



CHALMERS



Argus - Increasing Driver Awareness via Ambient Light

Exploring the Possibility of an All-around Awareness System

Bachelor's thesis in Industrial Design Engineering

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CHALMERS UNIVERSITY OF TECHNOLOGY

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Cover: Visualization constructed in VRED showing the final concept Argus

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Abstract

This project explores current and potential future driver awareness systems. The aim was to investigate how such systems are perceived by users and to develop a concept that enhances driver awareness without increasing cognitive load. A combination of interviews, questionnaires, benchmarking, and literature studies were done to gather relevant understanding and insights. The findings suggest that users desire more information while maintaining a sense of control, particularly regarding areas outside the driver's current field of vision in existing blind spots. It also suggest that existing awareness systems can be improved through a reconstruction of feedback. The final concept, Argus, provides increased spatial awareness through ambient light and communicates information about the surroundings in an intuitive and non-intrusive way.

Sammanfattning

Detta projekt utforskade nuvarande och potentiella framtida *driver awareness*-system. Syftet var att undersöka hur befintliga system uppfattas av användare samt att utveckla ett koncept som förbättrar förarens *driver awareness* utan att öka deras kognitiva belastning. Projektet baserades på intervjuer, enkäter, marknadsanalys, litteraturstudier och användartester för att skapa en bred förståelse för området. Utifrån den insamlade datan identifierades centrala önskemål och krav kopplade till dessa system.

Resultaten visar att användare efterfrågar utökad information, samtidigt som de inte vill att bilen fattar egna beslut, då föraren vill behålla känslan av kontroll över fordonet. Vidare identifierades en problematik kring döda vinklar, både i relation till speglar och bilens A-stolpar.

Projektets huvudsakliga resultat är konceptet Argus, som förbättrar den rumsliga uppfattningen kring fordonet genom ambient belysning. Konceptet bygger på strategiskt utplacerade ljuskällor som kommunicerar rörelser i omgivningen på ett intuitivt och diskret vis, med potential att förbättra förarens lägesuppfattning i komplexa trafiksituationer.

Executive Summary

This bachelor's thesis was done based on a project brief by the automotive companies Lynk & Co and Zeekr. The project explored the development of a user-centered all-around awareness system. Driver awareness is a key factor in road safety. It impacts how effectively drivers can perceive the traffic environment, comprehend the current traffic situation, and project the future traffic status. As vehicles and their systems become more advanced, it is increasingly important that the systems effectively support the driver's awareness.

The purpose of this project was to understand users' perception on existing awareness systems and explore how driver awareness can be further improved. The objective of the project was to develop a user-centered concept that improves driver awareness without increasing users' cognitive load. A definition of driver awareness was created, which applies situational awareness in the context of driving, meaning the awareness of events happening outside the car in the surrounding traffic.

The project initially focused on problem definition and data collection through literature studies, benchmarking, questionnaires, interviews, and observations. A key insight from this phase was that many users found existing systems too intrusive and therefore disabled them. Additional findings included a desire for more information about the surroundings, especially regarding areas outside the driver's current field of vision and existing blind spots. Besides vehicle related blind spots, the driver's field of vision can often be obstructed by the surrounding environment, including infrastructure and other vehicles. However, systems that intercepted actions and reduced the driver's sense of control were not appreciated.

Based on the insights and knowledge gained from the initial phases, ideas regarding increased awareness were generated. These ideas were combined, merged, and put together through several iterations of idea generation, resulting in a final concept based on interior ambient lighting that increases driver awareness via visual feedback.

The final concept Argus provides increased driver awareness through ambient light and is visualized in Figure 0.1.



Figure 0.1: Overview of the Final Concept

Argus is based on strategically integrated light sources located in the front doors, on the A-pillars, and at the center front beneath the windshield, correlating to the zone it informs about. Through subtle light patterns that correspond to external events, one of them presented in Figure 0.2, the system communicates information about the surroundings in an intuitive and non-intrusive way. This allows the driver to remain visually focused on the road while becoming more aware of nearby traffic and surrounding vehicles.



Figure 0.2: Three Sections of Moving Ambient Lights on Front Door

This report presents the research and development process, key insights, and results from these phases, as well as a discussion of the project and the future of ambient lighting as an awareness system.

Acknowledgements

This report was written as part of a bachelor's thesis in which a group of six students explored the design of driver awareness systems. The bachelor's thesis was conducted within the course IMSX16 in Industrial Design Engineering at Chalmers University of Technology. The stakeholders involved in the project were Lynk & Co and Zeekr, two automotive companies within the Zhejiang Geely Holding Group operating primarily in the European and Chinese markets.

We, a group of six students from the Industrial Design Engineering program at Chalmers University of Technology, would like to thank our supervisor, Oskar Rexfelt, for his invaluable support and guidance on our journey of exploring and refining driver awareness systems in cars. Likewise, we would also like to thank Anton Romell and his team from Zeekr, and Stefano Oliva from Lynk & Co, for proposing such an exciting and rewarding thesis project and for supporting us throughout the entire process. Special thanks go to Andreas Dagman for facilitating the initial contact with the stakeholders and establishing the collaboration with Lynk & Co and Zeekr.

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1

Introduction

The automotive industry is currently undergoing a fundamental transformation, advancing from passive crash protection toward active accident prevention. While new regulations mandate advanced awareness systems to save lives, the resulting flood of information paradoxically increases the driver’s cognitive load. Since a minor lapse in awareness can have severe consequences for both the driver and the surrounding traffic, the need for intuitive, user-centered systems has never been greater. This chapter introduces the project, exploring how awareness systems can support the driver without adding to the complexity of modern driving.

1.1 Background

This project explores how demanding traffic environments and new vehicle technologies require a user-centered approach to all-around awareness to enhance road safety.

From Passive Protection to Active Prevention

Every year, more than 135,000 people are seriously injured in vehicle collisions across Europe (“EU road deaths drop by 3% in 2025 - Mobility and Transport”, n.d.). This statistic has contributed to the implementation of the European Union’s General Safety Regulation (GSR), which makes systems such as intelligent speed assistance, reversing detection, lane keeping assistance, and attention warning mandatory for all new cars. This is expected to save 25,000 lives before year 2038 (“New Vehicle General Safety Regulation”, n.d.).

The new regulations shifts the focus from passive protection, such as seat belts and airbags, and toward active driver assistance systems (ADAS). It also presents a new challenge for the automotive industry, ensuring that advanced safety technologies support the driver without increasing cognitive load. This project addresses this development by exploring awareness systems designed to optimize driver awareness in cognitively demanding traffic environments.

Information Processing and Cognitive Limitations

Driving is a cognitively demanding task which requires the driver to continuously process a high volume of information. In the context of this project, an awareness system refers to a system that assists the driver in increasing awareness of their

surroundings, such as rear view camera and blind spot monitoring. These systems aim to increase driver awareness. Driver awareness refers to the situational awareness (SA) (Endsley, 1995) regarding the surrounding traffic environment.

The reduced time-to-market makes it more challenging to have a holistic overview of the design process as new systems are developed and implemented rapidly in order to stay competitive. Many of these systems are intrusive, meaning the feedback is forced upon the user which might draw the driver's attention away from the road. Together, these factors highlight the complexity of maintaining a high level of driver awareness, and underline the need for awareness solutions that support the driver without adding to an already demanding cognitive environment.

The Paradox of Visibility and Distraction

Modern cars are becoming smarter and new technology and systems is integrated constantly. Paradoxically, drivers are getting distracted by the systems. One particular area of interest is the touch screen infotainment system which has become the new standard in modern cars. According to road safety expert (Haghani, 2026), in interaction with the touchscreen, reaction times decrease by more than 50% compared to baseline driving which results in a high increase in the stopping distance.

Most modern vehicles use screens to enhance awareness, which in some cases can significantly increase distraction. Direct glances at screens while driving require the driver to look away from the road, which, as mentioned above, increases stopping distance and negatively impacts road safety. Cognitive load from such systems can cause a notable decrease in road safety and overwhelm the driver, which may result in frustration, distraction and exhaustion. Ultimately, this indicates a gap and a need for systems designed with more focus on the human-machine interaction (HMI).

Vulnerable Road Users and Interaction Gaps

Blind spots are areas outside the driver's field of vision that are also not covered by mirrors. In 2025, the number of EU road deaths reached around 19,400, of which about 18% were pedestrians and 9% cyclists ("EU road deaths drop by 3% in 2025 - Mobility and Transport", n.d.). Blind spot situations and driver's distraction are notable crash factors (Knight, n.d.). As the systems evolves and become more complex, there is a challenge balancing what information the system provides and the driver needs. Another challenge is to understand the driver's cognition, needs, wishes, and emotions regarding systems that assist the driving task, in order to transform them from complex and frustrating to simple and satisfactory. Understanding the driver's awareness and interaction with systems can contribute to a safer traffic environment for vulnerable road users by providing the right information at the right time, enabling the driver to form an accurate perception of the situation.

