	4	4	4.8	1
Demo G	5	1	6	2	5	5	3.8	1

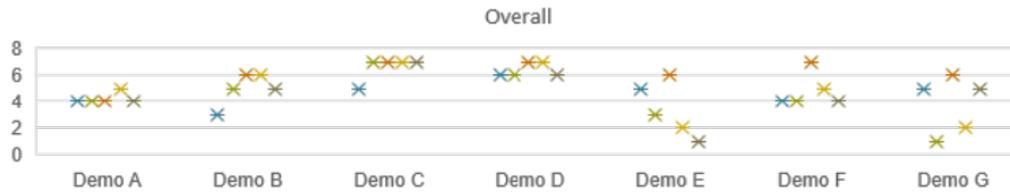


Figure 6.7: Post-demo: Overall Results

From the analysis, it can be concluded that Demo D received the best scores in both the top two box metrics as well as the mean and median measurements. Demo C secured second place and received the highest number of grade 7 ratings. These two demos have grading gaps of 1.6 and 1.4, respectively, compared to the third-place Demo B, indicating a significant difference that makes them superior to the other demos.

The distribution map reveals an interesting phenomenon: in the subsequent scoring of design, placement, and timing, both Demo C and Demo D received the highest scores. Although the overall scores of Demos B and F are close, B's scores for design and timing are notably lower. Demos F and A received relatively stable scores, ranking in the middle. Demo G received the worst scores in the three subcategories, but still scored higher than E in overall clarity. Considering E's highly scattered scores, certain aspects of user feedback may require closer attention.

Qualitative Analysis

KJ-analysis is used for qualitative analysis. For each demo, an affinity diagram was drawn, which is showed in the Figure 6.8. The whole detailed feedbacks are documented in the Appendix E.

Since **Demo D** and **Demo C** received the best scores, the qualitative analysis will focus on these two concepts as examples, below showed Demo D's affinity diagram in the Figure 6.9. It is important to note that the fill-in questions in the post-demo questionnaire were not mandatory, so some participants did not leave any comments. However, in the post-session questionnaire, all participants were required to provide their reasons.

From the detailed KJ analysis as the table shows, participant feedback was classified according to modality into overall clarity, visual, and audio. It is further divided into different elements according to the content, such as direction, trajectory, effect,



Figure 6.8: Post-demo KJ-analysis.

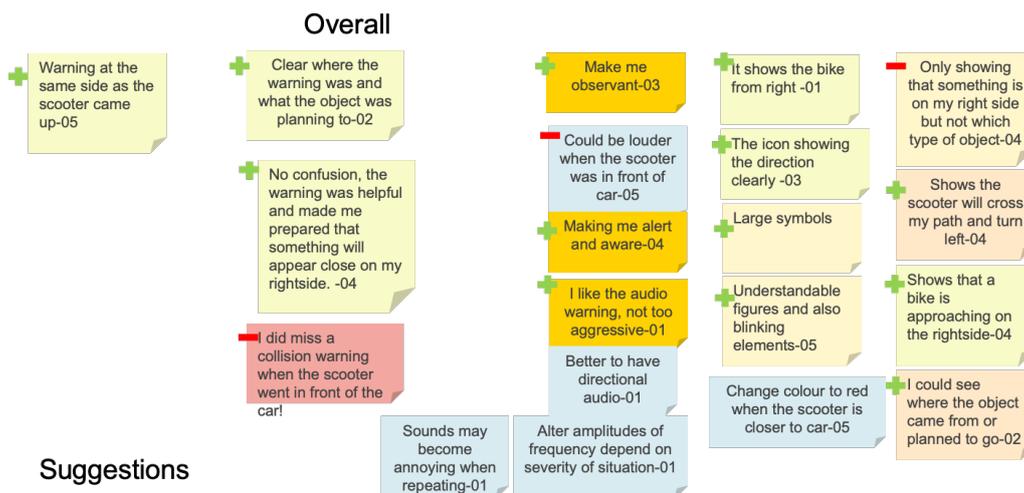


Figure 6.9: Demo D Affinity Diagram

vehicle type, etc. Showed the Demo D result as an example in the Table 6.1.

Among other demos, **Demo C** received close to the best evaluation. Similar to Demo D, the directional content received high praise. Secondly, the animation form of “object moving along with the ride” was also loved by users. However, users feel that the audio form of voice is a bit annoying. This kind of speech lasts too long, and users cannot focus on the scooter and visual warnings that have appeared in the field of view.

Demo F has the concept of real-time movement. However, the icons are too small and difficult to identify (linear); "warning sign moving around take my focus away" users reported that there were too many dynamic contents and were worried about being unsafe. But they really liked the blinking animation and the ambient light to emphasize what was going on. Users have suggested that it might be better if side ambient light could be used.

Subsequent options without audio are considered to have an improved user experience if audio is added, as noted in Appendix A. **Demo B** and **Demo A** share similar issues, such as the "icon (linear) should be more visible" warning sign not being clear enough in the current design. Additionally, due to differing scenarios, the two warnings lack distinction. The difference is that Demo A's placement is preferred by most participants, while Demo B's placement is favored by one participant, who stated, "it keeps the warning close to sight." Furthermore, Demo B has been criticized for containing too many words.

The color of **Demo E**'s card is well received by everyone because it can be clearly distinguished from the background. However its icon (linear) is not very conspicuous, and the three different card forms are also very difficult to understand quickly. Too many text reminders can also be distracting.

Demo G is considered a "moving thing is not necessary". At the same time, the selection of colors and icons has also been questioned, because blue and pedestrian do not make people think of a "warning for e-scooter."

Table 6.1: Demo D Analysis

Key	Explanation
Clear about where the warning was and which <u>direction</u> the risk will come from the side (5 of 5 participants)	This demo uses directional content to inform the participants about the direction of the risk. From their feedback, participants thought it was a good way to show the warning on the same side of the warning. So might keep showing the warning at this position for future concepts.
The <u>audio</u> makes me aware and observant that something will appear. (3 of 5 participants)	Participants think the audio reminds them and makes them aware there is something happening. Then they begin to check with the screen.
The figure could show me the scooter is planning to turn left, and it is understandable. (2 of 5 participants)	Not too many participants talk about the trajectory, but one the other has mentioned the design has an understandable figure. Although only two participants mentioned the planning route, it is still good to know trajectory could be important information for drivers
The <u>icon</u> should be larger and show which type of object (2 of 5 participants)	Participants thought it was good to have the icon, but it was a bit small, and they couldn't identify it really quickly. Actually, Demo D has a "vehicle type" icon showing as the bike. This could be interpreted that the information displaying the risk vehicle will influence participants' decision-making when they try to pay attention to that specific risk object.
The <u>audio</u> needs to be stronger when the scooter is in front of the car. And if the audio could be directional would be better (2 of 5 participants)	Participants ask for stronger stimuli for the second scene which has a more severe risk. But only the moment the risk comes since keeps showing the warning while the e-scooter at the side is a bit annoying.
The <u>color</u> of the icon should be changed to red when the scooter is closer to the car (1 of 5 participants)	Participant thinks the orange color is not enough for the second scene, since it almost crashes. A red color would be better to stimulate the driver.

6.3.2 Post-session

The post-session questionnaire was completed at the end of the testing when participants had finished experiencing all demos. Therefore, they could compare each demo and provide a comprehensive rank of the demos. The results of this part determine which demos will be retained and which are worthy of further detailed study of their characteristics to decide whether to apply them to the updated framework. Furthermore, the conclusion derived from the ranking of factors' significance should also be considered.

Quantitative Analysis

Here is the result of the post-session questionnaire showed in the Figure 6.10 and 6.11.

Participant	01	02	03	04	05	Average	Order
D	5	7	7	7	6	6.4	1
C	6	6	6	4	7	5.8	2
F	7	5	5	3	5	5	3
A	3	3	3	5	3	3.4	4
B	2	2	2	6	4	3.2	5
E	4	4	4	1	1	2.8	6
G	1	1	1	2	2	1.4	7

Figure 6.10: Post-session Average Score

	7st choise	6nd choise	5nd choise	4th choise	3th choise	2th choise	1st choise	Top 2
A	0	0	4	0	1	0	0	0
B	0	3	0	1	0	1	0	1
C	0	0	0	1	0	3	1	4
D	0	0	0	0	1	1	3	4
E	2	0	0	3	0	0	0	0
F	0	0	1	0	3	0	1	1
G	3	2	0	0	0	0	0	0

Figure 6.11: Post-session Top-two Box

Each demo received 5 ratings from 5 participants. The scores are allied and compared; the most preferred concept would get 7 points, and the least would get 1 point. The yellow highlighted the three demos that have audio warning in the first iteration. Demo D and F have a sound, while demo C has a voice. The red marks good scores, the green marks bad scores, and the bright yellow represents intermediate performance.

Demo D received the highest average score, indicating it is the most preferred demo among the seven evaluated. Three out of five participants chose **Demo D** as their favorite, and four out of five selected it as one of their top two choices.

Demo C ranked second in the study, while **Demo F** came in third. The overall evaluation results clearly indicate that **Demo D** should proceed to the next round. Additionally, retaining features from **Demo C** and **Demo F** could be beneficial for generating a relevant concept in the next iteration.

Demo A received the highest average score among all concepts without audio. However, **Demo E** ranked higher in specific choice results, with 3 out of 5 selections being the 4th choice. **Demo B** also performed well in the average score analysis, but opinions were highly divided in specific rankings.

Qualitative Analysis

In the after-session discussion, participants had a chance to explain why they give this rank, and why the specific demo is their most favorite one. So a qualitative analysis was also conducted in this phase.

Why participants prefer Demo D This demo got the best score because it provides a very clear graphic in a directional content format. It is easy to understand what's happened and identify the direction and trajectory information. The audio sound is also appropriate for reminding drivers to be aware but not annoying. The staged warning with a color change lets drivers learn that further action is required. However, the vehicle type is still not clear.

Why participants dislike Demo G However, this demo got the worst ranking. "I would not consider it as a warning" is the main reason why participants disliked this concept. The color used, the risk type (pedestrian), the lack of audio, and the movement of the warning caused so much annoyance and misunderstanding for participants.

Comments for other demos All demos that had audio were mostly ranked in the top 3 by participants. Demo C got second place ranking, and its motion/animation feature was highlighted by participants, but the audio voice(speech) was not as good as the sound. Demo F has a dynamic motion reflecting on the real-time movement, which is not preferred by participants. And its icon is also not clear enough.

Demo A and Demo B got quite similar results. These two concepts are quite simple, but their icons are still unclear enough that linear icons might not be a good choice for this warning. B also received comments that too much text is annoying. Demo E has a scattering evaluation. Some think it is the best without warning, and some think it is the worst. However, the colors used for those cards are highly valued.

Last but not least, two participants thought it was unnecessarily complex for the second scene warning as they had already noticed the risky e-scooter; too much information would distract them. This could be interpreted as the first scene playing a role as a pre-warning for the second warning, so the study might need to test what the participants' feedback is if less information is shown in the second scene.

6. 1st Iteration

19. How important are the following factors for creating a effective and satisfying warning? Please choose three of them which you think are important.

[More Details](#)

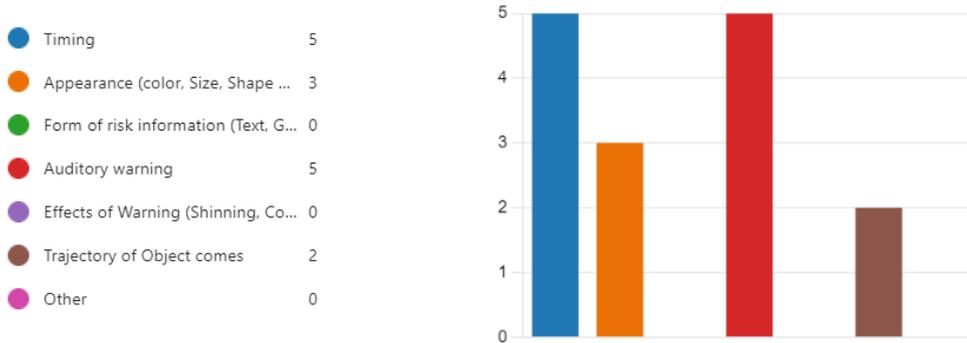


Figure 6.12: Elements Importance Ranking

Importance of Elements

Overall results are shown in the Figure 6.12. The audio is identified as the most important element of the warning. And the timing, as mentioned in the concept design part, which is difficult to calculate from an online video, furthermore, it's a challenge to get accurate feedback from qualitative research [7]. So, in the next iteration, it might be good to keep the timing variable the same for all demos.

The factors of "appearance" and "trajectory of the object" also received high scores following the two previously mentioned factors. Therefore, these design elements should be carefully evaluated in the next iteration. The trajectory, interpreted by some participants as an additional level of direction, will still need to be monitored. Direction, being basic information derived from all analyses, will be implemented directly.

6.4 Deliverables

The deliverables are a conclusion gained from the 1st iteration testing and will be used as input for the next iteration.

6.4.1 Design Suggestion

The Table 6.2 above listed all the suggestions for the usability problems found in the 1st iteration.

6.4.2 Updated Framework

Then, the framework of the concept design could be updated in Figure 6.13. Some features that have been tested with the bed effect will be eliminated (grey), and some other features have been added according to the participant's suggestion (under the

Table 6.2: Suggestions from Participants

	Usability Problem Suggestion
Visual	Use a larger symbol and filling icon
	High contrast with the background (refer to Demo E)
	Correct or at least similar vehicle type, shouldn't confuse
	Less text
	Choose the right color that represents a warning, e.g. red.
Effect	Blinking is a good effect on getting driver awareness
	Color change according to the situation emergency/severity
	Less dynamic movement of the warning. But a simple motion may be better for understanding
Audio	Audio is necessary
	Sounds are better than voice (speech)
	Directional audio might improve the user experience
Placement	Directional content that corresponds to the risk is good
	Closer to the vision would be better
Timing	The two warnings are too close, it might be better than reduce the content complexity of the second one

line box). The line boxes mean the factors could work but require further exploration of their usefulness.

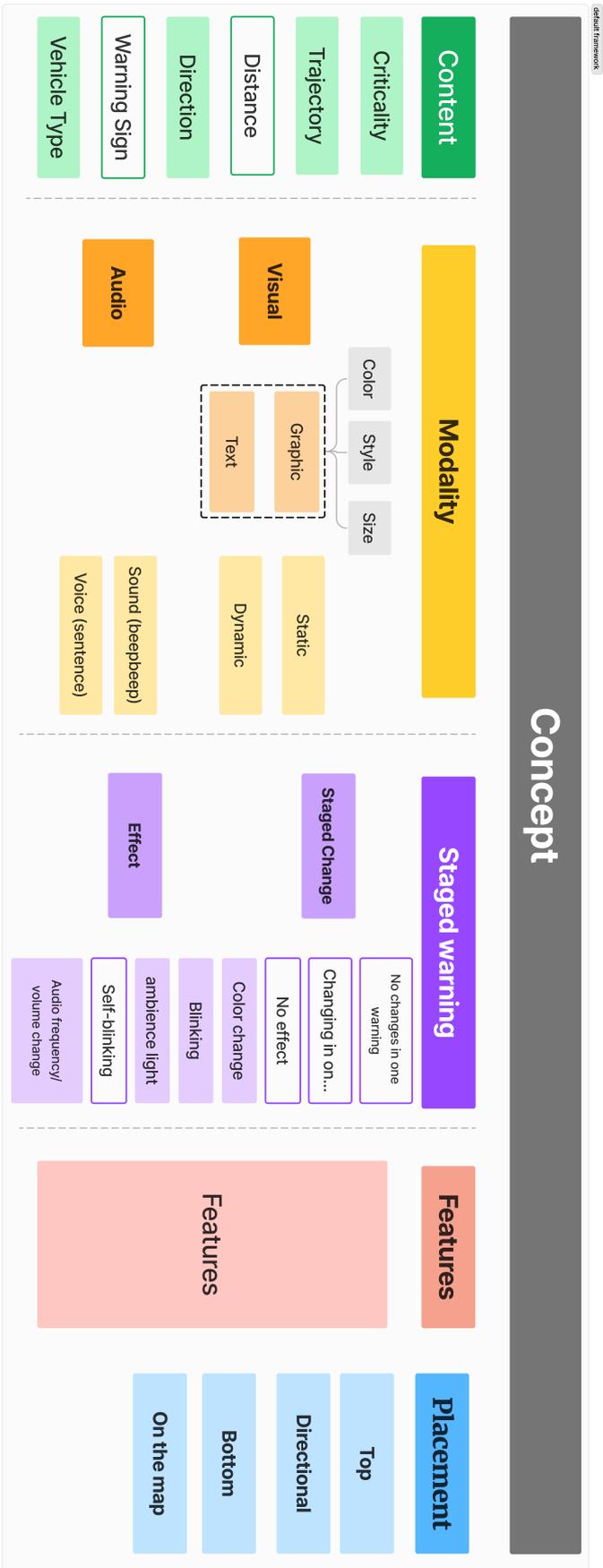


Figure 6.13: Elements Importance Ranking

7

2nd Iteration

The second iteration aims to redesign the interfaces, incorporating feedback from participants gathered during the first iteration to improve overall experience and usability. Design guidelines from existing literature were also applied to some concepts in this iteration to potentially enhance participants' awareness and enrich their overall experience.

7.1 Concepts Redesign

Different redesign plans are proposed for different models. Table 7.1 shows the relationship between new demos and the demos from the 1st iteration.

Table 7.1: Relationships between demos in this iteration and the first iteration

New Demo	Source
D	Keep the original demo from 1st iteration
H	Demo D
	Users' feedback towards Demo D
I	Demo D
	Demo C (dynamic information and 3D model)
	Literature findings
J	Demo C (3D model)
	Demo F (ambience light)
	Demo F and G (blinking)
	Literature findings
K	Demo A
	Demo E (high contrast background)
	User feedback
L	Demo E
	Literature findings (guidance text[44], less than four information[8])

Demo D, which performed the best in the first iteration, was retained in its original form for the second iteration. Based on participant feedback, a modified version of Demo D was developed, named Demo H. Demo K and Demo L were redesigned interfaces based on Demos A and E from the first iteration, respectively. Demos I and J were developed by integrating and modifying all first-round interfaces according to the feedback from the initial users and insights from a literature review.

7.1.1 Connection Logo

In the second iteration, a connection logo was incorporated into every demo. This logo, indicating that the e-scooter is connected to the car via V2X, was mandated by the company to ensure that users could easily identify when a connection was established. The potential impact of the logo on the effectiveness of the warnings was uncertain, necessitating an evaluation during the second round of usability testing. The connection logo was consistently applied across the various demos for this assessment. The two versions of the connection logo are shown in Fig. 7.1.

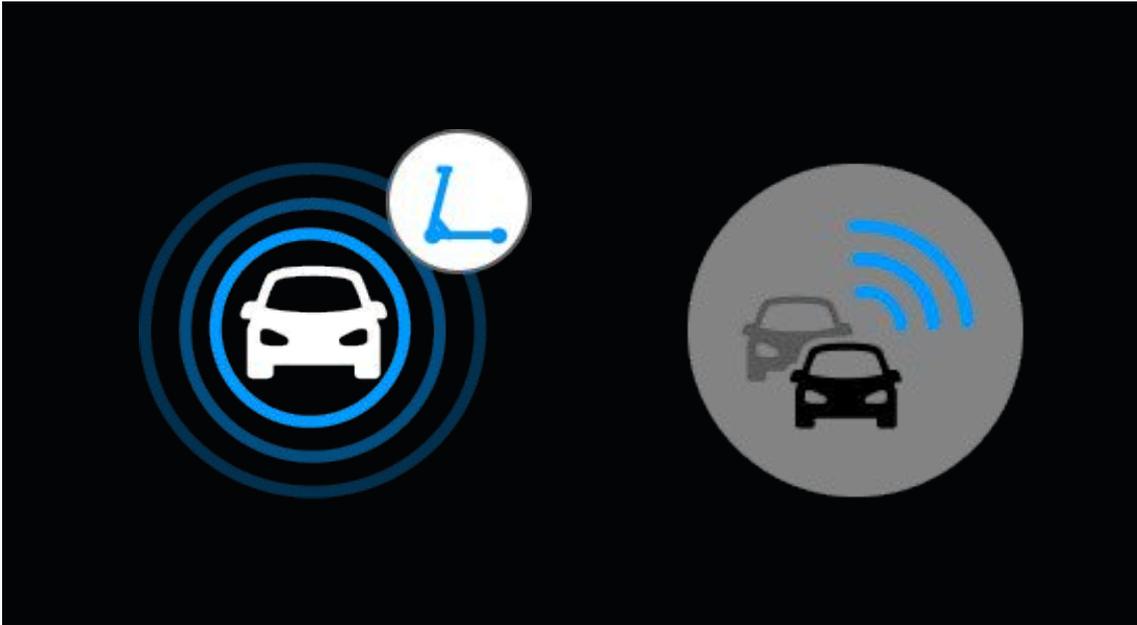


Figure 7.1: Two version of Connection logos applied in the second iteration

7.1.2 Demo H

Demo H is the modified version of demo D, which is the most prominent demo, it is redesigned according to the feedback from the participants in the first iteration. The changes from demo D to demo H are listed in the Fig. 7.2 and Table 7.2

7.1.3 Demo I

Demo I and Demo H are similar in many aspects. The key difference between the two demonstrations is that Demo H features an independent vehicle sign to display the type of connected car, whereas in Demo I, the vehicle sign is integrated into the animation and does not appear as a separate logo. This integration is intended to reduce the number of information modules, which, according to the SA theory[15], can decrease information processing time. From the previous concept, the user needs to perceive the icon and then the intersection condition and finally merge the two pieces of information together. By using a joint graphic [12] that presents level 2 information directly [16], drivers could apprehend the situation more easily. The Fig. 7.3 and Table 7.3 described the features of Demo I.

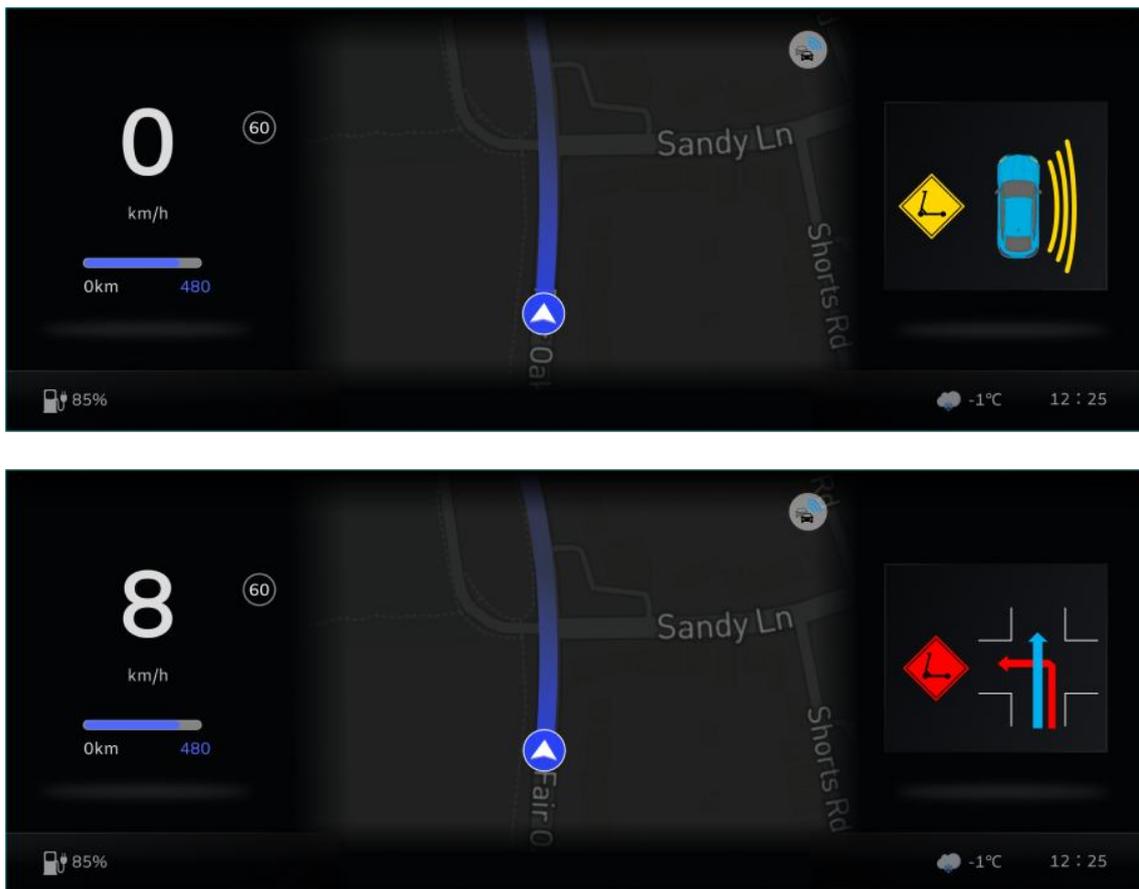


Figure 7.2: Demo H

Table 7.2: Redesign Demo D

Features	Demo D	Feedback to Demo D	Demo H
Audio warning	<ul style="list-style-type: none">· Non-directional audio· Sound Audio· Non-staged Audio	<ul style="list-style-type: none">· Better to have directional audio· Alter amplitudes of frequency depending on the severity of the situation (staged Audio warning)	<ul style="list-style-type: none">· Staged audio warnings, audio changed frequency according to emergent level.Directional audio
Blinking	No blinking effects	It is good to have blinking elements	Add blinking for e-scooter trajectory
Color	Yellow and orange	Change the color to red when the scooter is closer to the car.	Use red color to increase emergent
Staged warning	Single stage in the first warning; 2 stages in the second warning	The first stage warning in the second warning easy to neglect	The situation was divided into three emergent stages: low-high-medium(low).
Graphic design	The vehicle sign shows the bicycle	Only showing that something is on my right side but not which type of object	The vehicle logo changed from motorbike to E-scooters

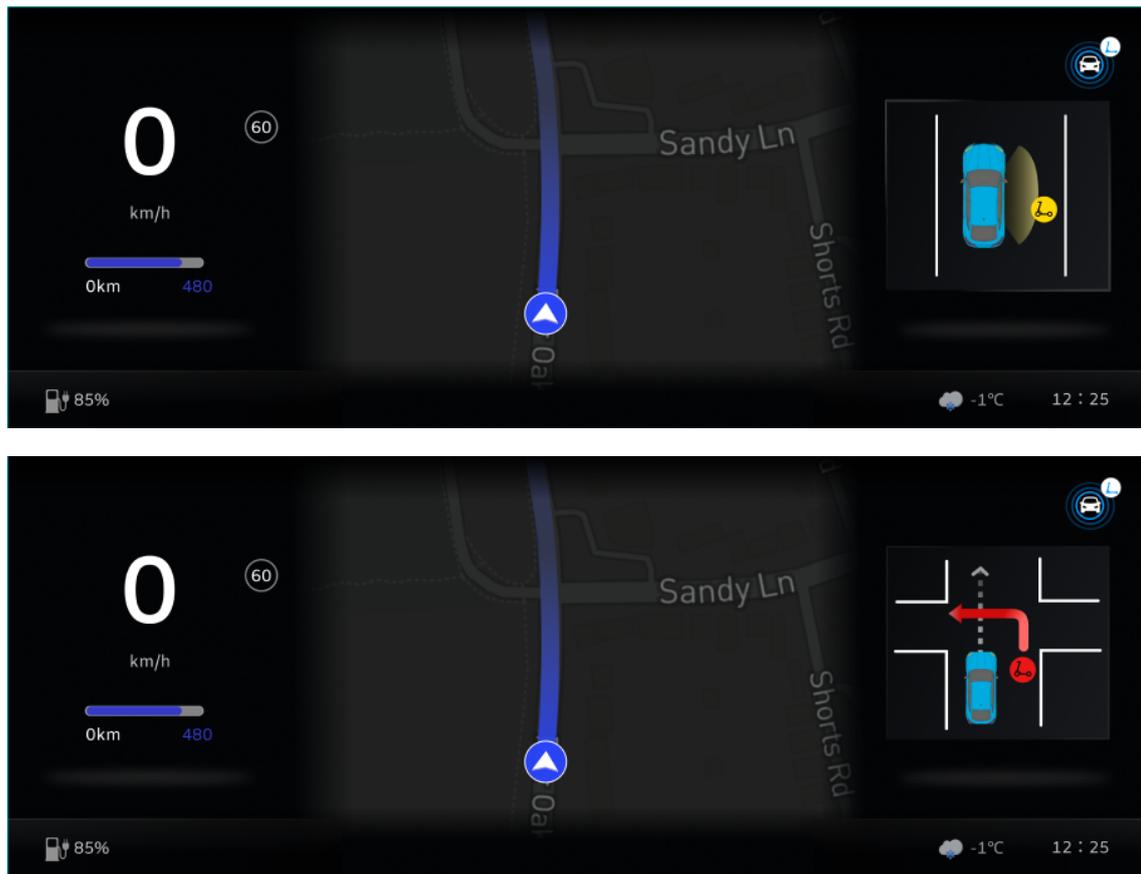


Figure 7.3: Demo I

Table 7.3: Redesign Demo I

Features	Demo I
Audio warning	<ul style="list-style-type: none"> · It uses the beep audio warning. · Directional warning · The frequency of the warning sound changes with the urgency of the situation.
Blinking effects	<ul style="list-style-type: none"> · Blinking effects are applied in the on predicted trajectory elements and the directional gradient light.
Color	<ul style="list-style-type: none"> · Use two distinct colors to indicate warnings of varying urgency levels. For blind spot warnings, use yellow; for forward collision warnings, use red.
Trajectory	<ul style="list-style-type: none"> · The blind spot warning does not provide a predicted trajectory; however, it does display the E-scooter's real-time position. · In the forward collision warning, the predicted trajectory indicates where the e-scooter is heading.
Staged warning	<ul style="list-style-type: none"> · Blind Spot Warning and Forward Collision Warning have different emergent levels and are represented by different colors and audio warning frequencies.
Graphic design	<ul style="list-style-type: none"> · The vehicle sign is integrated into the animation and does not appear as a separate logo.

7.1.4 Demo J

Demo J is designed based on all of the first-round models and implements the situation awareness [16] theory. Similar to the Demo I but in a different format. Using a 3D model and a joint graphic [12] in the warning could directly convey the level 2 information [15] to the driver. The most significant distinction between Demo J and the other models in the second iteration is its more straightforward effect (blinking ring) and quicker animation. Unlike the other models, which use a two-stage warning for forward collision warnings based on the urgency level, Demo J employs a single-stage alert warning. As 2 of 5 participants said in this scenario, it is better to lower the effect of the second warning. Figure 7.4 shows the hi-fidelity of Demo J, and Table 7.4 lists its key features.

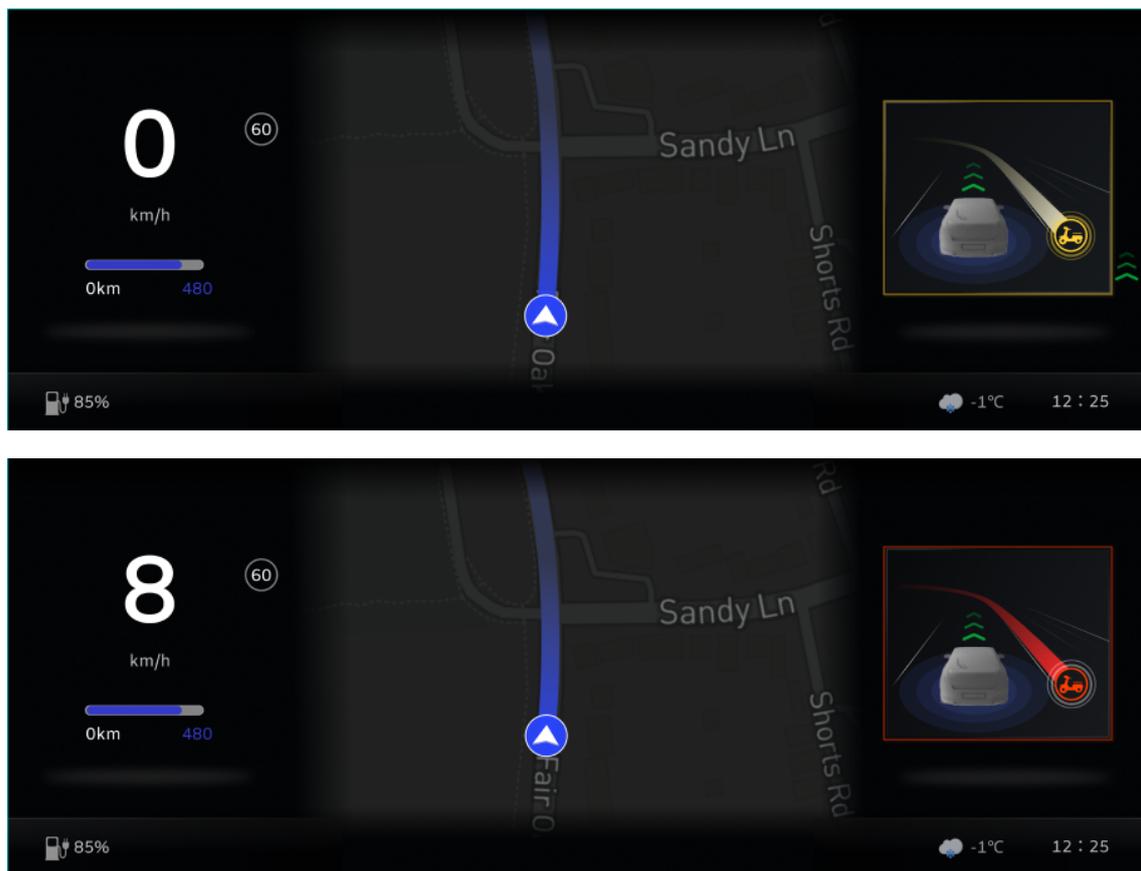


Figure 7.4: High-fidelity of Demo J

Table 7.4: Redesign Demo J

Features	Demo J
Audio warning	<ul style="list-style-type: none"> · It uses the beep audio warning rather than the speaking audio warning. · The warning is directional which corresponded with the direction where the objects are relatively located. · The frequency of the warning sound changes with the urgency of the situation.
Blinking effects	<ul style="list-style-type: none"> · A blinking ring effects is used to make the vehicle stand out.
Color	<ul style="list-style-type: none"> · Use two distinct colors to indicate warnings of varying urgency levels. For blind spot warnings, use yellow; for forward collision warnings, use red.
Trajectory	<ul style="list-style-type: none"> · The heading of the e-scooter and also the cars is shown through the predicted trajectory.
Staged warning	<ul style="list-style-type: none"> · Blind Spot Warning and Forward Collision Warning have different emergent levels and are represented by different colors and audio warning frequencies.
Graphic design	<ul style="list-style-type: none"> · A motorcycle icon is used to represent the e-scooter. · The vehicle sign is integrated into the animation and does not appear as a separate logo.