1.2 Purpose

The purpose of this project was to explore the possibility of an all-around awareness system by understanding the user's perception of existing awareness systems and exploring how driver awareness can be further improved.

1.3 Objective

The objective of the project was to develop a user-centered concept that improves driver awareness without increasing the user's cognitive load.

The main focus of the project was to increase driver awareness in traffic contexts that are cognitively demanding by developing concepts for user-centered awareness systems that can be implemented in the near future.

Research Questions

To guide the project process, the following research questions were used as a framework. The areas in bold represent the main areas investigated, with the sub-questions serving as more specific guidance.

Driver Awareness

- What defines driver awareness?
- What affects driver awareness?

Existing Driver Awareness Systems

- What defines an awareness system?
- What different types of driver awareness systems are implemented today?
- What are the benefits and drawbacks of existing awareness systems?

The Context

- What characterizes the traffic situation in the selected context?
- What is important for drivers in the selected context?

Human-vehicle Interaction

- What affects drivers perceived safety and control in the vehicle?
- How does an awareness system avoid cognitive overload for drivers?
- How do users perceive and evaluate an all-around awareness system?
- How do awareness systems affect driver behavior?

Gaps and Requirements

- Are there gaps in current awareness solutions that need to be addressed?
- What user demands are to be placed on an all-around awareness system?

Awareness System Concept Development

- What concepts could lead to an all-around awareness system?
- How can the concept be tested and evaluated?

1.4 Scope

The scope of the project was to deliver a final concept, not a production-ready product. The project therefore did not delve into how specific technologies such as sensors, cameras, or radars function. However, a conceptual understanding of such technologies was necessary for the development of the final concept.

According to On-Road Automated Driving (ORAD) Committee (n.d.) there are six levels of automation for vehicles, from fully manual (Level 0) to fully autonomous (Level 5). The project focused on automation Level 2, which refers to cars with advanced driver assistance systems that can intervene with steering and acceleration. Studies have shown that at automation level 2, the frequency and duration of off-road glances increase significantly, which highlights the need for improved awareness systems (Chakraborty et al., 2024). It is possible that, at this low level of automation, the driver gains a false sense of safety and perceives the vehicle to provide a higher level of automation than it actually does. This limitation was applied to ensure the relevance of the project in the near future, where most vehicles still operate at this level.

2

Final Result: Argus

The main result of this project is the final concept *Argus*, developed to increase driver awareness. Similar to the Greek mythological giant from which the concept takes its name, see 3.6 Argus: the 100-Eyed Guardian, it can be stated to have *a hundred eyes*, as it continuously monitors the surroundings of the vehicle. Many awareness systems today demand the driver's direct visual attention, which impairs their ability to keep the eyes on the road. On top of that, both the vehicle itself and external factors such as infrastructure and surrounding traffic, can obstruct critical areas of the driver's field of vision.

Argus provides increased spatial awareness through functional ambient lighting. The system is based on strategically integrated light sources located in the front doors, on the A-pillars, and by the windshield, correlating to the zone it informs about (see Figure 2.1). Through subtle light patterns that correspond to external events, the system communicates information about the surroundings in an intuitive and non-intrusive way. This allows the driver to remain visually focused on the road while becoming more aware of nearby traffic and surrounding vehicles.



Figure 2.1: Cabin Perspective of the Final Concept

2.1 Functionality

Argus consists of distinct light sources integrated into a single system. The following section presents the functions of the individual lights, as well as the functionality of the system as a whole.

Light Placement

As a complement to the binary blind spot light in the side mirrors, ambient lights integrated in the front doors uses light pulses to communicate the relative position and speed of vehicles in the driver's blind spot. This enables a more intuitive understanding of surrounding traffic (see Figure 2.2).



Figure 2.2: Three Sections of Moving Ambient Lights on Front Door

The light bar on the A-pillar serves not only as an indication that an object is obscured in the blind spot area behind the A-pillars, but also as a warning for objects approaching from the side. Both situations require similar response from the driver; slowing down and remaining attentive to the surroundings, which is why they are integrated within the same light element. However, to support a clearer understanding of the situation, the feedback is differentiated through separate segments that activate depending on the context (see Figure 2.3).

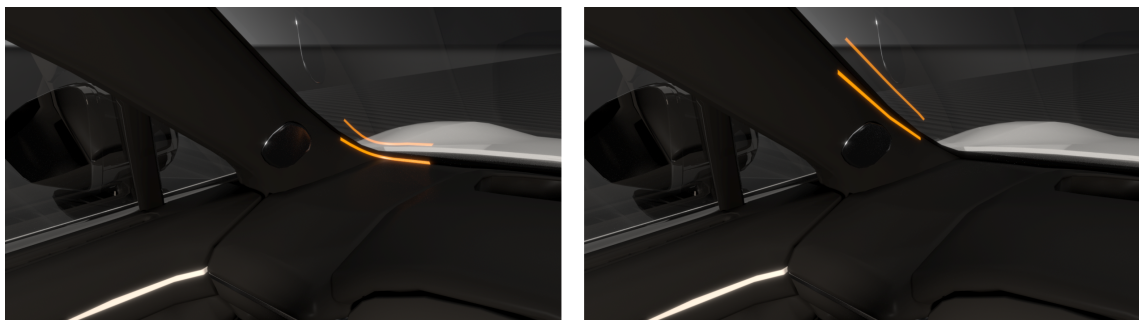


Figure 2.3: The Curved and the Vertical Light on the A-Pillar

A subtle horizontal light bar is positioned at the center front beneath the windshield (see Figure 2.4), where illumination originates at the center and progressively extends outward along the LED strip as the distance between vehicles decreases, acting as a visual alert for tailgating behavior.

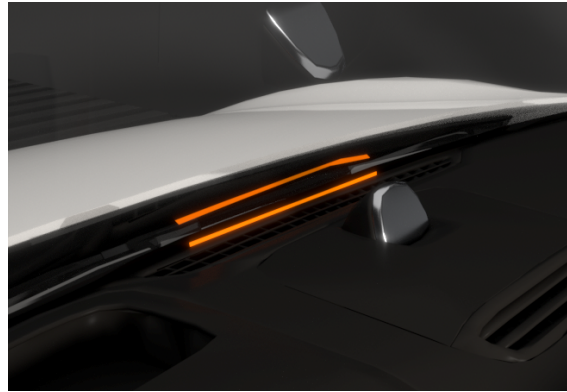


Figure 2.4: Horizontal Light Bar Along the Windshield

System overview

The system is designed to feel as a cohesive awareness system rather than functioning as separate light sources. This allows a single object to be shown across multiple zones. Since the systems are distributed across different light sources mapped to its surroundings, no single element is prioritized over another. If a vehicle is present in the blind spot while the distance to the car ahead is too low, both lights will activate, indicating the need for extra attention. To make the system feel as one, a consistent customizable color is used across all light sources. In addition, similar movement patterns are used to encourage intuitive learning and promote the subconscious understanding of the correlation of outside events to interior lighting patterns.

The light strips will adapt their intensity based on ambient light conditions and time of day to ensure visibility without causing glare. Also, the light fades in to avoid triggering an emergency response before the driver has had a chance to scan the surrounding area.

3

Theoretical Background

This chapter describes the definitions used in the project, methods for measuring awareness, car accident risk factors and statistics, as well as regulations and trends within the automotive industry. It also covers existing awareness systems, vision and visual feedback systems, and the meaning behind Argus.

3.1 Definitions

Throughout the report, the concepts of *Driver Awareness*, *Driver's Awareness*, *Driver Awareness System* and *The Maki Roll Theory* will be used. Since there are no established definitions to be used, definitions have been developed based either on existing theories or as self-developed conceptualizations and visualizations.

Defining Driver Awareness

Driver awareness was the main concept of the project and is based on the already existing theory of situational awareness (Endsley, 1995). Situational awareness is a cognitive theory about the perception, comprehension, and prediction of elements and their status within the environment (Bohgard et al., 2019). The theory consists of three parts:

- Perception of the elements in the environment
- Comprehension of the current situation
- Projection of future status

An important aspect of the three components is that each depends on a distinct ability: perception of environmental elements requires practiced attention, comprehension of the current situation requires knowledge, and projection of future states requires experience.

In this project, driver awareness will be defined as situational awareness applied in a traffic context. Translated into the traffic context, driver awareness can be interpreted as:

- Perception of the elements in the traffic environment
- Comprehension of the current traffic situation
- Projection of future traffic status

This means that driver awareness describes the cognitive understanding of a certain traffic context. Achieving high driver awareness was one of the main goals of the project and is also essential to maintain safety in traffic. High driver awareness can be achieved through practiced attention, knowledge, and experience of driving in a traffic context.

Defining Driver's Awareness

Driver's awareness is another important concept that refers to the awareness of a specific driver in a particular moment or situation. It focuses on the individual's current state and is used when describing the extent of a driver's performance or behavior. In comparison to driver awareness, driver's awareness is more subjective and not considered being a cognitive theory. Driver's awareness is based on the concept of performance shaping factors (PSF) (Bohgard et al., 2019), where an individuals overall ability to complete a task is affected by several factors: internal factors, external factors, and stressors.

The internal factors that can affect an individual's performance are physical conditions (for example, age, hearing, and vision) and mental conditions (for example, personality, emotional state, and stress tolerance).

The external factors that can affect an individuals performance can be latent (for example, vehicle ergonomics, traffic density, and weather conditions) and operational (for example, communication tools, navigation system usability, and driver monitoring systems). External factors that may affect the driver also include auditory, visual, and haptic feedback from the systems mentioned above.

Stressors that can affect an individual's performance are psychological stressors (for example, risks, distractions, and high workload) and physiological stressors (for example, fatigue, discomfort, and exhaustion).

Defining Driver Awareness System

A driver awareness system is a vehicle system designed to support the driver by enhancing awareness of the surrounding traffic environment. Technologies employed in driver awareness systems (for example, cameras, radars, and sensors) are used to improve the perception, comprehension, and predictions of future states regarding traffic elements, resulting in higher driver awareness. When the driver receives the information through system feedback, the purpose is to enhance the overall driver awareness. Driver awareness systems are operational external factors affecting the performance of the driver. In contrast, an all-around awareness system is a vehicle system designed to provide a comprehensive overview of the traffic context.

Defining The Maki Roll Theory

The maki roll theory, see Figure 3.1, was developed to illustrate how the project group conceptualized the relationship between driver awareness, driver's awareness, and driver awareness systems. The figure shows how driver awareness emerges through the interaction between the driver's internal awareness and the vehicle's awareness systems. This relationship can be compared to the layered structure of a maki roll. In the model, the orange circle at the center represents the driver's individual awareness, which corresponds to the core filling of the Maki roll. The surrounding white area represents the vehicle's driver awareness systems, comparable to the white rice layer that supports and surrounds the filling. The dark outer boundary symbolizes the combined or total driver awareness that can be reached through the interaction between the driver's awareness and the awareness systems, similar to the nori shell enclosing the maki roll. Finally, the dashed outer circle represents the traffic context in which this interaction takes place, comparable to a maki roll placed on a plate.

An illustrative example is a relatively small core filling, which represents low driver's awareness, for instance due to limited driving experience, fatigue, or reduced stress tolerance. A comparatively thick rice layer may represent a modern vehicle equipped with a range of driver awareness systems. Together, these components constitute the total driver awareness as conceptualized in the model. A larger maki roll represents a higher level of driver awareness. While the rice cannot expand the core, it may reduce it if the awareness systems themselves demand attention away from the driving context.

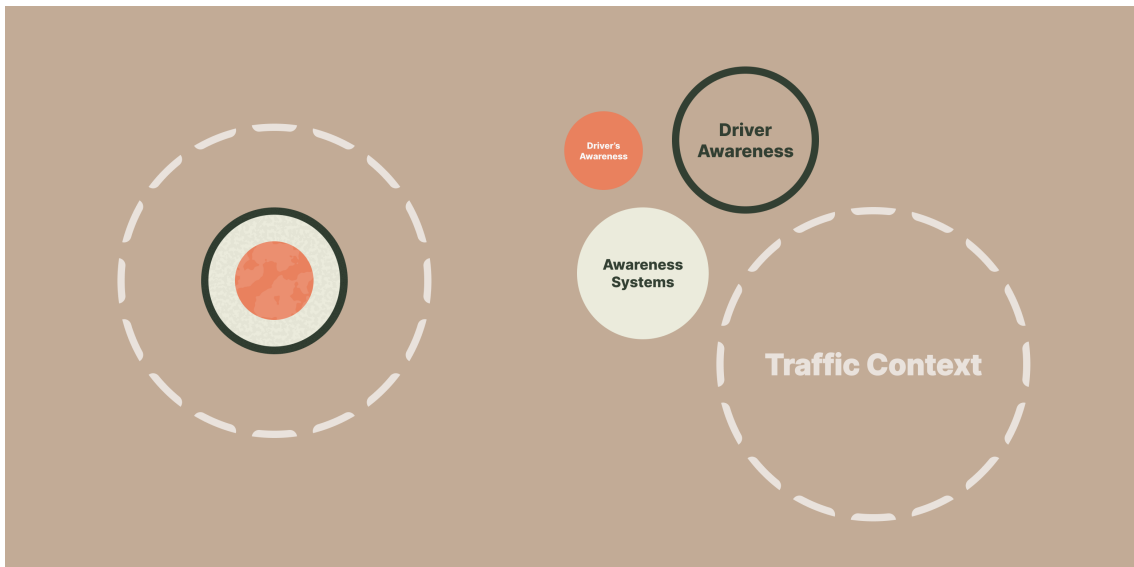


Figure 3.1: The Maki Roll Theory

3.2 Measuring Awareness

Driver awareness can be assessed using a range of methods, depending on the purpose of the evaluation. The Situation Present Assessment Method (SPAM) and the Situation Awareness Rating Technique (SART) are two methods used to evaluate awareness. Both were originally developed to assess situation awareness of pilots in air traffic control contexts (Durso et al., 1999).

SPAM

The Situation Present Assessment Method is a probe-based technique that measures a person's cognitive workload and attentional availability in real time ("Situation Presence Assessment Method (SPAM) | SKYbrary Aviation Safety", n.d.). SPAM measures the time between the presentation of a query and the participant's response, where the questions rely on information available in the current environment rather than memory.

SART

The Situation Awareness Rating Technique is a simple post-task subjective rating method that measures the driver's own perception of focus ("Situation Awareness Rating Technique (SART)", 2019). SART uses a seven-point scale, from low (1) to high (7), in which participants rate their own performance across different categories.

3.3 Car Accident Risk Factors

Blind spots and tailgating are both critical concerns in road safety. The statistics below provide an overview of the risks associated with blind spots and tailgating behavior.

Blind Spot-Related Accident Statistics

Blind spots are areas around the vehicle that are not directly visible to the driver ("Vehicle blind spot", 2025). Approximately 40% of a vehicle's surrounding area consists of blind spots (Friedman, 2025), where blind spots account for approximately 18% of all intersection crashes (Santos, 2026). Over time, A-pillars have become wider to improve roof structural strength, which has increased blind spots and, consequently, the risk of collisions (Kelley, 2025).

Tailgating-Related Accident Statistics

Tailgating refers to a driving behavior in which a driver follows another vehicle too closely without leaving sufficient distance to avoid a collision if the vehicle in front suddenly brakes ("Tailgating", 2025). Intentional tailgating can occur when a driver is angry or as an attempt to change other drivers' behavior. Dense traffic and lack

of knowledge about the recommended safe distance can instead cause unintentional tailgating (Stephens et al., 2023). Tailgating contributes to 33% of all car accidents, and about 75% of tailgaters are unaware of the three-second rule for maintaining a safe following distance (“100+ Tailgating Accident Statistics (2026, Verified)”, 2026). In addition, between 50% and 89% of all rear-end collisions are caused by or involve tailgating behavior (“Tailgating”, 2025).

3.4 The Car Industry

The car industry is a big industry that is very regulated with a fast paced innovation. To understand this report it is essential to have a grasp on a few current regulations and systems that most modern cars have. This section will supply all the necessary theoretical knowledge.

European New Car Assessment Programme

The European New Car Assessment Programme, or NCAP for short, is an independent organization that focuses on improving vehicle safety for consumers. NCAP’s safety rating is a global benchmark on how well a vehicle performs in different categories “EuroNCAP | Euro NCAP – Helping you choose the safest cars since 1997” (n.d.).

Existing Awareness Systems

Due to the long history of the automotive industry and the central role of cars in many peoples’ lives, numerous systems and technologies have been developed to make driving safer and easier. It is crucial to understand the systems from the past to understand what this project is trying to achieve in the future. The most prevalent systems that are necessary to understand for this report are listed in Table 3.1.