7.1.5 Demo K

Demo K is based on demo A of the first iteration and modified based on feedback from participants in the first iteration. The Figure 7.5 shows the high fidelity of this demo.

Demo K primarily presents information using card formats, with the e-scooter's connectivity to the car displayed through both graphics and text. The icon used the filling style since linear style got a negative feedback from the first round. However, this warning does not include the predicted trajectory of the e-scooter. Additionally, Demo K employs ambient lighting to signify the e-scooter's position relative to the car.

7.1.6 Demo L

Demo L, similar to Demo K, uses a card format to display warnings, shown in Figure 7.6. Unlike Demo K, which uses concrete graphics to depict the e-scooter, Demo L employs abstract symbols (warning icons) to represent it and provides explanations in the text. A change compared to the original demo is that Demo L has replaced the text of the detailed guidance "Vehicle right-side" with a shorter advice "Right" [44] [4]. Additionally, the relative distance between the e-scooter and the car is displayed numerically. The map included in Demo L highlights dangerous areas where cars could potentially collide with e-scooters.

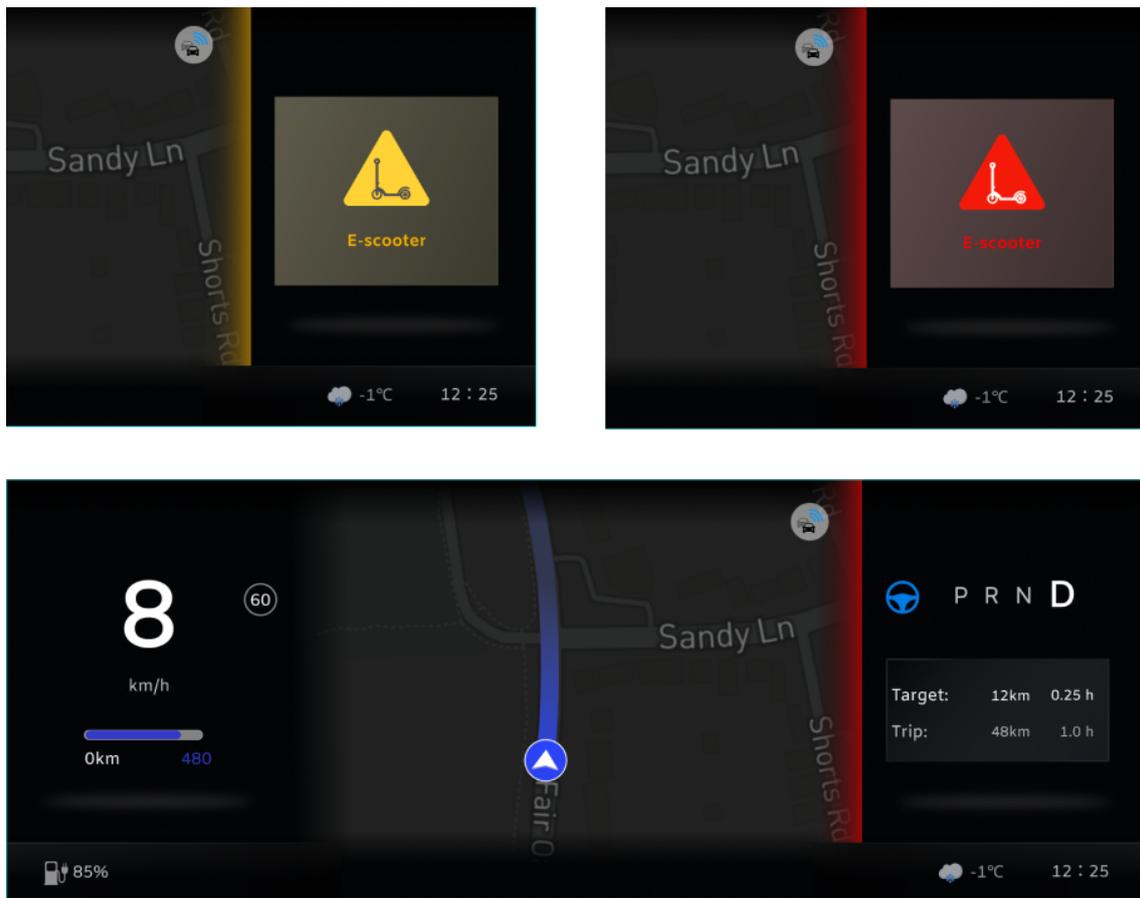


Figure 7.5: High-fidelity of Demo K

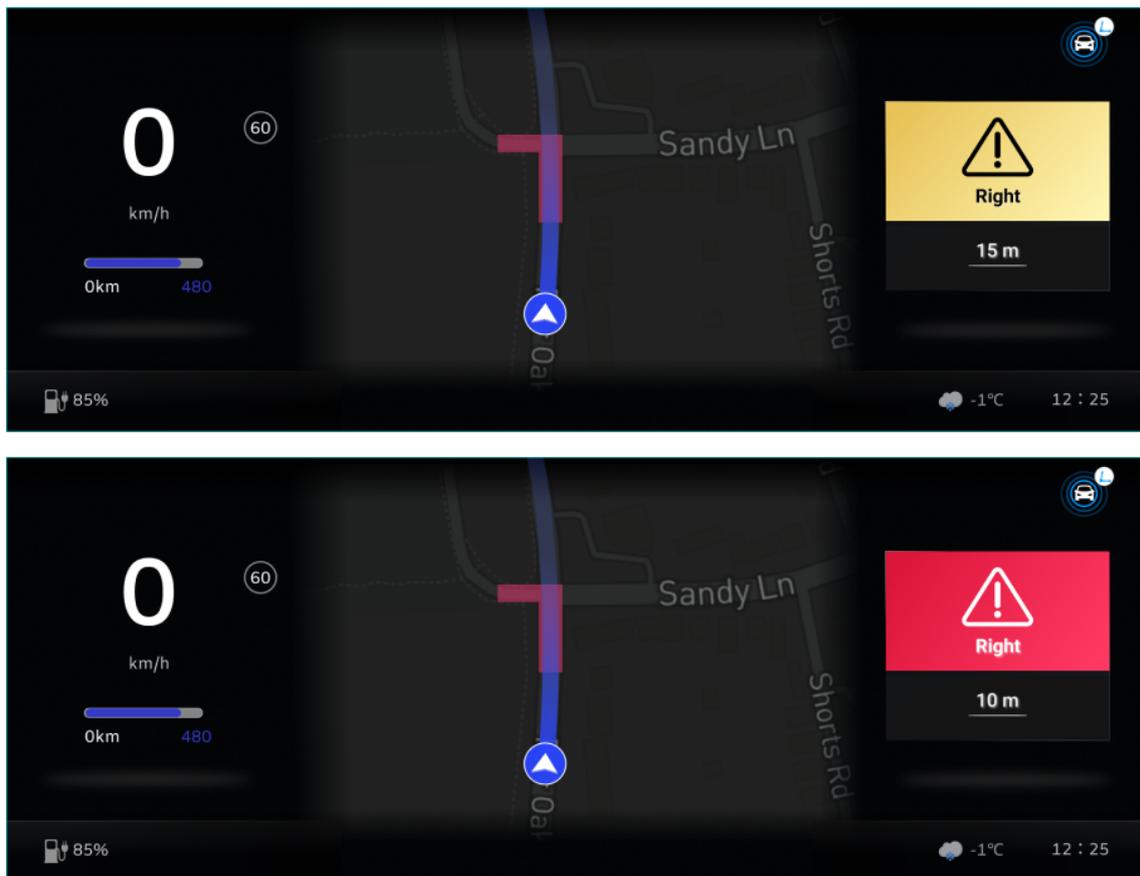


Figure 7.6: High-fidelity of Demo L

7.2 2nd Usability Testing

7.2.1 Participant

In total 6 participants were recruited from the Magna company, 2 of them were female, and 4 of them were male. The participants were between 26 to 49 years old. All of them had more than 6 years of driving experience. And they all drive at least a few times a week or even every day.

Overall, all the participants have a natural attitude toward their interactions with e-scooters. Two participants reported that they had a near miss once with e-scooters. The reasons were similar in that they were distracted and did not see the e-scooter.

7.2.2 Configuration

The driving simulator consists of an adjustable seat and a steering wheel originally from a Volvo car, a computer screen, and an iPad and a MacBook Pro computer, shown in the Figure 7.7.

The computer screen is connected by HDMI cable with the MacBook Pro as an expanded screen, where the view from the windshield will be played. The iPad is wirelessly connected to the MacBook Pro and used as an extended screen. The computer screen mimics the windshield where the scenario played on it while the iPad functioned as the cluster.



Figure 7.7: 2nd Iteration usability testing configuration

The driving scenario is the same one used in the first iteration. While different from the first iteration, the warning information was placed separately on the iPad

(Cluster), so that it would be closer to the reality of driving. The interface of the cluster and the warnings were drawn through Figma and animated through Adobe After Effects.

7.2.3 Procedure

The usability testing is still divided into three phases: Pre-testing, Testing, and post-testing. The figure 7.8 shows the overall process of the 2nd usability testing.

Pre-testing

In the Pre-testing phase, the moderator concisely introduced the project's theme, aim, and the stage of this usability testing in the entire process. All participants were from within the company, and they signed relevant confidentiality agreements with the company in advance, so they were just reminded about the confidential regulation without having to sign added information for this experiment. Then they completed the demographic survey with is the same in the first iteration.

After that, the moderator introduced the experiment settings, including the function of each screen and the screen on the car it simulates to help them get familiar with the experiment settings. Then the participants are informed about the rounds of the testing they would test, and the testing processes include experiencing the warning and completing the after-demo and after-session questionnaires.

Later, the moderator asked the participants to sit in the driver's seat and adjust the seat until they felt comfortable being able to view the two screens (Windshield and Cluster) with ease. To help participants better immerse themselves in car driving, the same sensitizing introduction from the 1st iteration will be used.

Testing

The participants ran a practice trial before the experiment trial. In the same way as the formal trial, there was a demo viewing and a post-demo questionnaire. The scenario in the practice trial was similar but not identical - both had the key elements of emergent situations with e-scooters but happened in a different location, so the road elements were different. The practice trial aims to help participants fully prepare for their tasks and become familiar with the question format in the post-demo questionnaire. As participants answered this round of questionnaires, they were given a screenshot of the warning they had just experienced to use as a reference.

There were in total 6 formal rounds of testing corresponding with 6 warning designs, the scenarios were all the same in the formal rounds. After viewing each demo, a questionnaire about participants' experiences with warnings was asked to complete.

Post-testing

After the participants viewed all six warning design demos, they were asked to rank them based on their experience and how much they liked them. In this iteration, an improvement from the pilot is that participants will be informed at the beginning that they need to sort all demos in the final stage. So they could start sorting after they had finished each demo with an instant impression. The moderator would ask about the reason for the rank and other related questions. The participant was encouraged to provide any other feedback and comments after the questions were answered.

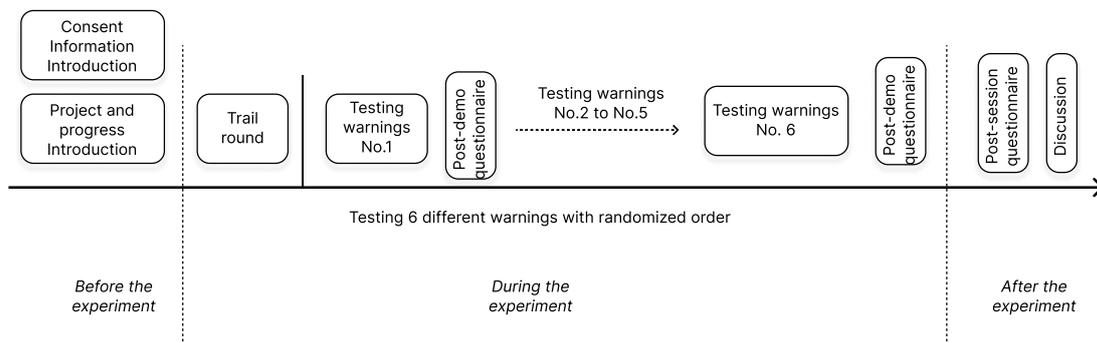


Figure 7.8: The process of 2nd usability testing

7.2.4 Questionnaire

Post-demo Questionnaire

After viewing each demo, participants were asked to complete the post-demo questionnaire. This questionnaire is quite aligned with the one used in the 1st iteration, but there have been some changes. The full questionnaire can be found in the Appendix D.

Firstly, since a new connection feature is added to the concept, a related question is also required. Secondly, the “importance of elements” part has been moved from post-session to post-demo. Last, since we asked participants to start thinking about sorting during the post-demo, a reminder was added about grading each demo based on their experience separately. The reminder will be in the fake questionnaire, which informs participants before everything starts.

Post-session Questionnaire

After experiencing all the demos, the participants were asked to rank the 6 demos from the most and the least favorite based on their overall experience.

7.3 Result and Analysis

The following section discusses the results of the post-demo and post-session questionnaire. Both qualitative and quantitative analysis are involved. For 7-point Likert Questions, mainly quantitative analysis was used; the average scores were calculated and compared with each other. For qualitative data, KJ analysis was used, and an affinity diagram was drawn so that Participants' insights were concluded and compared with each other.

7.3.1 Post-demo Questionnaire

The post-demo questionnaire was asked to be completed after participants each demo when the participants had fresh impressions. Post-demo focused on more specific features, for example, participants' comments on specific design elements.

Quantitative Analysis

The Single Ease Question (SEQ) is a usability metric used in user experience research. It's a 7-point rating scale that assesses how difficult users find a task after attempting it in a usability test. From the table, it can be concluded that Demo D and Demo I got both 5 in the top 2 box metrics. As for the mean and median, Demo I got the highest score.

From the chart, it can be found that Demo K and Demo I performed better in the static and dynamic design. Demo H, Demo I and Demo K perform better than the other demos in the placement. Interestingly, Demo H and Demo J perform better in the timing, although all the warnings have the same timing for warning. It is might because the different designs and animations give participants different feelings. For audio warning, all the demos are relatively similar, Demo J and Demo K are slightly better than the others.

Qualitative Analysis

KJ-analysis is used for qualitative analysis. For each demo, an affinity diagram was drawn. Method introduction is in the section 3.2.2.

7.3.2 Post-session Questionnaire

Quantitative Analysis

A post-session questionnaire was completed after all the demos were experienced by the participants so that they could compare each demo and provide a comprehensive rank of the demos.

The post-session questionnaire is first analyzed. The rankings were assigned with scores, with the first-ranked receiving 6 points, the second-ranked receiving 5 points, and so on, with the last-ranked receiving 1 point. Detailed information was showed in the figures and tables below.

Table 7.5: Quantitative Analysis of 2nd Post-Demo Questionnaire

(a) Single Ease Questionnaire										
	1	2	3	4	5	6	Top 2	Mean	Median	
Demo	D	4	4	7	7	7	6	4	5.83	6.5
	H	7	5	6	7	7	6	5	6.33	6.5
	I	7	5	7	7	7	7	5	6.67	7
	J	5	5	7	7	7	5	3	6.00	6
	K	6	6	4	5	7	7	4	5.83	6
	L	4	4	1	5	7	6	2	4.50	4.5

(b) Static Design										
	1	2	3	4	5	6	Top 2	Mean	Median	
Demo	D	4	3	7	4	3	6	2	4.50	4
	H	7	6	5	7	6	5	4	6.00	6
	I	7	5	7	6	7	6	5	6.33	6.5
	J	7	2	7	7	6	4	4	5.50	6.5
	K	7	6	7	6	7	7	6	6.67	7
	L	4	5	7	5	1	5	1	4.50	5

(c) Dynamic Design										
	1	2	3	4	5	6	Top 2	Mean	Median	
Demo	D	7	3	7	5	1	6	3	4.83	5.5
	H	6	5	5	7	6	6	4	5.83	6
	I	7	6	7	6	6	4	5	6.00	6
	J	5	2	7	7	6	5	3	5.33	5.5
	K	7	6	4	6	6	7	5	6.00	6
	L	4	4	4	5	1	4	0	3.67	4

Table 7.6: Quantitative Analysis of 2nd Post-Demo Questionnaire (continue).