Table 3.1: Existing Awareness Systems

System	Description	Source
Lane Assist	Helps the driver stay in lane using cameras and sensors; primarily used for highway driving.	(“Lane centering”, 2025)
360° camera	Stitches multiple camera views into a 360° visualization on the center screen; typically activates during parking or when reversing.	(“Surround View Cameras”, 2024)
Speed Assist	Alerts the driver via audio cues when the current speed limit is exceeded.	(“Intelligent speed assistance”, 2026)
Blind Spot Monitoring	Detects objects in the driver’s blind spot and provides visual alerts, often via indicators on the side mirrors.	(“Blind spot monitor”, 2026)
Adaptive Cruise Control (ACC)	Maintains a set speed while automatically adjusting to the distance and speed of vehicles ahead.	(“Adaptive cruise control”, 2026)
Driver Monitoring	Monitors the driver’s eyes and attention levels, providing warnings for fatigue or distraction.	(“Driver monitoring system”, 2026)
Exit Warning	Warns occupants when opening doors if an approaching vehicle is detected.	(“Volkswagen’s new exit warning system reduces dangers when opening the doors”, n.d.)
Automatic Emergency Braking	Automatically applies brakes to prevent or mitigate collisions with objects ahead.	(“Automated emergency braking system”, 2026)
Seat Belt Warning	Provides an alert if the driver or passengers have not fastened their seat belts.	(“Seat belt”, 2026)
Traffic Sign Recognition	Uses cameras and navigation data to identify and display road signs to the driver.	(“Traffic-sign recognition”, 2026)
Digital Rear View Mirror	Replaces the standard mirror with a high-resolution screen showing a live feed from the rear of the vehicle.	(“Digital Side Mirror Insights”, n.d.)
Digital Side View Mirror	Uses external cameras and internal screens to replace traditional side mirrors, showing the vehicle’s flanks.	(“Polestar 4”, n.d.)
Tesla Traffic Visualization	Overlays real-time traffic data on the map to optimize routing, ETA calculations, and automatic re-routing.	(“What is Tesla Live Traffic Visualization”, n.d.)

3.5 Vision and Visual Feedback Systems

Vision is the most important sensory input and plays a dominant role in decision-making while driving (“Why Is Vision the Most Important Sense in Driving?”, 2026). This section presents theory on the importance of vision, the driver’s field of vision, and ambient lighting as a visual feedback system. It provides a better understanding of vision and how variations in visual feedback can influence driver behavior.

Importance of Vision

Vision constitutes approximately 80% of human sensory experiences (J. Fink et al., 2022), making it the most dominant of the five senses (Ahn et al., 2015), with the human eye capturing more than 90% of information from the surrounding environment. Color perception is an important part of vision and influences how we experience the surrounding world by supporting object recognition, scene organization, and visual memory, while also adding an aesthetic aspect (Gegenfurtner, n.d.). Together with luminance and shape, color is processed within the same neural circuits to create a clear representation of the visual environment.

Driver’s Field of Vision

The central vision area is the part where the driver is most aware and sees most clearly. The driver also receives input through peripheral vision, which is essential for driving. However, due to poor resolution, the driver should rely on the central vision field to accurately perceive the surroundings (Zhaoping, 2024). Parts of the peripheral vision are obscured by the car’s A-pillars, which vary depending on the vehicle and the driver’s seating position. Other vision areas include the blind spot, which the driver can not be aware of without a movement of head or other form of assistance, and the rear vision area which is covered by the different mirrors. Figure 3.2 shows the driver’s field of vision areas (Sołowczuk, 2021) as well as an approximation of the area obscured by the A-pillars. As the figure shows, a driver’s vision is around 180 degrees. This mainly consists of peripheral vision and partly central vision, which additionally decreases with higher speeds.

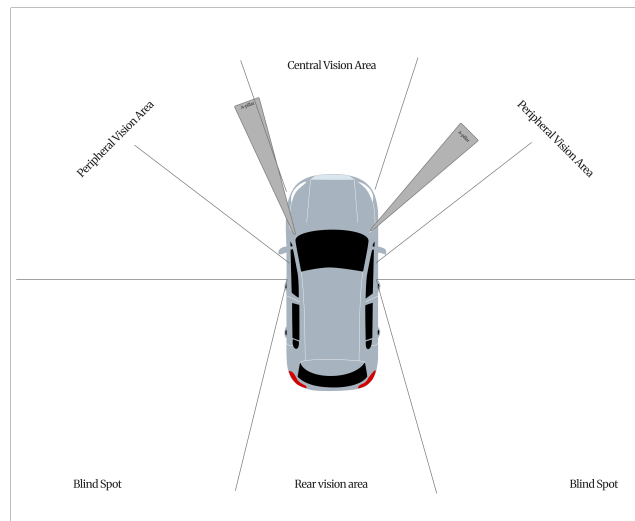


Figure 3.2: Driver's Field of Vision

Ambient Lighting as Visual Feedback

The advent of Light Emitting Diodes (LEDs) in the late 20th century has revolutionized design possibilities of modern automotive lighting (Croft, 2025). LEDs are now standard in exterior and interior applications, including headlights, taillight indicators, and interior lighting (Kapur, n.d.). Since the advent of LEDs, many car manufacturers started experimenting with ambient lighting for a luxury experience. The use of ambient lighting systems as aesthetic, contributes to a more immersive driving experience by enabling customization and enhancing the overall interior atmosphere.

Variations in LED color, brightness, animation, information, and placement of interior lighting systems can influence the drivers' emotional responses, different studies show (Kim, Lee, et al., 2022).

The color and temperature of lighting significantly affect drivers. Warmer white light improves problem-solving skills and overall performance, while cool white lighting hinders long-term memory (Wang et al., 2025). High frequency color lighting, such as blue and purple, improves alertness ("Preh: Ambient lighting for car interior - design and safety", n.d.) and have the highest preference and uniqueness among the colors (Kim, Choi, & Suk, 2022). They also convey a futuristic image towards the customers (Kim, Lee, et al., 2022). Low frequency color lighting, such as orange and yellow, are considered soft (Kim, Choi, & Suk, 2022) and increase the feeling of comfort ("Preh: Ambient lighting for car interior - design and safety", n.d.). The color red is considered unique and rough, but had the lowest preference among the colors (Kim, Choi, & Suk, 2022). In terms of alerts and feedback, the colors red and green are perceived as the most intuitive and effective colors (Abd El Ghani et al., 2024).

Lighting with dynamic patterns are considered more unique than light that is constantly on (Kim et al., 2021). Driver alertness is highest with blink light, followed by fade and collide animation patterns (Wang et al., 2025). Blink behavior causes the highest alertness and should be used for urgent notifications (Kim, Lee, et al., 2022). Smooth blinking should be used for non-urgent notifications, since it is less energizing with lower alertness. On-behavior light is considered unobtrusive and more relaxing than the other animation patterns, with high satisfaction. Behaviors such as collide, spread, and move show lower satisfaction, with spread perceived as more interesting, obtrusive, and energetic than the others. When an alert is intended to feel more cutting-edge, spread can be used as an alternative.

The physical placement of interior lighting is important, with a focus on optimizing illumination in significant and intuitive areas (Abd El Ghani et al., 2024). This helps balance the visual field, creating a less intrusive and more immersive experience. An indirect placement of interior lighting reduces alertness and is perceived as less obtrusive than direct lighting (Wang et al., 2025).

3.6 Argus: the 100-Eyed Guardian

According to “Argus, n. meanings, etymology and more | Oxford English Dictionary” (n.d.) Argus means "A mythological watchman or guardian with one hundred eyes. Hence: a very vigilant person; a person who keeps watch; a guardian." The concept is named Argus and the analogy is to provide the driver with increased awareness of the situation with multiple seamless inputs. Argus does not only look ahead but also all-around which reflects the objective of the project.

4

Methodology Framework

Throughout this project, various methods have been used to define related terms, collect and analyze data, generate ideas, evaluate ideas, and visualize the concepts. This chapter briefly describes the methods used.

4.1 Data Collection Methods

This section contains the data collection methods used during the project. The selection includes both methods for collecting qualitative and quantitative data.

Literature Studies

Literature reviews are an in-depth search for knowledge regarding the areas that are of interest to a project (Wikberg Nilsson, 2021). A literature review is conducted to establish a theoretical foundation and to ensure that the project is up to date with current research on the subject. A common method for this is to use databases with a focus on scientific articles to ensure that the information is credible. The credibility of the articles can be checked with different tools in cases of uncertainty. For instance, there are databases that list fraudulent publications and other tools that checks if a publication is peer-reviewed.