(a) Placement										
	1	2	3	4	5	6	Top 2	Mean	Median	
Demo	D	6	3	7	6	1	4	3	4.50	5
	H	7	5	7	7	6	6	5	6.33	6.5
	I	7	6	7	7	7	5	5	6.50	7
	J	5	3	7	7	6	4	3	5.33	5.5
	K	5	6	7	7	6	7	5	6.17	6
	L	6	3	7	6	1	6	4	4.83	6

(b) Timing										
	1	2	3	4	5	6	Top 2	Mean	Median	
Demo	D	5	3	7	6	2	5	2	4.67	5
	H	6	3	7	7	6	3	4	5.33	6
	I	5	3	7	4	3	6	2	4.67	4.5
	J	4	6	7	7	6	4	4	5.67	6
	K	4	5	4	6	6	7	3	5.33	5.5
	L	6	3	4	5	6	7	3	5.17	5.5

(c) Audio										
	1	2	3	4	5	6	Top 2	Mean	Median	
Demo	D	3	3	5	4	1	5	0	3.50	3.5
	H	4	4	5	5	2	5	0	4.17	4.5
	I	4	4	5	5	1	3	0	3.67	4
	J	5	3	5	5	5	5	0	4.67	5
	K	5	4	5	4	5	5	0	4.67	5
	L	4	4	5	3	1	5	0	3.67	4

Table 7.7: Participants Feedback on Demo D

The icon did not show the correct vehicle type. (3 out of 6 participants)	In demo D, the icon type shows the wrong icon type – bicycle, rather than e-scooter. The participant believed that the information displayed in this graphic didn't match the actual situation.
Audio warning and color should be able to distinguish emergent levels. (2 out of 6 participants)	In Demo D, the audio doesn't change in different severity of situation
Warning should present clear information about where the objects are and where it is going. (3 out of 6 participants)	The arrows and the icons show clearly where the object is and where it is going, which is helpful for participants.
Orange and yellow are too similar. (3 out of 6 participants)	Yellow and Orange are too distinguishable, and they cannot express the difference of urgency.

Table 7.8: Participants Feedback on Demo H

The warning presents the situation well but with too much information. (3 out of 6)	The warning contains too many icons and information. Participants think it is complicated and distracts them from the windscreen.
The color change from yellow to red reflects the severity change. (3 out of 6)	Yellow and red can well reflect the difference in urgency.
Warning should present clear information about where the objects are and where it is going. (3 out of 6 participants)	The arrows and the icons show clearly where the object is and where it is going, which is helpful for participants.
The audio could be more intense and stronger. (3 out of 6)	Participants felt the current voice was not intensive enough to convey the level of urgency

Average scores

Each demo received 6 ratings from 6 participants. The scores are tallied and compared.

Firstly, we calculated the average scores of each demo, the results are shown in Figure 7.9. Demo J got the highest average score, indicating it was the most favorite demo. The average scores of Demo D, Demo I, Demo H, and Demo K are close to each other, and it was hard to tell which one was better than the others. Demo L got the lowest average score which means it was the least preferred.

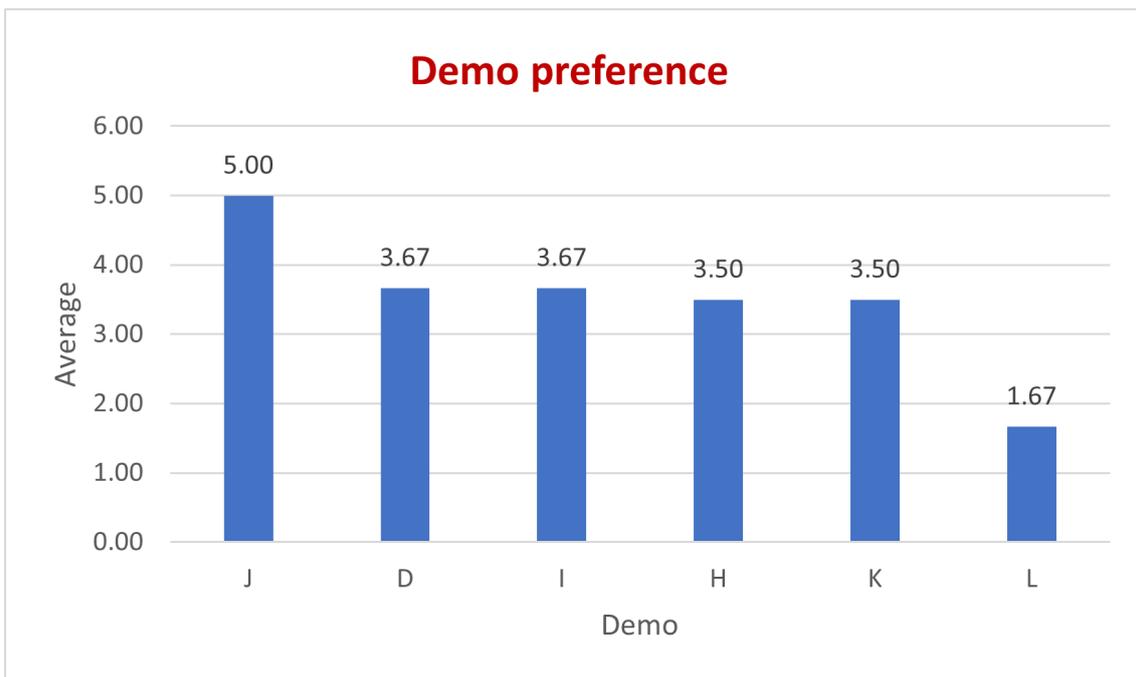


Figure 7.9: Overall preference about demos in 2nd iteration

Top 2 Box

The top two boxes' analysis and results align with the average scores, it shown in the Table 7.9. From the analysis of the top 2 boxes, it can be concluded that Demo G was the favorite demo. Four people put Demo J in their first or second place, among them Three people think it is the best demo and one person put it in second place.

Demo D got three points in the top 2 box analysis, one person thinks it is the best demo among the six, and two people put it in second place. However, two people also put demo D in the last place. Demo H and K got two scores in the top 2 boxes. There were no people who put Demo L in their first two boxes.

It can be concluded from the post-session demo that Demo J is the overall most favorite demo. Demos D, I, H, and K perform similarly, participants have different

Table 7.9: This table calculated the number of people who put the demo in the first and second places

Demo	6th	5th	4th	3rd	2nd	1st	Top 2 Box
J	0	0	1	1	1	3	4
D	2	0	0	1	2	1	3
I	0	1	2	2	0	1	1
H	0	1	3	0	2	0	2
K	0	3	0	1	1	1	2
L	4	1	0	1	0	0	0

opinions on how they like these demos, resulting in their final overall scores being similar. Demo L is the least-liked demo in the second iteration.

Qualitative Analysis

In the after-session discussion, we asked the reason they give this rank and why the specific demo is their favorite one. Here we mainly analyzed the main reason why participants prefer the specific demo.

Why do participants prefer Demo J?

Demo J is the most popular model in the second iteration according to the ranks, here's an analysis of why it's so popular.

The predicted trajectory was the most emphasized feature in these discussions. Demo J offers a very clear and concise predicted trajectory for the e-scooter, enabling a clear understanding of the vehicle's current position and future direction. Although like demos I display the same information, the design of the predicted trajectory in Demo D is superior to others.

Besides, the color change from yellow to red presents the emergence of the situation as well as the directional audio and staged audio warning.

Feedback of other Demos Demo D was overall good, effectively describing the situation. Some people appreciated the way it displayed the blind spot warning, finding it eye-catching. However, the main drawback is the icon for the vehicle type, which shows a bicycle instead of a scooter. Additionally, the colors yellow and orange are not sufficiently distinguishable in the warning design.

Demo H is the modified version of Demo D according to the feedback from the 1st iteration. Overall, despite providing relatively complete information, the improvements in design H are not substantial compared to design D. Some users noted that it contained too much information and criticized the method of displaying trajectories as inadequate. Additionally, despite the fact that all demo warnings were displayed simultaneously, some users perceived design H as appearing too late. This may be attributed to its more complex design, including graphics and animations, which likely increased the time needed for users to recognize and process the information, thereby creating a perception of delayed appearance.

Demo I received similar feedback from participants as Demo H. The color change from yellow for low-emergency situations to red for high-emergency situations effectively represents the severity. However, it was reported that the warning appeared too late, despite the timing being consistent across all demos. Some participants mentioned the animation did not align very well with the real-time relative position, so it was a bit distracting for them.

Demo K According to participant feedback, the primary issue with demo K is the absence of crucial information. The alert fails to indicate the origin or destination of the e-scooter. Although the design aims to convey the urgency and direction of danger through various display ambient lights, this intent is not apparent to users in this round.

Demo L Most participants expressed difficulty understanding Demo L. The abstract vehicle icon failed to clearly indicate the type of transportation connected to the car. Furthermore, the terms 'left' and 'right,' intended to show the location of the e-scooter, were not intuitive enough for users. Additionally, no one noticed the dangerous areas marked on the map, suggesting that the design was not effectively communicated to the participants.

7.4 Takeaways from the Second Iteration

This section mainly discusses the experience and rules gained from the second round of usability testing which can be retained to the third iteration.

7.4.1 Visual

Icon and symbols should be large and visible enough in the warning design

If there are symbols or icons in the warning, it is important that the meaning of the symbols is clear and intuitive. Therefore, the logo and its content should be big enough so that they can be seen with ease within a short reaction time.

Icons and symbols should convey the correct information and avoid misleading

Icons and symbols, whether abstract or concrete, must convey information accurately and prevent the transmission of incorrect details or misunderstandings. In our specific scenario, the icon should depict an e-scooter rather than a bicycle to correctly represent the vehicle type. Additionally, in the demonstrations of D, H, and I, the design of the warning image is problematic. Its resemblance to an arrow misleadingly suggests a direction, which could confuse users.

In emergent situations, use strong colors to increase the stimuli

Red conveys a greater sense of urgency than orange and yellow do. Therefore, when a high level of urgency is required, choosing red can enhance user attention.

Warnings should be as simple and intuitive as possible

Excessive information can increase cognitive load. For warnings, it is crucial to minimize the number of informational modules and avoid unnecessary changes to reduce complexity. It is usually suggested to have no more than 4 elements at the same time in a warning [8].

Warnings should use less text and 3D model might improve the effectiveness

Aligning with the first iteration findings, the text may be challenging for the driver to understand in an instant scenario. Using a 3D car model is a more effective method for representing the car's situation and other objects.

7.4.2 Effects

Animation effects in warnings, such as blinking and blinking rings, can enhance people's attention in emergency situations, helping them to quickly grasp important information.

7.4.3 Placement

Under the current experimental conditions, the current placement is reasonable, but there are participant feedback that many warnings are currently on reflectors, which may be more reasonable.

7.4.4 Audio

Directional audio is helpful In this round, all models utilized directional audio. Compared to the first round, they received improved feedback regarding audio warnings. Participants reported that the integration of graphics and sounds effectively indicates directionality, thereby enhancing the user experience and ease of use.

Different emergencies can be reflected through changes in the frequency of sound In this iteration, different alert frequencies were applied to represent various levels of urgency and received more positive feedback than in the first iteration.

7.4.5 Connection Logo

In this round, the newly introduced connection logo, intended to display V2X functions, neither enhanced nor detracted from people's attention and convenience. A likely reason for this is that in emergencies, individuals prioritize essential information and overlook secondary details. Since the connection logo failed to provide crucial information about danger warnings, participants generally ignored it. Based on all the above qualitative and quantitative analyses, demo J could be identified as the eugenic result of this iteration and would continue to be used in the third iteration.

8

3rd Iteration

This iteration aims to find the optimal in-car display for placing the V2X warning in our chosen scenario. The best-performing demo from the second iteration, Demo J, was adopted as the test warning in this round. In total, three different in-car displays were tested through usability testing: HUD, Cluster, and Infotainment.

8.1 Introduction

After two iterations of HMI design and usability testing, Demo J was selected as the optimal HMI solution. It is considered the result of the two rounds of iterative design. Therefore, Demo J, as the current best concept, was used as the basis for the third iteration.

According to the experimental plan, other demos from the second round were no longer used in this round. The goal of the third iteration was to find the optimal in-car display position for placing collision warnings. Displaying warning information on side view mirrors has become increasingly popular. However, due to equipment limitations, we had to exclude side-view mirrors from our study. The possible display options were limited to the HUD, Cluster, and Infotainment system. Figure 8.1 below shows the three common displays in the car.

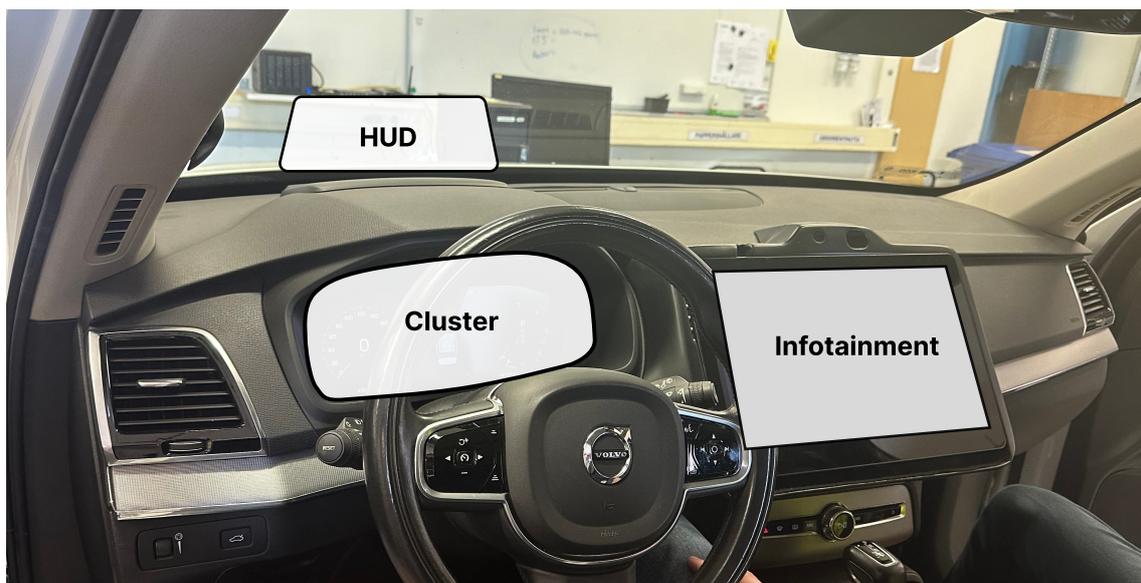


Figure 8.1: Three In-car displays

8.2 Concepts Redesign

Demo J has received feedback from the 2nd iteration takeaways that the mopped bike icon didn't as good as the e-scooter icon, and the blinking ring is better to use the same color with the other warning information. So these two small adjustments were implemented in the third iteration of a redesign.

The purpose of the third round is to determine the optimal position for the warning. To adapt the warning to different interfaces, changes were made accordingly. However, these changes did not affect the fundamental characteristics of the warning, such as sound, appearance design, dynamic effects, and timing. Below is a description of the interface design presented by demo J, adapted to three different displays.

8.2.1 Warning on Infotainment

Shown in the Figure 8.2. Researchers stated that the closer the display was positioned to the driver, the more favorable the effect on driving performance due to reduced visual demand. However, the infotainment system is the furthest display from the windshield and typically presents information about entertainment, communication, and office-related functions, which are not directly related to the vehicle or road situation.[4]. To achieve the best performance, the warning unit is located on the left side of the screen so that it is closer to the driver. Besides the warning unit, other parts of the infotainment interface display navigation functions. Navigation is a common feature of the infotainment interface.

8.2.2 Warning on Cluster

Shown in the Figure 8.3. The cluster interface kept the same format as the last two iterations. The warning unit is on the right side of the interfaces, which is the same side of the e-scooter.

8.2.3 Warning on HUD

Shown in the Figure 8.4. HUD differs significantly from the other two interfaces in terms of size, background color, and other aspects, requiring more substantial adjustments for adaptation. Due to the limited display space, warnings on the HUD should be brief yet concise. Although the HUD display is transparent, it can still obstruct part of the driver's view and cause distractions. To minimize this distraction, only critical and urgent safety-related information should be displayed on the HMI.