Benchmarking

Researching competitors and the target market is a fundamental part of the design process. Market research consists of finding the solutions of competitors inside or outside the scope and then analyzing them either for inspiration or to avoid previously made mistakes. Benchmarking current solutions can be done throughout the process with the intent of finding new ideas or to iterate old solutions (Arnold-Feret & Arnold, 2001).

Questionnaires

Questionnaires are a quantitative data collection method used to gather data from a specific demographic about a certain topic. They consists of a structured series of questions, administered either digitally or in written form. In a research context, this method is primarily used to gather the respondents opinions, attitudes and behaviors regarding the topic (Hahn, n.d.).

Interviews

Interviews are a structured conversation with participants with the intent of understanding their perspective on a certain topic according to Wikberg Nilsson (2021). The sought after information is often, but not limited to, opinions, attitudes, experiences, and behaviors. Interviews can be used during different parts of the process and with different target groups depending on the intended use of the information. Semi-structured interviews are a type of interview that are not fully structured and have room for follow-up questions, probing, and questions that are not initially planned to be asked during the interview.

Participatory Observation

Participatory observations are often used by designers to better understand the problem from the users' perspectives or to research current solutions by using the product or service itself (Wikberg Nilsson, 2021). Participatory observations allows the designer to identify important aspects to consider during the development of new solutions or planning of interviews and user tests.

4.2 Analysis Methods

The following section presents the analysis methods used to analyze the collected data.

Thematic Analysis

Thematic analysis is a method to analyze qualitative data in a structured way with some level of flexibility. It is widely used to identify, analyze, and interpret larger amounts of qualitative data. The method consists of six steps: familiarization with data, generating initial codes, generating, retrieving and naming themes, and writing a report (Ahmed et al., 2025).

The KJ-method is a well established analysis method in the modern design process. It involves label making, label grouping, chart making, and verbal or written explanation (Scupin, 1997). The key concept is to sort information into groups without any preconceived biased, and feelings are to be superior to logic. When groups have been formed according to their respective area, the relationship between groups or labels is to be specified and expressed through a written or verbal explanation.

4.3 Ideation Methods

This section presents the methods used for ideation. This includes a specific matrix, brain storming, brain writing, and brain drawing.

What-Where-How-Matrix

This matrix, developed by the project group, serves as a way to generate ideas, see Appendix B. The first column *What?* is made up of different objects and road users that one might face in traffic. *Where?* refers to the position of the object in relation to the drivers different visibility zones around the car, see Figure 3.2. *How?* consists of different ways to receive feedback divided into whether the feedback is audial, visual, or haptic. The matrix can be used in different ways. One prominent way is by combining a specific object or road user with a visibility zone and listing every possible feedback for that scenario, where each feedback is exemplified by a solution. This allows for a wide holistic exploration of potential configurations of feedback for the driver in relation to the object or road user.

Brain storming

Although brain storming today is more viewed as a conceptual approach and less of an established method, the primary objective is to generate large amounts of ideas surrounding a specific problem or topic. The key part of brain storming is to create a safe environment where no idea is criticized and every participant feels comfortable sharing their idea regardless of quality (Wikberg Nilsson, 2021).

Brain Writing

According to Wikberg Nilsson (2021), brain writing is an alternative brain storming method where each individual is given a certain time to write down ideas. The ideas are then passed along to the next participant in order to expand the idea with their own, or creating new ideas of the previously written ones. This method is used to make use of all the creative capabilities available within the group.

Brain Drawing

Brain drawing is similar to brain writing, with the key difference of sketching ideas instead of writing (Wikberg Nilsson, 2021). Sketching the ideas instead of writing opens up for individual interpretation and allows for a broader perspective and a more diverse outcome.

4.4 Concept Evaluation Methods

This section presents the concept evaluation methods used in the project. These consists of ranking concepts, six thinking hats, and a decision matrix.

Ranking Concepts

This is a method utilized by the project team to rate the initial concepts on a scale from 1-10 based on three factors; which level of awareness the idea can result in, how realistic and practical it is, and what every individuals intuition says about the

idea. Afterwards, the mean value can be calculated and the concepts be ranked. This method is not completely objective but can result in a ranked list of concepts and also gives opportunity to every individual in the group to take part in the selection process.

Six Thinking Hats

Edward de Bono's method called Six Thinking Hats focuses on the evaluation process of concepts by asserting different roles to each member (Wikberg Nilsson, 2021). The roles are meant to represent either an attitude or a way of thinking. The method is used to raise a wide variety of feedback to each concept and force members to express thoughts that may not align with their own.

Decision Matrix

When selecting or evaluating a concept, different matrices can be used to weigh against several criteria relevant to the project (Wikberg Nilsson, 2021). The variation of the matrix used in this project included several criteria related to the project. To ensure a fair comparison, an individual weighting factor was used, where some criteria were set as more important to the project and, therefore, should have a greater impact on the total score.

4.5 Concept Refinement Methods

This section presents the methods used during the concept refinement phase. This includes user testing, prototyping and visualization.

User Tests

The context, elements, and layout of the user test can vary depending on subject and purpose of the study. This can be used to evaluate the guessability of a system. It can assess if a product communicates what is intended to the user. Afterwards, there is a possibility to explain what is actually happening and get feedback from the user. Based on the documentation and interpretation of the result, the insights can help with further development of the concept.

Wizard of Oz

Wizard of Oz is a prototyping method in which the user interacts with a system which they believe is autonomous, but in reality a human operator controls the model secretly. It is an effective method that focuses on user-behavior rather than the technology behind the system. Wizard of Oz gives the possibility to evaluate systems early without building complex ones ("What are Wizard of Oz Prototypes?", 2026).

5

Project Process

This chapter explores the core challenges of awareness systems and how they are perceived by users. To ensure a foundation of reliable insights, a mix of interviews, questionnaires, and participatory observations were conducted. These research methods provided the necessary data needed to bridge the gap between user needs and the final concept developed in this project.

5.1 Process Structure

Since the project was of an exploratory nature, the process was iterative, moving between research, problem definition, user testing, and idea generating as well as concept development. The connection between the different areas of the project is visualized in Figure 5.1 and 5.2. Understanding driver awareness, which was part of the first phase of the project, was the foundation on which the entire project was based. The three pillars represent the research activities required to enable the synthesis of a final concept that represents the outcome of the project.

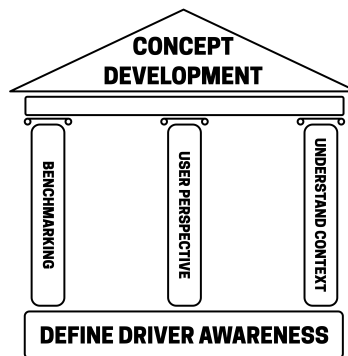


Figure 5.1: Illustration of Key Project Areas

Since the project was a collaboration with the stakeholders Lynk & Co and Zeekr, an important part in the early stages of the project was to have a clear understanding of what the project would consist of and what it would deliver. This was done through a counter brief that was signed by both parts. The counter brief was made to clarify the project's goals, research questions, and what the synthesized outcome would be.