8.3 3rd Usability Testing

The third Usability test aims to find out the relatively better in-car display for presenting the warnings. This usability testing adopted a within-subjects design,

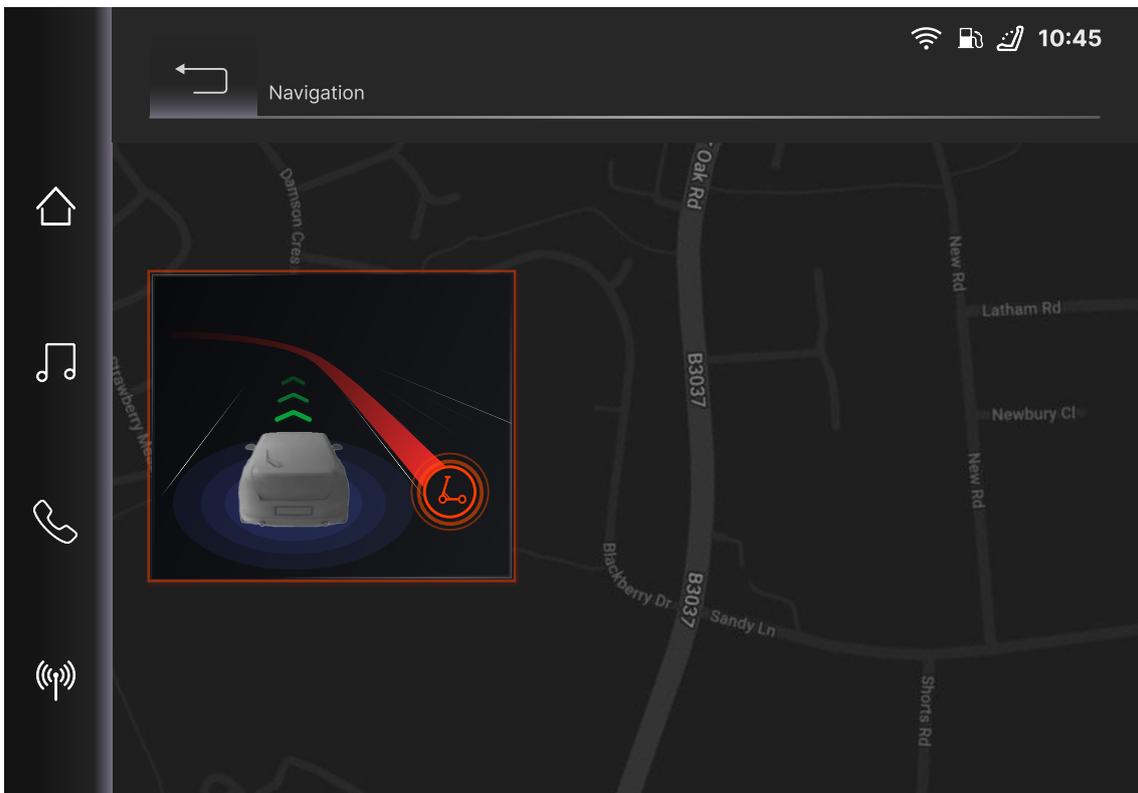


Figure 8.2: The warning unit on infotainment

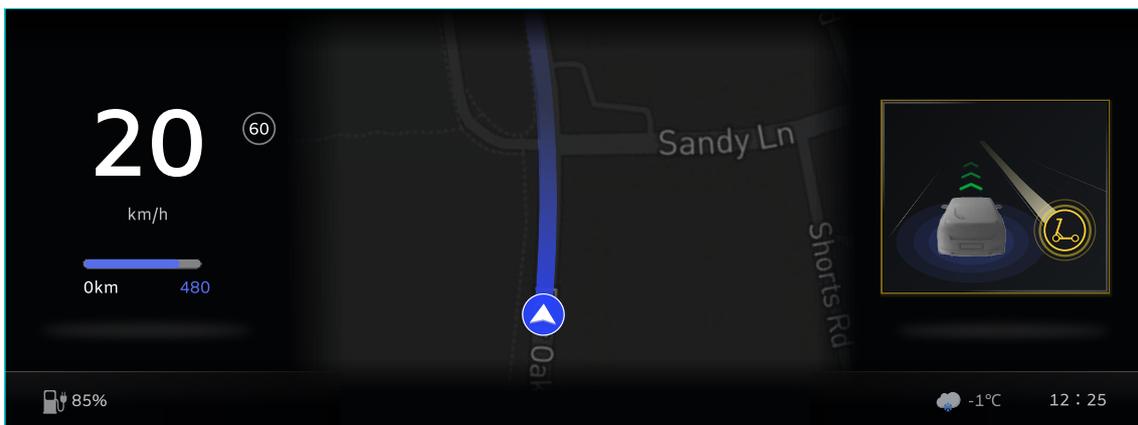


Figure 8.3: The warning unit on cluster

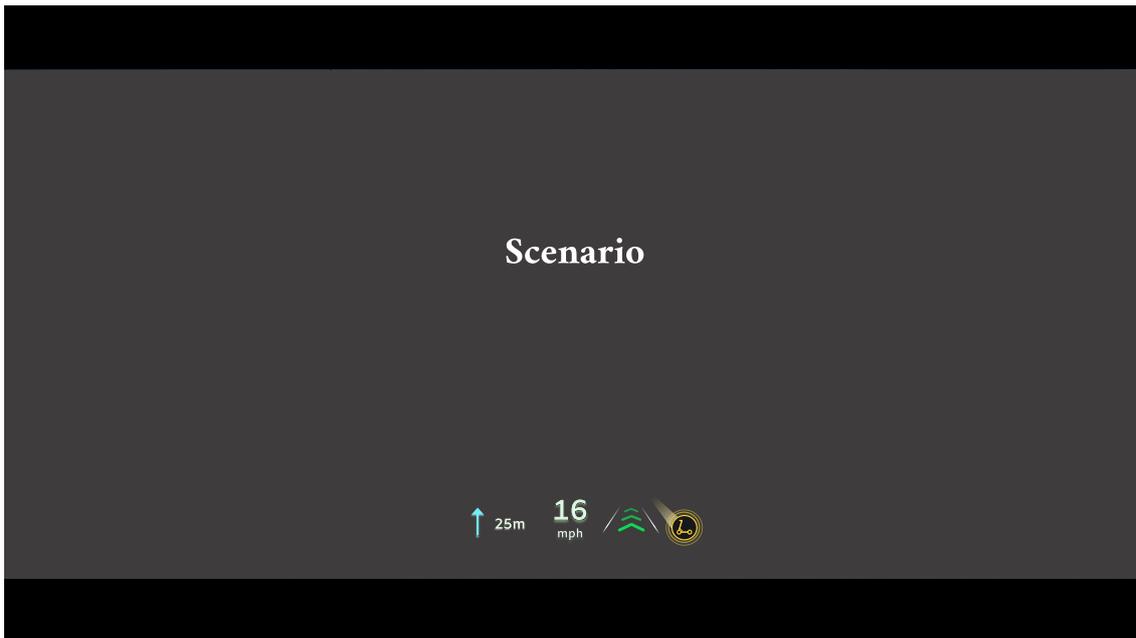


Figure 8.4: The warning unit on HUD

all participants take part in every condition, and in this iteration, there are three different kinds of conditions - warning on the HUD, warning on the Cluster, and warning on the infotainment.

8.3.1 Participant

There were a total of five participants in this iteration: two females and three males. The participants ranged in age from 26 to 52 years old, and all of them had more than 6 years of driving experience.

In the last two rounds of usability testing, ten different participants were involved. One of the biggest differences in the participant recruiting method in this iteration was that participants were selected from the 1st and 2nd iterations. A total of five participants were chosen for the 3rd usability test: three from the 1st iteration and two from the 2nd iteration. The main criteria for selecting participants was their language skills, this is because they could provide more feedback. The selected participants provided clear and informative feedback in the first two rounds of testing.

The advantage of recruiting participants from previous iterations is that they can compare this round with the last one. From their feedback across these two iterations, it can be determined whether the usability problems identified in previous rounds were resolved and if the overall experience has improved after the iteration.

8.3.2 Configuration

The same driving simulator was used in this iteration; however, compared to the previous iteration, an additional pad was added to simulate the cluster or infotainment system as needed. Similar to the second iteration, the setup includes an adjustable seat, a steering wheel, a computer screen displaying the driving scenario video, an iPad simulating the cluster or infotainment system, and a MacBook Pro acting as a control center to manage the content shown on the displays. Audio warnings were played through headphones. The figure 8.5 shows the configuration of the 3rd Usability testing.

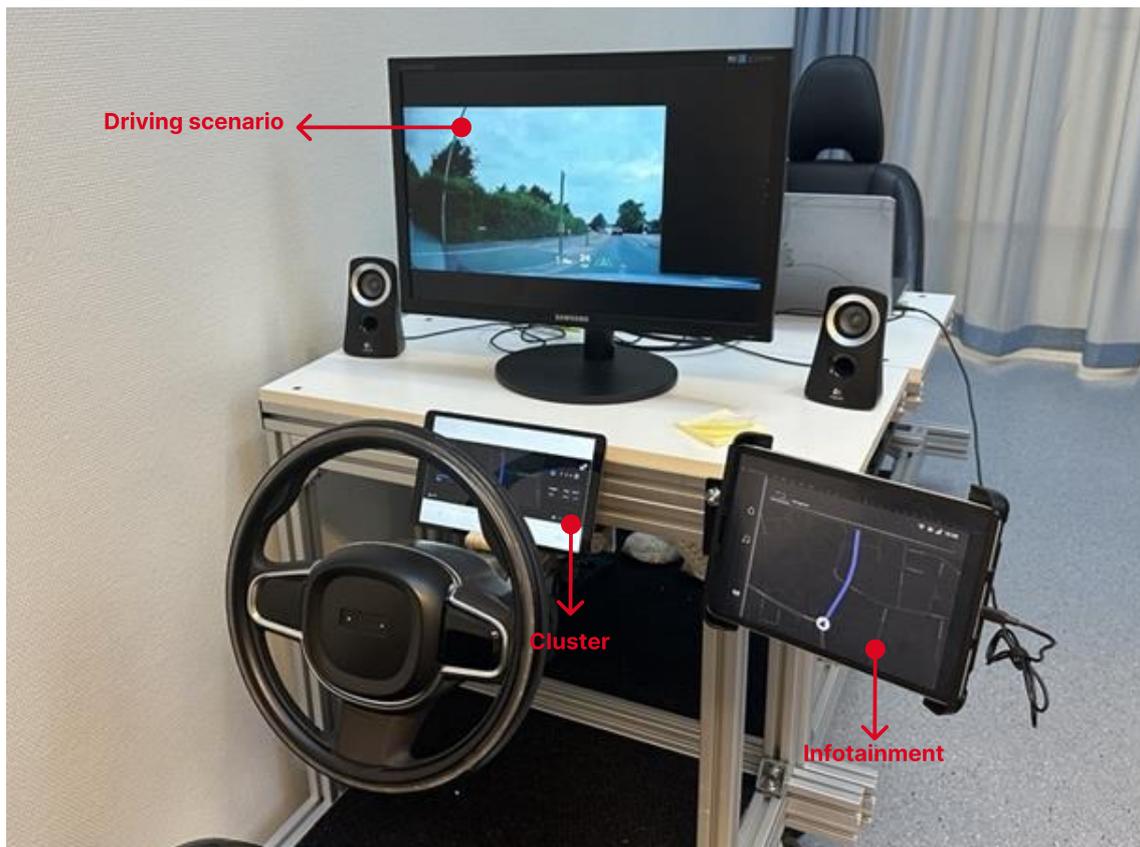


Figure 8.5: 3rd configuration

8.3.3 Procedure

Figure 8.6 showed the detailed procedure. Firstly, participants were updated on the project's progress since their last involvement, without disclosing the criteria for this usability test. Next, they moved to the car seat and adjusted it until they felt comfortable and had all the screens in view. The trial round then began, designed to help participants familiarize themselves with the experimental setup, including the functions of each display, and to prepare them for the testing procedures.

The formal testing began after the trial round. The formal test included three rounds of testing. In each round, participants experienced demos with warnings in different

locations. After three rounds, participants had experienced all three demos.

After each demo, there was a post-demo questionnaire. This questionnaire was semi-structured, with questions related to ease of use, physical distraction, cognitive workload, and usefulness.

The post-session questionnaire was completed after participants had viewed all three demos. Participants were asked to rank the interfaces they had experienced according to their overall preference. In the final discussion session, participants were asked to explain the reasons for their rankings and to provide any other comments they had.

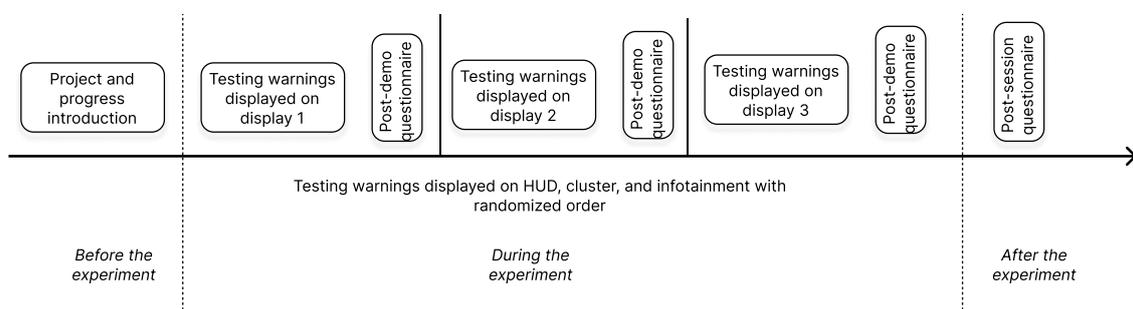


Figure 8.6: The procedure of 3rd usability testing

8.4 3rd Usability Result Analysis

As the same as the usability tastings in the last two iterations. The post-demo questionnaire collected people's insight towards specific features and the post-session questionnaire collected the overall impression about the 3 demos.

8.4.1 Post-demo Questionnaire

The questions in the post-demo questionnaire are 7-point Likert questions - the single ease question, questions regarding physical distraction, cognitive workload, and usability. Qualitative questions asked the reason they rate. The questionnaire can be found in the appendix D.

Quantitative Analysis

The records of quantitative analysis results are placed in Appendix F. From Appendix F, it is clear that the demo with the warning placed on the HUD performed overall slightly better than the other two demos. The demo with the warning placed on the infotainment system scored 0 points for overall experience and physical distraction. The two demos, which with warnings on the cluster and the HUD, performed similarly, but the HUD demo was slightly better.

Qualitative Analysis

Since post-demo quantitative analysis cannot see clear gaps between each other, the analysis of qualitative data can be useful and vital.

An exploratory thematic analysis of the data collected during the post-demo was performed. Generally, warnings on the HUD cause the least physical distraction. Participants 2, 3, and 4 mentioned that they don't need to look elsewhere to get the warning since they can always focus on the road when the warning is placed on the HUD. Participants 2 and 4 also stated that they are always more attentive with regard to the HUD. It appears that warnings placed on the HUD help participants understand the situation more easily, as mentioned by participants 1, 3, and 4. This suggests that warnings on the HUD are more intuitive for reflecting the situation. However, a drawback of the current design is that the connection logo is set on the dashboard, which can be disjointed as it appears on a different display from the warnings when the warning is placed on the HUD or infotainment system. It is suggested that the warnings and the connection logo should be on the same screen.

Warnings on the cluster can be helpful for drivers to understand the situation. Participants 1 and 3 reported feeling safer with warnings on the cluster. Participants 2 and 3 mentioned that having the information directly in front of the driver, instead of to the right as with the infotainment system, was beneficial. Participant 4 noted that this location is relatively easy to notice and find. However, Participant 1 pointed out that it can cause distraction because the driver has to shift their sight to the cluster, potentially missing important information on the road.

Unlike the first two positions, when the warning was on the infotainment system, a lot of feedback about distraction was received. All five participants reported that the warning is "not in their direct line of sight" and "too far from their view when driving," requiring them to shift their focus from the road to the infotainment system. Participant 1 mentioned that he reacted more slowly compared to the warnings in the other two locations. Participant 5 stated that he had to spend more time looking away from the road.

In conclusion, the infotainment system causes more distraction than other warning placements because it is located too far from where the driver's eyesight should be focused on the road [4]. This finding is consistent with the literature. The HUD causes less distraction and makes it easier for participants to understand emergent situations. The same warning on the HUD is perceived as clearer and easier to understand. Warnings on the cluster are also helpful, as they are relatively close to the road and easy to understand, although they can be more distracting than warnings on the HUD.

8.4.2 Post-session Questionnaire

As mentioned before, participants were asked to rank the three demos according to their preference. The following chart describes the results of the post-session

Table 8.1: Thematic analysis of participants' feedback on three demos

Theme	Codes	N	Participants
HUD			
Physical distraction	I didn't need to look to my screen on the right/allows me to keep my eyes on the road	3	P2, P3, P4
Cognitive workload	The connection logo shown on the dashboard is misleading and distracting	2	P5
	I am always on top of attention in my driving	2	P2, P4
Clarity	It is easy to understand the situation that the Warning and the threat appear at the same time	3	P1, P3, P4
	It increases the visibility	1	P1
Ease of use	Easy to see both my and the scooters direction	1	P1
	It is useful to have it in the windshield right in front of you.	1	P3
Cluster			
Physical distraction	It is nice that the information is right in front of you, instead of to your right.	2	P2, P3
	It is distracting because I want to look at all the screens to know that I am not missing any important information.	1	P3
Cognitive workload	I feel secure about the situation when the car helps me to react on the scooter.	2	P1, P3
	The graphics are complicated for the warning takes a second to understand.	1	P4
Ease of use	It was very easy to find the warning and figure out what was going on.	2	P3
Infotainment			
Physical distraction	Warning not in direct eyesight, too far away from the view when driving, make me look away from the road	5	P1, P2, P3, P4, P5
Cognitive workload	I react slower than the warning on the HUD and Cluster	1	P1
	It makes my drive easier	1	P3
	I put more time with my eyes away from the road ahead.	1	P5

questionnaire in the Table 8.1. Four out of five participants ranked the infotainment system last because it is too far from the road, making it distracting. Participants noted that more time is needed to notice and understand the warnings displayed on the infotainment system.

It is hard to determine the best place for placing the warning, whether it is the cluster or the HUD. Three out of five participants preferred the HUD because they felt it was close to their line of sight and the least distracting. However, two out of five participants preferred the warning on the cluster, finding it easy to notice and feeling accustomed to looking at information on the cluster while driving.