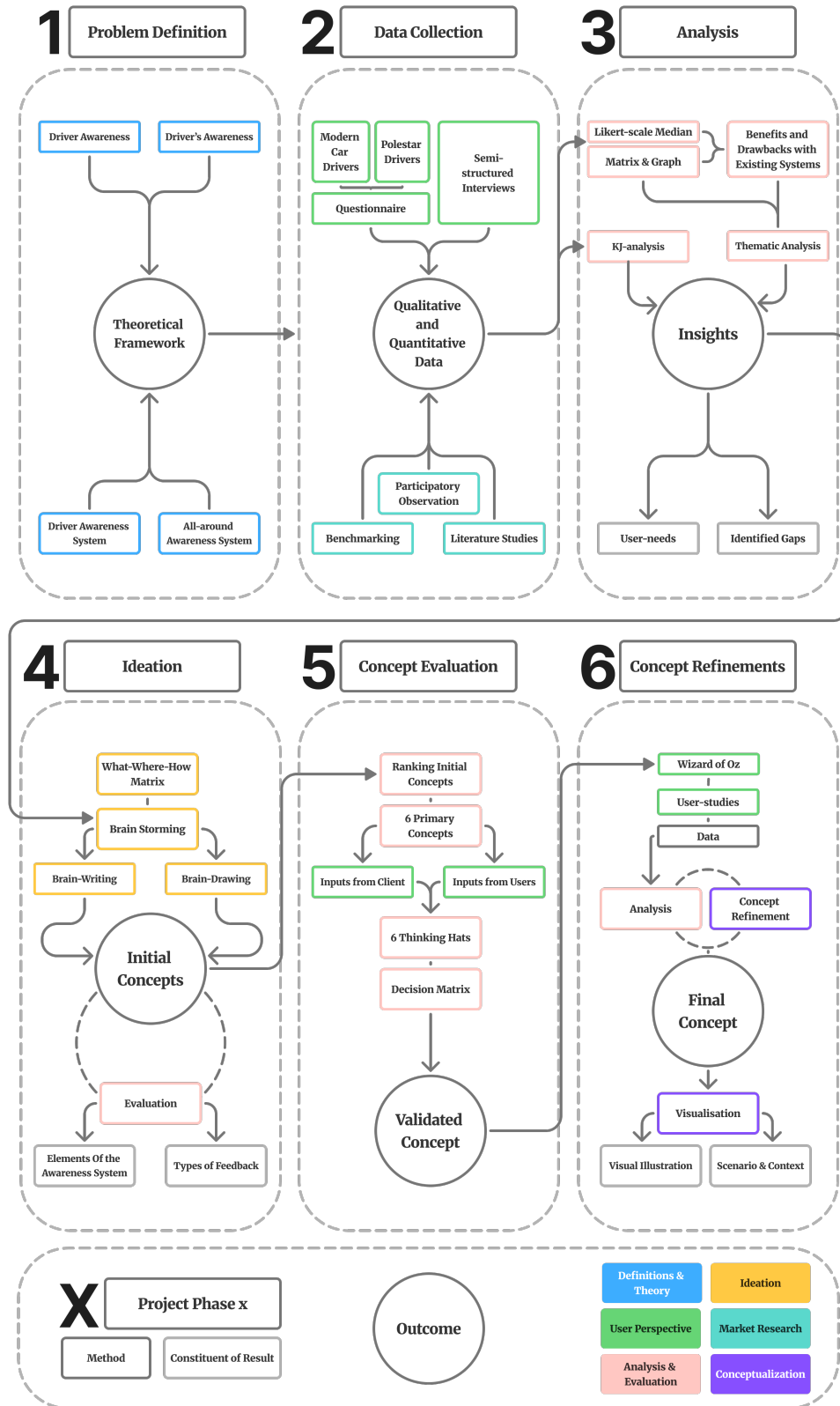


Figure 5.2: Process Description

5.2 Problem Definition

The initial phase consisted of problem definition. This included both defining the problem that would be solved and researched, as well as defining the necessary definitions of attributes needed to guide the solution of the problem. The goal was not primarily to solve a specific problem, but more to explore the possibilities of future solutions in the area of driver awareness. To explore these areas, a clear definition of the term driver awareness was needed.

Initial research was conducted on existing definitions and currently used terminology. Since no official definition of driver awareness was found, a project-specific definition was developed to clarify the exact meaning and scope of the term. This definition was established by applying the model of situational awareness to the context of driving, see Section 3.1, Defining Driver Awareness. Similarly, driver's awareness was defined by conducting literature studies on cognitive load and focus, which was subsequently applied to the context of driving.

5.3 Data Collection

To fulfill the goal of exploring the possibilities of an all-around awareness system, the scope had to be quite broad. After the definitions were established, further research was conducted to gather necessary facts and insights from users to create a functional, effective, and user-appreciated system. The goal of the research was mainly to get a deeper understanding of the subject, investigate gaps in the market, and explore the users' perspective on existing systems as well as possible future ones.

Literature Studies

Initially, focus was on research according to the Research Questions stated in Section 1.3 Objective. The main purpose of the research was to identify existing knowledge and technologies regarding driver awareness and awareness systems, as well as creating a theoretical background for the rest of the project. Articles from scientific databases such as Scopus, an abstract and citation database that covers peer-reviewed literature in fields such as science and technology ("Scopus | Abstract and citation database | Elsevier", 2026), were used. The literature search was conducted using keywords such as *driver awareness*, *situational awareness*, and *awareness systems*. The subjects studied were mainly feedback, measuring of driver awareness, safety ratings, and situational awareness. After a quick assessment of the relevance of each paper, it was added to a library and insights were noted.

Market Research

To get an overview of existing awareness systems and how these technologies work, research and benchmarking was done. Different awareness solutions in existing car models from different brands were studied to collect objective and subjective data and understand the usability aspects of the current solutions. This consisted of

literature studies, online research, and visiting car dealers to investigate existing technologies on the market. The data were summarized and analyzed to get an in-depth view of the present market. The research primarily focused on cars with either technologies that differentiate from the rest of the market, or cars that rank high on “EuroNCAP | Euro NCAP – Helping you choose the safest cars since 1997” (n.d.) list of Safety Assist Rating. This helped to get a first overview of the already existing technologies and possible gaps in current awareness systems.

Questionnaires

To understand users’ perceptions of existing awareness systems in modern vehicles, two initial questionnaires studies were conducted (see Table 5.1). The questionnaires were distributed across several online forums dedicated to automotive enthusiasts in order to maximize participation and gather diverse input. The sampling approach was primarily based on convenience sampling, as participation depended on individuals voluntarily responding to posts published in the forums. However, because the forums specifically targeted individuals with an active interest in cars, the sampling method also exhibited characteristics of purposive sampling. One version of the questionnaire was directed specifically at owners of a Polestar 4, as the vehicle’s digital rear-view mirror was of particular interest of study. The remaining questionnaires were similar in structure but were open to participants owning other vehicle models as well.

The structure of the questionnaires consisted of a start section with general questions about the participants and their cars. This was followed by their experience of driving on an everyday basis and different situations they find particularly challenging. The questionnaires also included a 6-point scale in which participants rated how important they considered different existing safety systems. The scale was designed without a neutral option, requiring respondents to take a position in their answers. The questionnaires can be found in Appendix C.

To ensure each individual’s integrity and confirm their consent to the storage of personal data collected through the questionnaire in accordance with GDPR until the end of the project, a written agreement was included in the questionnaire (“Integritetsskyddsmyndigheten | IMY”, n.d.). The respondents were required to provide their consent by checking a box before submitting the questionnaire responses. For the interviews, verbal consent regarding the storage of personal data was obtained instead of a written agreement. An interview guide was created based on the questionnaire (see Appendix D), and eight qualitative interviews were conducted.

Semi-structured Interviews

All interviews began with information regarding GDPR and permission to record the interview. Each interview was conducted by two project members, where one was responsible for leading the interview while the other took notes and asked follow-up questions. The majority of the interviews were conducted via an online meeting, where the interview was recorded and then transcribed using the Microsoft Word

transcription tool. The transcription allowed for a more efficient analysis of the interviews.

While the questionnaires mainly focused on gaining quantitative opinions on existing technologies, the interviews focused on gaining a deeper understanding of the driving experience in relation to awareness technologies, as well as aspects of driving that may require more or less assistance or intervention. The interviews followed a semi structured layout, where general questions about the participant and their car were first asked, followed by similar questions as in the questionnaire. However, the interviews allowed more room for elaborative responses, where probing questions were used to guide participants toward relevant topics. The sample of participants was also a convenience sampling, since it was mainly people from the same forums (see Table 5.1). The same 6-point scale was used, but this time the participants were asked to explain and elaborate on why they graded the system the way they did.

For an overview of the number of studied users and the methods used, see Table 5.1.

Table 5.1: Overview of Number of Users and Their Corresponding Region

Method	Number of Participants	Region
Questionnaire 1	32 drivers of various modern vehicles	Sweden
Questionnaire 2	56 drivers; including 40 Polestar 4 drivers, 15 Polestar 2 & 3 drivers, and one Audi driver	Mainly Europe, US, and Australia
Interviews	8 drivers of various modern vehicles	UK, US, and Sweden

Participatory Observations

As mentioned in Section 5.3, Benchmarking, visits to car dealers were conducted to gather input on selected awareness systems in real world settings, as well as shorter interviews with car dealership staff on consumer behavior regarding the latest technologies. The digital rear view mirror of Polestar 4 was one of the studied technologies, where the visual scope and clarity were of specific interest. Additionally, a participant observation with a Volvo XC60 was conducted, where the 360° camera, head-up display, and rear camera were tested. Testing mainly focused on blind spots in the 360° and rear view camera as well as the visual clarity of the head-up display.