8.5 Takeaways of 3rd Iteration

In this iteration, three positions for placing the warning were tested through usability testing. After analyzing the results of both the post-demo and post-session questionnaires, some design guidelines can be concluded.

Firstly, the HUD and the cluster are recommended for placing warnings. Among the three positions, the HUD causes the least distraction, as it is closest to the driver's line of sight while driving.

The cluster can also be preferred by drivers. Although it may cause some distraction, users are accustomed to checking information on the cluster.

Warnings on the infotainment system should be avoided because they are too distracting, being located too far from the driver's line of sight while driving.

9

Final Solution and Guideline

In this chapter, the final results of the thesis are presented in two sections: the HMI prototype and a design guideline for Vehicle-to-everything(V2X) warning that answers the research questions "what information should show to the driver and in which way".

9.1 Final Concepts

The prototypes of the V2X warning were built with high-fidelity interfaces in Figma and added interaction/animation using the software Adobe After Effects. As this project has already operated three iterations for changes, the results mainly focused on concluding the improved features from iterations and making small adjustments based on third-iteration user feedback instead of describing all the visual elements again.

In the first iteration, the study identified users' needs and insights for staged warnings, modalities, the presence or absence of different elements, and visual design preferences based on the testing of existing warning designs. In the second iteration, literature findings and user feedback were applied to clarify users' specific preferences in the scenarios, and then a design that users found the most intuitive was chosen. Finally, after solving the problem of when and what information is effective in the current scenario, the third iteration was conducted to determine the placement and finalize the concept.

9.1.1 Head-up Display

The head-up display has been selected as the best placement to show the warning according to the results of the third iteration 8. From the 3rd iteration, one valuable piece of feedback is that one participant noticed the connection logo, and he thought showing the connection feature on different screens was not good.

So, an adjustment would be moving the connection logo to the HUD screen at the same position where the warning will be shown later, and then all related information will show on the same screen. When the warning is ended, the connection feature will keep showing when the e-scooter stays close to the car, as one of the findings in the second iteration shows how it has displayed in all of the demos. According to Campbell's research[8], V2X warning should prioritize and filter the information, so the group decided not to add a sound for this feature to stand out from the warning

as the effectiveness of the feature is still not determined. The final concept of the HUD is shown in the Figure 9.1.



Figure 9.1: Final concept for head-up display

9.1.2 Instrument Cluster

As stated in the previous part, not all the cars have a head-up display, so the demo for the instrument cluster still keeps working as a substitute version for different types of cars. The final concept didn't make too many changes compared to the one used for the third iteration, only enlarging the logo and changing the color of the blinking ring due to the feedback from the second iteration. One possible adjustment is to remove the direction arrow of the car 3D model since one participant in 3rd iteration said it was a bit too much information for this warning. Also, according to [8] no more than four information sections should be shown in the warning, and three would be better if the element is not necessary. However, most of the participants in the second iteration and third iteration didn't mention it, so the opinion will just remain.

Although the connection-logo feature didn't receive much valuable feedback from the second iteration of testing, participants were aware of it in the third iteration. So, there might be a learning effect for users to get used to the information showing on the screen. The feature may need further exploration in the future, but in this scenario, the concept will remain, as shown in Figure 9.2.

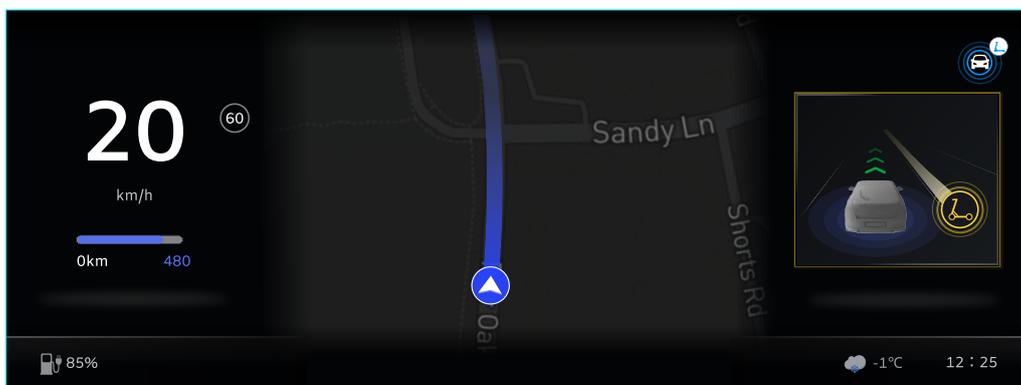


Figure 9.2: Final Concept for Instrument Cluster

9.2 Guideline

In this section, we will conclude a design guideline based on the conclusions in three iterations and interpretation of the framework 6.1. This will help identify important features to consider for V2X warning design in order to ensure a good user experience. This design guideline is aimed to provide researchers and industry designers with a reference for future exploration related to V2X warnings and e-scooters.

The guideline is developed following the information framework: staged warning, modality, content, and visual design & effect. It is mentioned that the results are not related to legal content.

9.2.1 Staged Warning

Iterative studies showed that the multiple staged warnings did not have an obvious impact on user experience based on user feedback. Some participants even complained that the changes were too quick (2 seconds), as shown in Figure 5.1, making them difficult to notice clearly. This aligns with the literature review's finding that staged warnings might decrease user experience from a subjective perspective. However, all participants highly praised the color-changing effect based on the severity of the situation. This effect has been utilized in some staged warnings to provide a pre-warning before the e-scooter approaches, but no user specifically mentioned that it made a significant difference.

According to Ma's research [6], single-stage warnings generally performed better than multi-staged warnings in subjective data, and multi-staged warnings outperformed objective utility performance with single-stage warnings. From this project, based on user feedback, one potential reason is that the two warning scenes are so close, only 3.5 seconds between the first end and the second start. Participants have commented that they had already noticed the risky e-scooter, so it is unnecessary to give a second warning that is strong and complex. Even two participants said they wanted to keep showing the first warning on the screen when the scooter was close to the car. Because they might have already recognized the first scene as a pre-warning for the second scene, that's why the classic "multi-staged warning" theory might not work. Then the supplement guideline could be stated:

1. Using different colors, typically yellow and red, to represent different stages according to the situation severity.
2. Too short a time will make the multi-staged warning very annoying. An appropriate time setting is 3 seconds or more [7].
3. When two warnings are very close and come from the same object, it is unnecessary to use a multi-staged warning since the first warning could be recognized as a pre-warning for the second.

9.2.2 Multi-modality

The study clearly demonstrated that multi-modality, specifically the combination of audio and visual elements, outperforms using only visual (1st iteration) or only audio (2nd iteration, Demo K) modalities. This approach significantly enhances the ability to catch the driver's attention and make them more vigilant about potential risks. More detailed guidelines are provided below:

1. Audio warning is a mandatory requirement for V2X warning, no matter how emergent it is.
 - (a) Frequency changes of the audio could help drivers understand how emergent the warning is.
2. Sounds usually work better than speech (1st iteration)
 - (a) Directional sound could help the driver intuitively identify where the risk coming from (2nd iteration)
3. Audio warnings are mainly aimed at getting drivers aware, and visual warnings provide detailed information.

9.2.3 Visual

Visual elements consist of the content and effect of the warning. This section will not repeat specific factors such as the blinking ring and ambient light. Instead, it will focus on the design strategy and the relationship between different elements.

1. Direction information is a mandatory element, while trajectory would also benefit for driver's decision-making.
 - (a) Do not add too much motion since it may distract drivers (1st and 2nd iteration). Static key information would be more clear and quicker for the driver to understand (2nd iteration).
 - (b) Using a 3D model is a clear and intuitive way of showing the risk direction, participants could understand it easily (1st, 2nd and 3rd iteration)
2. The blinking effect is a good way to highlight significant information.
 - (a) If the effect has a decoration element (eg. ring), it should use the color aligned with the warning information (2nd iteration).
3. The vehicle type may not need to be very accurate, it could be efficient if the correct icon (2nd iteration), but using a similar speed vehicle type will not cause too much confusion (1st iteration).
 - (a) Warning icon is better to use a filling icon instead of a linear one.
 - (b) The vehicle icon should have larger and thicker lines to help the driver easily identify the vehicle.
4. The warning should have a high contrast against the background (1st iteration).
5. Colors chosen for warning are usually yellow, red and orange (1st iteration).
6. Usually has no more than four types of information in the warning, the information should be carefully filtered.

9.2.4 Placement

The project has yielded clear results in Chapter 8 showing that a head-up display is the best placement for displaying warnings, aligning with literature findings [14] [12]. However, due to user habits and practical factors, some participants also selected the instrument cluster as their preferred option. Regardless of the screen used, directional content is consistently preferred. The guidelines are as follows:

1. The warning should be shown on the same side that the risk object coming from.
2. Making the warning close to the sight would ease the process of recognizing information.

10

Discussion

10.1 Results

The project aimed to create a warning design between an e-scooter and a car that integrated with Vehicle-to-Everything (V2X) technology to enhance the driver's safe driving and increase the knowledge of which type of information related to the scenario that is essential to give and in which way. The objective is believed to be fulfilled as the final concept has been generated and design guidelines identified that argue for several important aspects to be included and highly praised for their clearness and effectiveness among participants.

The results are mainly based on qualitative iterative user studies and complement the existing literature by design strategy guidance regarding staged warning, multimodality, information type (text or graphic, dynamic or static, warning sign or vehicle icon), visual design (effects, icon style, 3D model), placement, dedicated for e-scooter warning and producing a positive user experience. As clearness and satisfaction are important for driver user experience in the situation awareness process, this project can contribute to a safer traffic environment in the future.

The final concept and design guidelines will offer valuable insight for the company regarding which types of information is essential and how to effectively communicate them to drivers. Especially, giving some potential insights about how to distinguish a V2X warning with the normal one, more specifically, the connection logo and the information given much earlier than the usual detection, and how to manage them. The delivered HMI design prototype will be used for further testing, perhaps in a real car. Ultimately, the results of the thesis will contribute to the development of useful Vehicle-to-Everything warnings for the E-safer project.

10.1.1 Compare to Current Research

Since concept evaluation can only be performed in a set scenario context in the test, the interval between two warnings in the scenario may have caused the results of multiple staged warnings to be different from some studies, but it is consistent with the subjective performance research results of Ma et al[7]. More accurate results require a lot of quantitative analysis to support.

In addition, the results show that graphic information is easier to recognize than text information. Among different types of text, explicit information in the form of advice does not differ from other types of supporting text in terms of effect (Demo E

and Demo L), which is different from the research results [44];. However, short text does perform better than detailed guidance, it is consistent with previous studies[44]. For audio warning, the sounds works better than the speech, which is not align with the literature finding [9]. One of the reason might be the resource we used is different from the research resource, which indicate the specific design of the element would be important.

10.1.2 Limitation

The limitations of the results are due to the resources and the method used. Since dynamic video prototyping is employed, the timing of each concept could be set manually. However, because the scenario video is sourced online (Appendix A), it is challenging to determine the exact speed and relative position of the e-scooter in the video. When interpreting and implementing the real-time dynamic concept [14], the animation is not accurately reflected in Demo F and Demo I, which also conclude from the user feedback about possible improvement. The result of dynamic and static information does not align with previous research, so this factor might have an impact. Another limitation is the learning effect during the evaluation process. The group has used a randomized order for each participants and add a trail round to minimize the impact, but still some participants said they have got more prepared for the scenario after the first one. If the future study have more time of implementing demos, it might be a good way to use several different scenario or making a joint long video to show warning multiple times.

Last but not least, timing is also a limitation for this project, as all benchmarking analysis concepts are based on the video clips. There isn't a configuration manual to describe this, so the timing of the first iteration concepts might differ from the original design. In the second iteration, the same timing was used for all concepts. Therefore, user feedback about timing could be assumed as how easy it is for users to understand and grasp the specific information, hence reflecting on the effectiveness of the design. However, timing is always a significant factor in the warning, as stated in the Chapter 6 result. Therefore, further conclusions regarding the design concept might need to be drawn when it is possible to have a configured scenario.

10.2 Process

10.2.1 Procedure

The procedure of the process followed our refined human-centered design method [17]and combined with a benchmarking analysis [21]. It has a rigorous logic about reaching a better user experience peak and resolving all the research questions. But according to the previous research [12][14], head-up display is usually identified as a better place for the V2X warning. One question might be why the project decide to start with the instrument cluster but not focus on developing design for HUD, here are reasons:

- Firstly, following the project HCD method, the group didn't find a clear consensus on placement, and most existing solutions are implemented at the position of cluster or infotainment system.
- Then, as clarified before, not all the cars have HUD, which has also been a reflection from participants. Therefore starting with a more common position can suit for general users.

10.2.2 Post-demo and Post-session

The project process is also a process of continuous adjustment. Post-demo and post-session questionnaires are included in each iteration. The two methods support each other. Post-demo can provide specific feedback on each concept, and the results can reflect a certain trend; post-session can compare all concepts, collect qualitative data and comprehensively obtain the optimal solution.

There is an interesting phenomenon that the final results of these two questionnaires are sometimes inconsistent. For example, in the second round, it was found that the users with high final rankings in the post-session may not necessarily have a good experience in the post-demo. There may be several reasons and how the group solved it: During the post-demo, the user's personal preference for a certain point will have a great impact, so the debrief is used in the free discussion part to verify the participants' thoughts through qualitative data; the group also uses random order to avoid Primacy and Recency Effects, Learning and Adaptation Effects; Post-session allows participants to compare all demos directly with each other, which can highlight strengths and weaknesses not apparent in isolation, so the group mainly refer to the result of the post-session to choose the final concept that send to the next round. This phenomenon aligns with Lewis' research [21] that usability testing is a climb-hill process. The group got scattered data in the second round, but finally, the overall user experience will be improved after combining the quantitative results with qualitative analysis.

10.2.3 Participants

The project primarily involved using internal colleagues as participants, all of whom have more than six years of driving experience, making their insights valuable. However, there is a demographic imbalance. While gender representation has been well-balanced, the majority of participants are aged between 26 and 57, with less representation from the younger generation (defined as under 25 according to youth policy in Sweden [54]) and elderly after 57. Consequently, the project's findings, such as the preference for static information, may differ if younger or elder individuals were involved.

Another is the systematic limitation of a small-sample size iterative design process. Previous studies have verified the effectiveness of using this method, however, there still a potential challenge is that the designer sometimes need to judge among scattering, different aspect feedback [21], and a small sample size might lead the project deviation of the direction. This phenomenon is evident in Chapter 7; one or two

participants might have their own “ideal” warning in their mind, and although the analysis has considered those biases, it will still have a bit of an impact on the analysis.

A larger sample size might be a good solution to avoid this problem, but it will require much more time especially when participants’ schedule are varied. Therefore, due to the time limitation, the project method is good enough.

10.2.4 Scenario Choosing

The video used in this project depicts two common scenarios. It accurately portrays a situation that car drivers may encounter daily: an e-scooter approaching from a blind spot and preparing to turn onto the opposite side of the road. Conflicts between e-scooters and drivers are inevitable, so designing based on this scenario could help manage such situations and enhance driving safety.

However, this scenario video still have some limitations. The car’s perspective in the video is left-hand, consistent with Swedish driving habits, but the driving environment is in the UK, where people drive right-hand. This slight discrepancy can cause some interference for the participant. Additionally, the time interval between the two risks in the video is very short. During the experiment, it was found that this situation is not ideal for testing multi-staged warnings. The user receives another warning immediately before re-entering the driving condition. If the interval between the two risks can be longer, such as 30 seconds, it will be more conducive to testing.

10.3 Ethical Implications

The project aims to reduce the risk of collisions between cars and e-scooters by testing various V2X warning systems. This could have a positive ethical impact on human beings as it may improve road safety. For instance, warning systems using V2X technology, such as pre-warning and receiving more information from other resources to build collective perception, can lead to more comprehensive and safe driving situations when encountering e-scooters. Especially e-scooter riders are usually more aggressive and have irregular driving behavior [1].

However, while V2X technology has more information inputs, it may also lead to an extra mental workload for users due to information overload. It can prolong the process of situation awareness [15] from perception and understanding to decision-making, hindering the ability to make quick decisions in dangerous situations, which is not conducive to safe driving. Therefore, when designing the warning on HMI, it’s crucial to carefully adhere to design guidelines to prevent distracting users.

Another important ethical consideration in this project is user privacy, especially when building collective perception. When implementing the vehicle-to-everything warning system, it is essential to respect drivers’ autonomy to ensure they have control over their data. They should have the option to choose whether or not to

connect to the network and share their information. The "connection feature" design in the project is a good practice to inform the user about the status of the V2X function. Therefore, it could be transparent when gathering data from the car and provide clear consent mechanisms when asking the driver for configuration.

10.4 Future Work

10.4.1 Connection Feature

The connection logo has been tested in the second and third iterations. Although the results of the second test seems neutral since most of participants didn't recognize it; the third iteration received feedback from some participants who recognized it as part of the warning system. According to the V2X design guideline [8], which prioritizes filters and schedules information, the connection logo feature still needs further evaluation to determine if it effectively conveys warning information and if it could be interpreted as a pre-warning before the color changes. Other questions could be when the driver should receive that information before the risk(maybe 5 seconds), and if it should keep displaying when the object is still near the car or disappear immediately when the risk is gone. Following this project, all these factors could be considered as potential topics for future testing using a similar process.