A visit to Tenstar Simulation AB enabled participatory observation in a safe environment. More extreme driving distractions, such as texting while driving, were tested,

as well as high-speed driving in a police car simulator. At Tenstar, two interviews with expert users were conducted. One participant had several years of experience as a driving instructor, while the other had previously worked as a driver supervisor within the police force. The interviews focused on obtaining expert perspectives on driving behavior.

5.4 Analysis

After and in parallel with data collection, the gathered inputs were structured to enable further analysis. Data from the benchmarking was summarized and visualized on a spectrum to identify gaps and themes related to the intrusiveness of the systems. In addition, benefits and drawbacks of each system from the user-responses were listed and discussed. General inputs gathered from prior knowledge, research, and interviews were used to organize what to be aware of when driving and how to be aware of it. This created a foundation for generating ideas on new ways to increase driver awareness.

Analysis of Questionnaire Responses

Due to a large number of responses, there was a need to find an effective method to make the data more concise and manageable. A thematic analysis of the data was performed which means that the longer text-responses were reviewed, summarized, and added to a digital whiteboard on separate post-it notes. The categories were created and retrieved, and lastly, the output was documented and discussed among the group which led to insights for the next steps of the project. As previously mentioned, the questionnaire included a section in which participants were asked to evaluate existing awareness systems using a 1–6 scale, where 6 indicated highest importance and 1 lowest importance. To analyze the result of the 6-points numerical scale, the median value of responses for each system was calculated, which gave a measurement on how important the users perceived the different awareness systems. The median values of each awareness system were discussed and analyzed for gaps and insights.

Analysis of Interviews

To increase the efficiency of the analysis, the interviews were transcribed. The transcribed interviews were then analyzed with a KJ-analysis. Relevant quotes were chosen from the transcriptions and then grouped together with other quotes stating similar themes. This created categories of inputs that were named with suitable headlines. From this, insights were concluded to be used throughout the idea generating process.

Matrix and Graph Mapping

After extracting quotes from the user responses, the quotes were organized into a matrix where the columns represented different users and the rows their correspond-

ing questions. The quotes were also categorized and mapped to the most relevant research questions, providing a quick overview and a better understanding of the data for further analysis.

5.5 Ideation

To initiate the idea generation process, a discussion session was held to align individual perspectives on the project's goals and expected outcomes. Every member of the group had the opportunity to share their thoughts on the project's direction and their expectations for the final outcome. It made it possible to find similarities and differences on the thought process of the group members. Brainstorming was the primary method to come up with new ideas. The brainstorming sessions emphasized the generation of ideas rather than the quality of their descriptions or illustrations. By reducing the focus on presentation and realism, participants were encouraged to think more freely and explore unconventional and creative concepts.

Generating whole ideas for an all-around awareness system would not have been an easy task. In order to break down the problem, another approach was chosen. The strategy was to generate many small ideas that aim to solve minor issues or develop further existing systems which ultimately would result in an overall concept. Ideas were generated rapidly, in some sessions with a countdown timer to increase creativity and decrease conventional design-thinking.

Several methods were used to generate ideas, including visualizing concepts through simple sketches as well as verbal descriptions. Brain-writing was one of the first methods to be used by the group in a session planned specifically for the purpose of generating ideas. It made it possible to communicate complex ideas fast and simple, which would otherwise be difficult to illustrate visually. After each member added something new to every other idea with their own sticky note, it was time to thoroughly analyze and discuss every concept. The output was a mix of both simple and complex concepts in which all the members had a part. This created the first solid ground for upcoming sessions for generating ideas.

Although brain-writing made it possible to generate multiple ideas, it was decided to use other methods to explore even more new ideas. Brain-drawing was another method used multiple times in both planned sessions and on other occasions when communicating spontaneous ideas. A benefit of spontaneously generated ideas is that they tend to be more outside-the-box and can capture unique solutions when the brain is not forced to generate ideas. As a result of brain-drawing, many sketches and other illustrations were produced, shared, and discussed in the project group. This was a good compliment to previously mentioned methods.

Many other ideas came to life through inspiration by existing systems and combining them with new ideas. For instance, interviews with enthusiastic drivers, browsing the internet for modern cars, and visiting car-dealerships were all sources of inspirations throughout the process.

The matrix called what–where–how was also used to generate new ideas. By combining what the system should detect with where it appears and how the input is communicated, multiple solutions to the same awareness problem could be generated. By sorting out the ones that were non-realistic, a number of new ideas were generated that could later be combined with existing technologies or serve as a single new idea.

5.6 Concept Creation and Evaluation

After the ideation phase, there were a large number of ideas including entire systems, types of feedback depending on different driving contexts, and smaller ideas which consisted of elements of awareness systems.

Concept Down-Selection

During the ideation phase, the initial concepts were discussed and evaluated simultaneously. Afterwards, the ideas were listed and put together which prepared the concepts for the evaluation phase. The initial concepts were evaluated based on the three criteria: which level of awareness the idea can result in, how realistic and practical it is, and what every individual's intuition says about the idea. The evaluation led to six initial concepts that later were visualized and presented for the client, as well as a smaller audience at Chalmers. These presentations created an opportunity to evaluate and discuss the six initial concepts with external parts and receive feedback on each one.

Final Concept Selection

After the input from the presentations and internal discussions, it was decided to focus solely on one concept. This made it possible to work thoroughly and detailed with one concept instead of the alternative of working on a superficial level with many. The six concepts were later evaluated through Six Thinking Hats, which uncovered different perspectives about each concept. Three areas, each containing a few of the six initial concepts, were defined, see Section 7.1. One of these was eliminated directly, since it was not deemed as an awareness increasing system, but rather a distraction reducing one. In order to eliminate and choose concepts in a more methodical way, a decision matrix was created to choose between the two remaining concepts. The decision matrix included the following eight criteria (see Table 5.2) with different weights.

Table 5.2: Evaluation Criteria and Weight in the Decision Matrix

Criteria	Weight (1–3)	Description
Development Potential	2.5	Refers to the versatility of the concept and the opportunities for further iterations and scaling.
Project Benefit	2.0	Evaluates feasibility within the time frame and potential for high-quality results in the final report.
Team Motivation	1.0	Reflects internal interest and personal preference, driving the team’s dedication and momentum.
Feasibility	2.0	Addresses economic constraints, manufacturing costs, and technical viability in a real-world production environment.
Stakeholder Value	1.5	Measures the potential for the concept to be appreciated by Geely and its alignment with their interests.
Holistic Awareness	3.0	The degree to which the concept provides 360° coverage of the vehicle’s surroundings.
Awareness Enhancement	3.0	Evaluates how effectively the concept increases the driver awareness.
Cognitive Load	2.5	Assesses the risk of overwhelming the driver mentally and the efficiency of utilizing cognitive capacity.

Lastly, each concept was given a score from each project member according to each criteria, and a sum of the points was calculated, the result was discussed, and a final concept was chosen. With the knowledge acquired using the stated research questions as guidelines, a final concept was developed. It originated from one of the ideas created during idea generation. However, with the selection of this concept, the project narrowed down from the initially wide research scope. This meant that further iteration between problem definition and goals was performed. A clearer path was paved for the project. Further idea generation was done with brain storming and brain writing to explore the concept further. The main focus was to explore the additional problems that could be solved with this concept.

5.7 Concept Refinements

The last phase of the project consisted of user testing, analysis, refinements, and visualization of the final concept.

User Evaluation of the Final Concept

To evaluate users' perceptions regarding the concept, a low fidelity model utilizing controllable LED lights was implemented in a vehicle. In total, four participants performed the tests according, following a template that can be seen in Appendix G. The participants were new to the project to avoid preconceived conclusions. The evaluation focused on assessing the users' understanding of different light placements and movement patterns, and how these correlated to external events. This specific investigation aimed to identify whether certain placements or movement patterns required adjustment to become more explicit and intuitive for the driver. This was conducted using a semi-structured approach, employing a set of guided questions to facilitate an open discussion and capture diverse user inputs. Given its timing in the middle of the development process, the evaluation served both formative and evaluative purposes.

The procedure commenced with an introduction to the study, followed by obtaining GDPR consent and permission for voice recording. The test was performed in a stationary car, utilized as a meditating object to ground the participants. A traffic context was described to the users, and drawing inspiration from the Wizard of Oz methodology, the LED lights were controlled by a project member situated in the backseat. During the test, a preconfigured light pattern was displayed on a specific light source, after which the user was asked to interpret its purpose. Additional patterns, as mentioned in Table 5.3, were shown on the same light source while user inputs were recorded and written down by another group member sitting in the backseat. Finally, the intended communication of the light was explained, and the user expressed their opinion. This iterative process was repeated for various light sources until the session was concluded. The results were analyzed and discussed, leading to the selection of the light pattern and its placement in the vehicle.