10.4.2 Side View Mirror

During the testing process, as the first risk scene is a blind spot warning, some participants reflected that they are more familiar with using a side view mirror to detect it. Although there are still other ways to show this warning, such as using a camera to show a real-time video on the central panel [55], it would also be interesting to discuss how to implement this project's design to the side view mirror to suit different risk scenarios. The technique used for this topic could be a focus group for participants who have mentioned it to gain user insights about their needs for design implementing on the side view mirror.

10.4.3 Expand the Work

More Modalities

Due to the limitation of time and the resources for testing, the project mainly focuses on the modality visual and audio, which works best for pre-warning and standard warning [8]. However, the haptic, which has also been stated as an essential solution for the "last-second" warning, is not being tested. The project made that decision is because the time limitation, and V2X information is usually even come earlier than the normal car detection, so it didn't much involved with the "last-second" situation. However, as mentioned before, the e-scooterists are usually more aggressive [1], and as a new vehicle, it would be meaningful to test with all modalities for it. One possible way is to add a vibrator to the seat back or brake position to simulate the haptic modality for testing.

More Scenarios

Although the current scenario already includes two typical scenes, there are still more scenes worth discovering. For example, the warning design of other typical collision types mentioned in [10], how to apply this design guideline for those scenarios would be a challenging topic; or other related scenarios mentioned in the previous Chapter Market Research A, such as the e-scooter hidden behind the bus, and other scenarios involving more complex and diverse elements are worth exploring later.

11

Conclusion

In conclusion, this master's thesis has successfully explored car warning design within the context of V2X technology, providing valuable insights on how, when, and what information should be delivered to drivers. Our findings are underpinned by comprehensive market research and literature review, offering a robust foundation rooted in design concept development.

By adopting a user-centered design approach, we conducted three rounds of design iterations and usability testing with both general users and industry experts. The first and second iterations evaluated relevant aspects of warning designs, including color, effects, multi-modality, and staged warnings. The best-performing designs from these iterations were further adjusted in the third iteration, which focused on identifying the optimal in-car display for warning placement.

The iterative design process culminated in a high-fidelity warning design, suitable to display on both HUD and cluster, along with detailed design guidelines. While acknowledging the absence of some quantitative data, the research provides valuable insights with qualitative data from driver cognitive studies that contribute to both practical applications of the E-safer project and future research related to Vehicle-to-everything warning with e-scooters.

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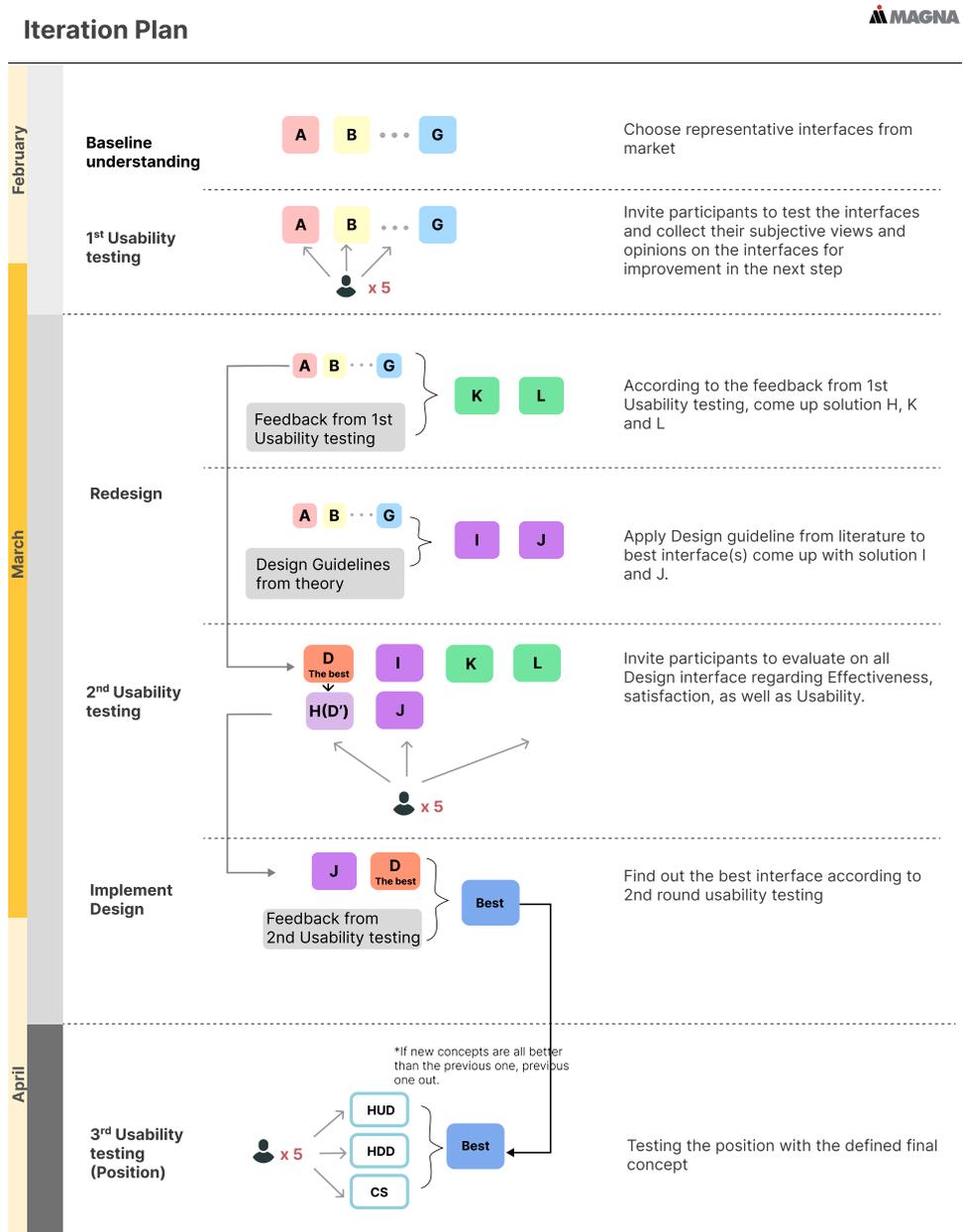
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A

Appendix: Iteration Plan



B

Appendix: Video Resource

Final Scenario Choosing:

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Other clips as an example:

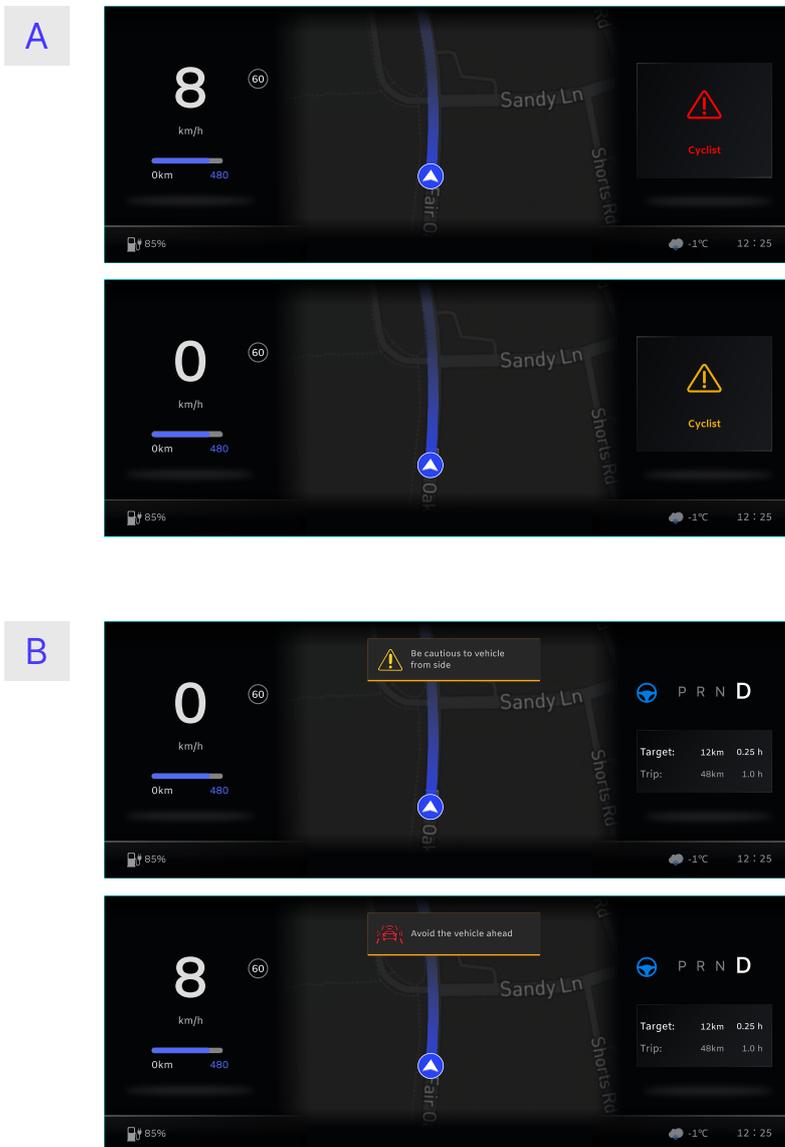
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Video reference:

1. Outdoor adventures 1. (2023, July 31). 4k driving in Stockholm city | Stockholm City terminalen - NK - kungsträdgården - strandvägen [Video]. Youtube. <https://www.youtube.com/watch?v=F6Y0miRc9xA>
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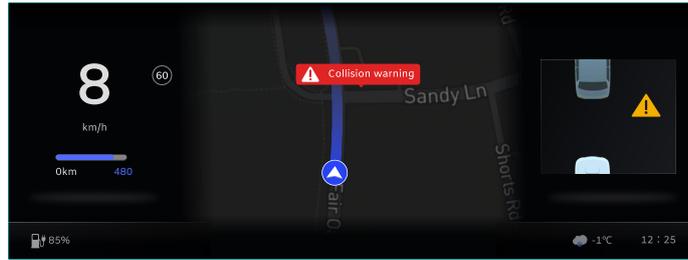
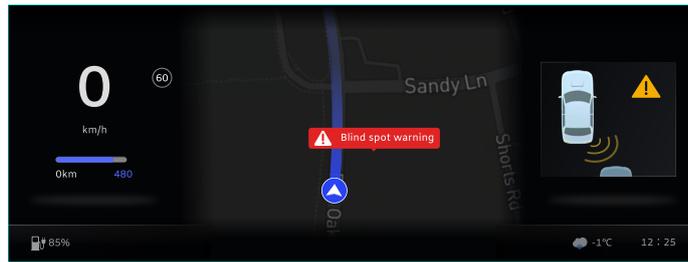
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Appendix: 1st All Concepts

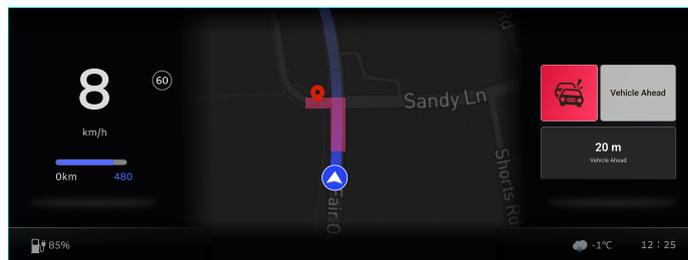
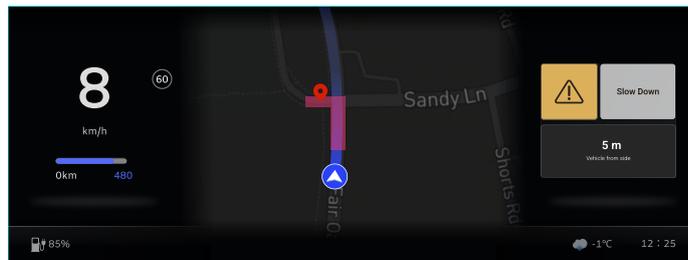


C. Appendix: 1st All Concepts

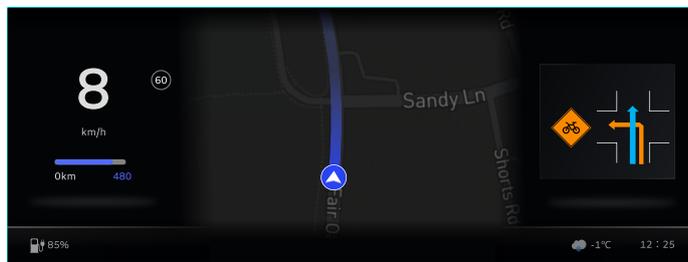
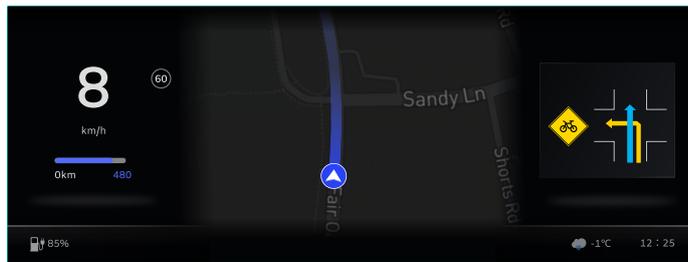
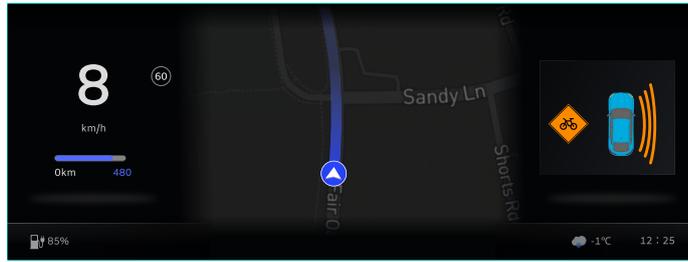
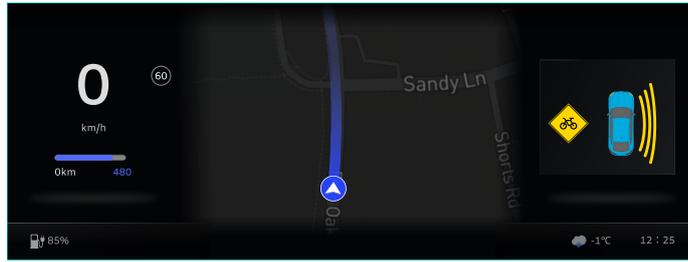
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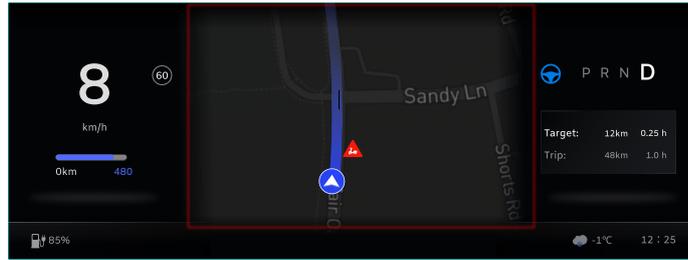
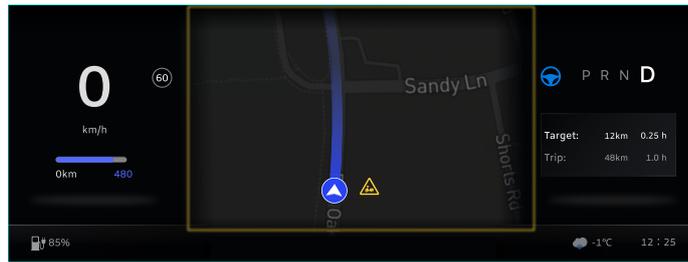


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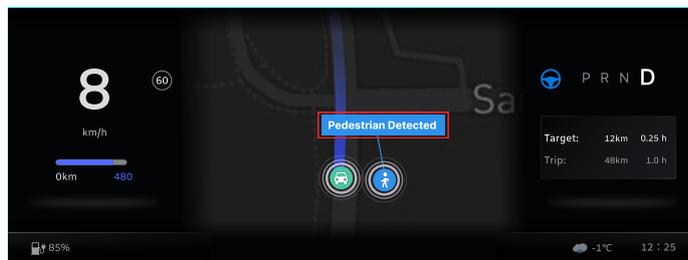
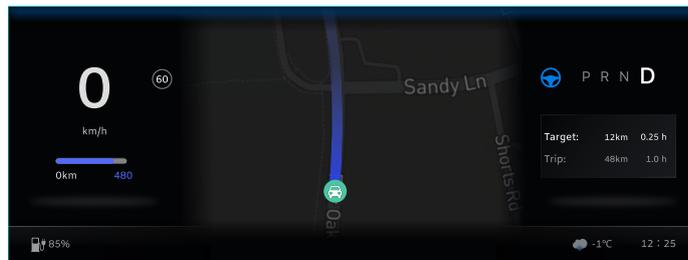


C. Appendix: 1st All Concepts

F



G



D

Appendix: Questionnaire

Basic information collection

* Required

1. Participant number *

2. Gender *

Male

Female

3. Age *

4. How long have you been driving? *

Less than 1 year

1-3 years

4-6 years

more than 6 years

5. How often do you drive (days in a week)? *

- never
- rarely
- few times a week
- almost days
- every day

6. what kind of car do you have? *

- Electric car
- Hybrid car
- Gas car
- I don't have a car
- Other

7. Your car brand

8. In general, how would you describe interactions with e-scooter riders when you are driving? (1-annoying; 5-pleasant) *Skip this question if you haven't encounter interaction with e-scooters

1	2	3	4	5
---	---	---	---	---

9. How many times have you ever experienced a near miss when interacting with someone riding an e-scooter *

- None
- Once
- Twice
- Three times
- More than three times

10. Have you ever had a incident with someone riding an e-scooter? *

- Yes
- No

11. What is the main reason do you think lead to a near miss?

12. What is the reason do you think lead to your last incident with a e-scooter?

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1st Iteration_Post-demo questionnaire

Please answer the questions according to your experience to this demo

* Required

1. Participant number *

2. Testing Demo *

Demo A

Demo B

Demo C

Demo D

Demo E

Demo F

Demo G

Overall impression

Read the following description about the warning and rate on how you agree or disagree with it

3. Overall, how clear is the information and how easy for you to understand what is happening? *

1	2	3	4	5	6	7
---	---	---	---	---	---	---

Very difficult

Very easy

4. Could you describe your overall impression about the warning? Do you have any confusion about it? *

5. The design elements, such as color, shape, size, animation effects convey the message well. *

1	2	3	4	5	6	7
---	---	---	---	---	---	---

Strongly disagree

Strongly agree

6. Why? [\(Design elements\)](#)

7. It will be better if it also contains auditory warning. *

1	2	3	4	5	6	7
---	---	---	---	---	---	---

Strongly disagree

Strongly agree

8. Why?_(Auditory warning)

9. I am satisfied with the placement and position of the warning. *

1	2	3	4	5	6	7
---	---	---	---	---	---	---

Strongly disagree

Strongly agree

10. Why?_(placement and position).

11. I am satisfied with the timing the warning occurs. *

1	2	3	4	5	6	7
---	---	---	---	---	---	---

Strongly Disagree

Strongly Agree

12. Why?_(Timing)

Overall impression_2

Read the following description about the warning and rate on how you agree or disagree with it

13. Overall, how clear is the information and how easy for you to understand what is happening? *

1	2	3	4	5	6	7
---	---	---	---	---	---	---

Very difficult

Very easy

14. Could you describe your overall impression about the warning? Do you have any confusion about it? *

15. The design elements, such as color, shape, size, animation effects convey the message well. *

1	2	3	4	5	6	7
---	---	---	---	---	---	---

Strongly disagree

Strongly agree

16. Why?_([Design elements](#))

17. I am satisfied with the placement and position of the warning. *

1	2	3	4	5	6	7
---	---	---	---	---	---	---

Strongly disagree

Strongly agree

18. Why?_([placement and position](#)).

19. The [Audio warning](#) is helpful and works well. *

1	2	3	4	5
---	---	---	---	---

Strongly Disagree

Strongly Agree

20. Why?_([Audio warning](#)).

21. I am satisfied with [the timing](#) the warning occur. *

1	2	3	4	5	6	7
---	---	---	---	---	---	---

Strongly Disagree

Strongly Agree

22. Why?_([Timing](#))

Suggestions for improvement

23. Could you please give any suggestions for improving this warning?

24. Do you have any other comments?

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1st iteration_Post-session questionnaire



After watching all the warnings, grading each warning according to your overall preference

* Required

1. Participant number *

2. Please grading the 7 demos and sort them according to your preference

Demo A

Demo B

Demo C

Demo D

Demo E

Demo F

Demo G

3. According to your preference the demo you like most is

- Demo A
- Demo B
- Demo C
- Demo D
- Demo E
- Demo F
- Demo G

4. According to your preference the demo you like the least is

- Demo A
- Demo B
- Demo C
- Demo D
- Demo E
- Demo F
- Demo G

5. Why you like Demo A the most?

6. Why you like Demo A the least?

7. Why you like Demo B the most?

8. Why you like Demo B the least?

9. Why you like Demo C the most?

10. Why you like Demo C the least?

11. Why you like Demo D the most?

12. Why you like Demo D the least?

13. Why you like Demo E the most?

14. Why you like Demo E the least?

15. Why you like Demo F the most?

16. Why you like Demo F the least?

17. Why you like Demo G the most?

18. Why you like Demo G the least?

19. How important are the following factors for creating a effective and satisfying warning? Please choose three of them which you think are important.

Please select 3 options.

- Timing
- Appearance (color, Size, Shape etc.)
- Form of risk information (Text, Graphic, Hybrid)
- Auditory warning
- Effects of Warning (Shinning, Color change, Ambience light, risk zone)
- Trajectory of Object comes
- Other

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2nd iteration_Post-demo questionnaire

Please answer the questions according to your experience to this demo

* Required

1. Participant number *

2. Testing Demo *

Demo D

Demo H

Demo I

Demo J

Demo K

Demo L

Impression

Read the following description about the warning and rate on how you agree or disagree with it.

3. Overall, how clear is the information and how easy for you to understand what is happening? *

1	2	3	4	5	6	7
---	---	---	---	---	---	---

Very difficult

Very easy

4. Could you describe your overall impression about the warning? Do you have any confusion about it? *

5. The static design elements, such as color, shape, size convey the message well. *

1	2	3	4	5	6	7
---	---	---	---	---	---	---

Strongly disagree

Strongly agree

6. Why?/ Any comments?_([Static design elements](#))

7. The dynamic design elements, such blinking, animation effects, predicted trajectory etc., help with understanding the situation well. *

1	2	3	4	5	6	7
---	---	---	---	---	---	---

Strongly disagree

Strongly agree

8. Why?/ Any comments?_([Dynamic design elements](#))

9. I am satisfied with the placement and position of the warning. *

1	2	3	4	5	6	7
---	---	---	---	---	---	---

Strongly disagree

Strongly agree

10. Why?/ Any comments_([placement and position](#))

11. The Audio warning is helpful and works well. *

1	2	3	4	5
---	---	---	---	---

Strongly Disagree

Strongly Agree

12. Why?/ Any comments_([Audio warning](#))

13. I am satisfied with the timing the warning occur. *

1	2	3	4	5	6	7
---	---	---	---	---	---	---

Strongly Disagree

Strongly Agree

14. Why?/Any comments?(Timing)

Improvement

15. What features do you like most and least about this demo?

16. Could you please give any suggestions for improving this warning?

17. Do you have any other comments?

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3rd Iteration_ Post-demo questionnaire



Please answer the questions according to your experience to this demo

* Required

Impression

Read the following description about the warning and rate on how you agree or disagree with it.

1. Participant number *

2. Testing Demo *

- HUD
- Cluster
- Infotainment

3. Overall, how **clear** is the information and how **easy** for you to understand what is happening? *

1	2	3	4	5	6	7
---	---	---	---	---	---	---

Very difficult

Very easy

4. Overall, the experience of the warning is **Pleasant** *

1	2	3	4	5	6	7
---	---	---	---	---	---	---

Strongly disagree

Strongly agree

5. The warning optimizes required action to prepare for the emergent situation *

1	2	3	4	5	6	7
---	---	---	---	---	---	---

Strongly disagree

Strongly agree

6. Why/Other comments?_ **Physical distraction** *

7. The warning reduces cognitive workload (attention, memory, decision making, etc.,) to get prepared for the emergent situation *

1	2	3	4	5	6	7
---	---	---	---	---	---	---

Strongly disagree

Strongly agree

8. Why/Other comments?_ **Cognitive workload** *

9. The Warning is useful and enhances your reaction to avoid potential collision. *

1	2	3	4	5	6	7
---	---	---	---	---	---	---

Strongly disagree

Strongly agree

10. Why/Other comments?_ **Usefulness** *

11. Do you have any other comments about the warning?

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 Microsoft Forms

E

Appendix: 1st Iteration Analysis

Overall clearness								
	01	02	03	04	05	median	mean	Top 2
Demo A	4	4	4	5	4	4	4.2	0
Demo B	3	5	6	6	5	5	5.0	2
Demo C	5	7	7	7	7	7	6.6	4
Demo D	6	6	7	7	6	6	6.4	5
Demo E	5	3	6	2	1	3	3.4	1
Demo F	4	4	7	5	4	4	4.8	1
Demo G	5	1	6	2	5	5	3.8	1
Design								
	01	02	03	04	05	median	mean	Top 2
Demo A	4	4	3	6	3	4	4.0	1
Demo B	1	3	1	6	5	3	3.2	1
Demo C	6	7	7	5	6	6	6.2	4
Demo D	6	6	7	5	6	6	6.0	4
Demo E	5	4	7	2	1	4	3.8	1
Demo F	5	4	7	5	5	5	5.2	1
Demo G	3	1	6	2	4	3	3.2	1
Placement								
	01	02	03	04	05	median	mean	Top 2
Demo A	5	3	6	5	3	5	4.4	1
Demo B	6	4	1	6	5	5	4.4	2
Demo C	6	6	7	6	6	6	6.2	5
Demo D	6	6	7	6	6	6	6.2	5
Demo E	5	3	7	2	1	3	3.6	1
Demo F	6	4	7	3	5	5	5.0	2
Demo G	1	1	6	3	4	3	3.0	1
Timing								
	01	02	03	04	05	median	mean	Top 2
Demo A	5	4	6	6	5	5	5.2	2
Demo B	6	4	1	2	5	4	3.6	1
Demo C	6	7	7	6	6	6	6.4	5
Demo D	6	6	7	6	5	6	6.0	5
Demo E	5	4	7	4	1	4	4.2	1
Demo F	6	5	3	6	5	5	5.0	2
Demo G	1	1	4	5	4	4	3.0	0

E. Appendix: 1st Iteration Analysis

C	Overall	Design	Placement	Timing	auditory	Suggestions
	<p>7 Very good, no confusion/ Clear and good/ Very clear warning. Easily understood where the object came from and where it went.</p>	<p>7 Very good symbol</p>	<p>6 I am satisfied with the first warning since the voice i telling that something is approaching and I can also see it on the dashboard. -04</p>	<p>6 Timing is good for the first warning. The second warning takes my focus away from the E-scooter in front of me. -04</p>	<p>4 First good, seond is unnecessary -04</p>	<p>A wording that is more like regular speech may make the warning less annoying. More like a passenger notifying you. -01</p>
	<p>7 The first warning is good, the second warning for front collision is a bit annoying since I can already see the e-scooter in fron of me. -04</p>		<p>6 Understandable placement that was moving along with the ride</p>		<p>2 The repetition of the sentence is good. Phrasing can be improved. This will be very annoying if the warning is triggered often. -01</p>	<p>The warning was great but possibly too disturbing. There is a chance that a driver would turn it off after a while. -02</p>
	<p>5 Very clear what is going on. The first warning had a weird phrasing of the situation, making it more confusing. -01</p>				<p>5 Clear with voice more understandable -05</p>	<p>One show the first warning, do not show the second. -04</p>
	<p>Good audio and symbols</p>					

E	Overall	Design	Placement	Timing	auditory	Suggestions
	<p>Paid too much focus on the HMI compared to the road.</p>	<p>Paid too much focus on the HMI compared to the road.</p>	<p>Yellow and red is easy to detect against that background.</p>			<p>Reduce the amount of text. -01</p>
	<p>Too many warning signs on the dashboard and too much text to read</p>	<p>LEAST Too many boxes, the information is a bit messy and takes my focus away from e-scooter on the road. -04</p>	<p>dont like that there are three warning signs and my attention is taken by all three of them.</p>			<p>Less text, more central (laterally) and in the windscreen is better. -02</p>
	<p>Too much text.</p>	<p>LEAST Lack of visible symbols and audio -05</p>				<p>Only have one box, not so much text, add sound warning. -04</p>

E. Appendix: 1st Iteration Analysis

F

Overall	Design	Placement	Timing	auditory	Suggestions
<p>Easy to notice without having to redirect my focus. Harder to know exactly why it is doing it.</p>	<p>Overall the second warning for the e-scooter in front of me made me aware that he is coming closer in front and making a left-turn. -04</p>	<p>5 A bit small but good -05</p>	<p>Color the side of the box where the threat is.</p>	<p>Color the side of the box where the threat is.</p>	<p>Just show one sign that something is approaching on my right-side also with sound.</p>
<p>the second one with the sound is much better.</p>	<p>The former G image is better</p>	<p>3 Didn't like the first warning since its moving around on the dashboard taking my focus away from the e-scooter on my right-side. -05</p>		<p>Larger symbols, closer too the windscreen.</p>	<p>Maybe a larger symbol and blinking</p>
<p>I liked the image from the last one better, but the audio was good</p>	<p>It was good that the shape was changing when it got closer -05</p>				

G

Overall	Design	Placement	Timing	auditory	Suggestions
<p>6 Ok but hav been more clear</p>	<p>2 Not necessary to see the warning sign travel around the car, made me focus on the moving sign on the dashboard instead of looking in front at the E.scooter. -04</p>	<p>1 Not notice any warning -01 <small>TimmyZhang</small></p>	<p>1 Not notice any warning -01</p>	<p>7 To get my attention/ React faster/</p>	<p>I did not notice any warning. -01</p>
<p>5 Good warning but combined with audio would be a bit better especially when the scooter was very near the car -05</p>	<p>4 Good -05</p>	<p>3 Not so good that it is moving around on the dashboard. -04</p>	<p>4 Too late -03</p>	<p>5 Just to wan me that there is a someone approaching. -04</p>	<p>Showing only which side the E-scooter is coming, no moving warning sig on the dashboard is better, also add a sound. -04</p>
<p>5 I would not consider it a warning. The car identified a threat and showed the object showing that it was aware of the escooter. -01</p>	<p>LEAST Did not notice any warning. -01</p>	<p>4 Perhaps closer to the window because you have the eyes there all the time especially when you found the scooter -05</p>	<p>5 Timing is ok -04</p>	<p>LEAST No sound and small symbols, far down, with text made it unclear what was happening. -02</p>	<p>with audio, and maybe a different colour (red) when its closing -05</p>
<p>1 Didn't hear or see a warning -02</p>	<p>2 It was warning for a pedestrian, i start to look for the pedestrian and then suddenly someone appear on my rightside with an E-scooter. Not so good representation/HMI. -04</p>		<p>LEAST Late timing -03</p>		

A

Visual

- Icon should be more visible
- Thicker line / filling
- Change the background of warning to have a higher contrast
- Make the icon larger

Effects

- color changing is good
- Add blink?
- Placement should corresponds with e-ecooters
 - Side > center
- Distinguished warning for the first and second warning

Audio

- Add audio
- Only audio for the second

B

Visual

- Icon should be more visible
- Dif shade or change the background to have a higher contrast
- Larger symbols
- Less text

Effects

- Popup occurred very quickly, slower animation?
- Placement
 - Keep the warning close to the sight (center in this study)
- Distinguished warning for the first and second warning

Audio

- Add sound

Timing

- 1st warning should be earlier

E

Visual

- **too many warnings boxes**, takes my focus away from e-scooter on the road.
- too much text, can't read it
- Lack of visible symbols and audio
- + yellow and red is easy to derected aganst background
- dont like that there are three warning signs and my attention is taken by all three of them.

C

Visual

- Icon/content
 - Good to know where (direction) the risk come from

Effects

- Moving along with the ride
- Placement corresponding with the scooter
- Remove the second warning visual content

Audio

- Voice could provide direction information
 - But sound is preferred
 - Or change the content of phrase, maybe like a passenger notifying you
 - Shorter speech
- Remove the visual of the second warning

Timing

- Giving the warning earlier or make the speech shorter

F

Visual

- Larger icon
- Simple graph

Effect:

- Side ambience light
- Blinking is good

Placement

- A warning sign at the corner or on the top would be good
- Less moving around, just the sign moving but relatively static

G

Visual

- No moving
- Do not use the pedestrian sign
- Use a more emergent color for warning (red)
- Larger symbol

Effects:

- Color changing is good.

Placement

- Closer to the window

Audio

- Add audio that warn the driver there is something approaching

F

Appendix: 3rd Post-demo Quantitative Analysis Record

Single easy question				Cognitive workload			
Participant No.	Cluster	HUD	Infotainment	Participant No.	Cluster	HUD	Infotainment
1	5	7	7	1	3	5	5
2	4	6	3	2	3	3	3
3	7	7	7	3	6	7	6
4	5	7	7	4	5	6	4
5	7	6	4	5	6	5	4
Average	5.6	6.6	5.6	Average	4.6	5.2	4.4
Top two Box	2	3	3	Top two Box	2	2	1
Overall experience				Usefulness			
Participant No.	Cluster	HUD	Infotainment	Participant No.	Cluster	HUD	Infotainment
1	4	5	6	1	4	7	6
2	5	6	3	2	4	6	3
3	6	7	5	3	7	7	6
4	5	7	5	4	5	7	4
5	7	6	4	5	6	6	4
Average	5.4	6.2	4.6	Average	5.2	6.6	4.6
Top two Box	1	2	0	Top two Box	2	3	2
Physical Distraction							
Participant No.	Cluster	HUD	Infotainment				
1	3	6	4				
2	4	6	2				
3	6	7	7				
4	5	7	3				
5	6	6	4				
Average	4.8	6.4	4				
Top two Box	1	2	0				

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