Final Concept Visualizations

After evaluation of the final concept, the design and the patterns were set for the concept. A model that allowed multiple visualizations was made in a CAD environment. The visualizations focused on the interior experience and visual design of the light pattern and its placement inside a Zeekr 7X car model.

5.8 Research Integrity and Ethics

During the research, interviews, and questionnaires, the project followed good research practice to ensure ethical conduct. The following four principles from ALLEA's European Code of Conduct for Research Integrity were applied: Reliability,

Table 5.3: User Evaluation and Lighting Pattern Overview

Name	Zones	Lighting Pattern	Indication
Front Door	Blind spots	Sweeping pulse, 1-point	1 passing car
		Faster sweeping pulse, 1-point	1 fast-moving passing car
		Sweeping pulse, 2-points	2 passing cars
A-Pillar	Obscured by A-pillars	Constant light, 4 seconds	Object obscured by the A-pillar
Windshield Corner	Peripheral vision area	Constant light, 4 seconds	Object approaching from the side
		Blinking 5 times	
		Sweeping pulse	
Windshield Front	Central vision area	Expanding from the center	Approaching another car or obstacle ahead
		Blinking 3 times	
Rear View	Rear vision area	Constant orange light	Approached rapidly by another car from behind
		Blinking red	

Honesty, Respect and Accountability, ALLEA - All European Academies (2023). Despite the projects fast pace and the team's limited prior research experience, quality was considered throughout all parts of the project, and the same can be said for honesty and accountability. Respect was particularly emphasized, with the team actively fostering a respectful and inclusive culture. Throughout the research phase, GDPR was followed to protect the integrity of all participants in questionnaires and interviews.

5.9 Source Credibility

For source credibility, databases recommended by the Chalmers Library were used, with Scopus being the primary database. Different combinations of related terms such as *driver awareness*, *awareness systems*, and *situational awareness* were used as keywords in the literature search. To find the most related ones, different boolean operators were used to narrow the scope of research and get closer to the objective of the project. In addition, related articles that had cited the base articles were reviewed, and built-in algorithms of the databases were utilized to get closer to the most relevant papers.

Although these databases are used and recommended by Chalmers Library and the retrieved information is valid with a very high probability, in times of uncertainty the validity of articles were checked. This was done through UlrichsWeb Global Serial Directory. This is a website with more than 300,000 periodicals where one can, among other functions, check if an article is peer-reviewed (“Ulrichs Serials Analysis System (USAS)”, n.d.). Cabell’s is another tool where fraudulent publications can be checked to avoid danger of false research (“Cabells”, n.d.).

5.10 Use of AI

AI was utilized as a tool in compliance with “Regulations for the use of AI tools in thesis work” (2023) and the examiner’s guidelines. The primary application of AI in this project was language and grammar refinement. Another use of AI consisted of generating situations and examples, such as lists of possible objects in a traffic environment. It is important to note that AI was not used to generate text, ideas, or other materials for the project. It did not substitute for any critical steps. Instead, it served as a tool for the repetitive tasks that AI is better suited to handle.

6

Results from Research Studies

Chapter 6 presents the results from questionnaires, interviews, and literature studies based on the research questions of the project, introduced in Chapter 1 Introduction. The findings are structured into four sections: driver awareness, existing awareness systems, driving context, and human-vehicle interaction. Together, they form the basis for identifying key gaps and user requirements for the development of future awareness systems.

6.1 Driver Awareness

As outlined in Section 3.1, Defining The Maki-Roll Theory, the level of driver awareness depend on how effectively the driver's awareness works alongside the driver awareness systems. Section 3.1, Defining Driver's Awareness, further explains how a driver's awareness is affected by internal factors, external factors, and stressors. The research findings indicate similar relationships as The Maki-Roll theory, supporting the proposed theoretical framework.

Internal factors related to age were a recurring theme during interviews and questionnaires, specifically sensory input such as vision. Since vision is the primary information channel while driving, its decline requires a shift in how awareness systems communicate with an aging demographic. Depth perception in screens and vision during night were some of the most prominent vision-related issues raised.

External factors affect driver performance and perceived control while operating the vehicle. Feedback modality from awareness systems serves as a critical determinant of how the system is perceived by the driver. Context related external factors such as traffic density or weather, are important to consider while improving the driver awareness since they are all involuntarily demanding of the driver's attention.

The skepticism toward new automotive technology can hinder a successful integration of advanced awareness systems. When drivers approach new systems with distrust, interviews showed that they are less likely to invest the mental effort required to utilize the system's full potential, often viewing the learning period as a burden rather than an investment. Consequently, if a system is not perceived as intuitive from the start, the driver may dismiss it entirely.

6.2 Existing Driver Awareness Systems

Through questionnaires, quantifiable results regarding the importance of different awareness systems and the perception of these systems were examined. Most systems included in the questionnaires were awareness systems, with the exception of some more safety-related systems such as emergency braking and lane assist. The question provided was *How important do you consider the following safety features to be?*. The respondents were asked to choose a number between 1-6, where (1) was less important and (6) was very important. Figure 6.1 displays the median average value for each awareness system.

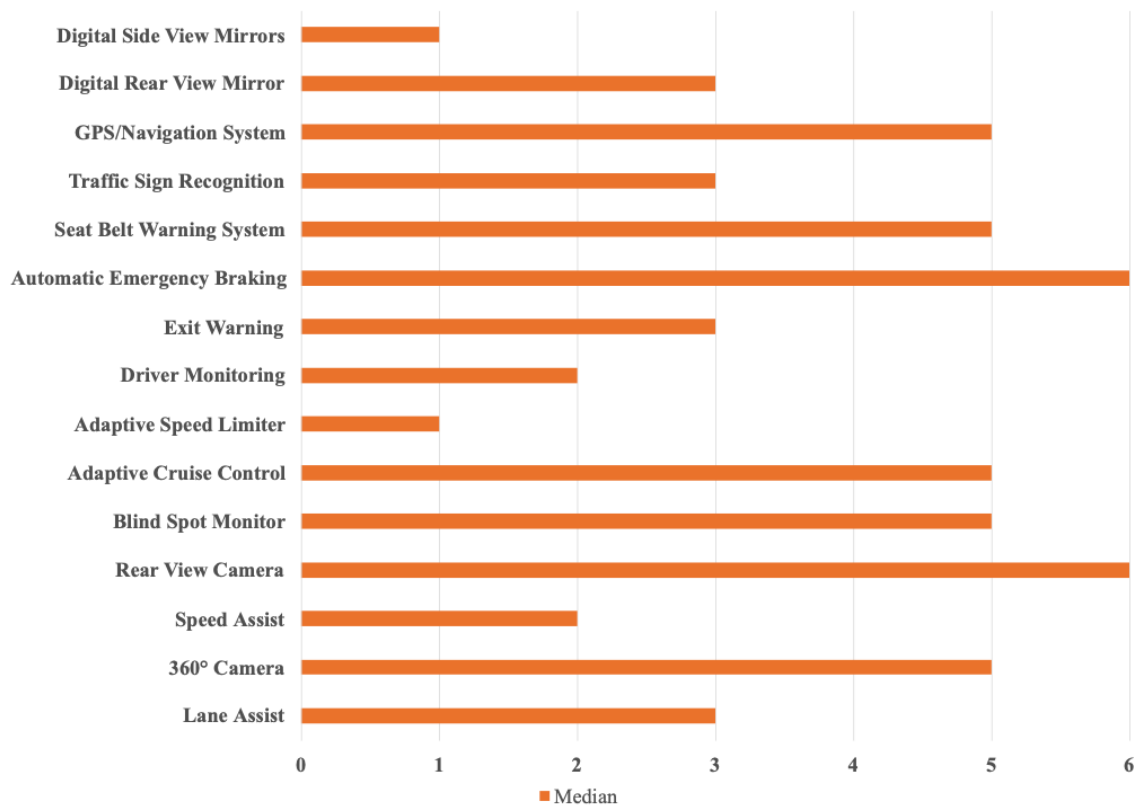


Figure 6.1: Median Values of User's Ratings on Awareness and Safety Systems

A key factor noticed when investigating the lower rated systems was that most of the time the score was heavily affected by the amount of irritation the system generated. This is visualized in the graph below where the horizontal axis represents the calculated median value, which is rated importance, and the vertical axis user appreciation, which were expressed through the open-ended questions. As the graph shows, the least appreciated systems are those with most intrusive feedback such as adaptive speed limiter and lane assist, which are located in the lower-left corner of the graph.

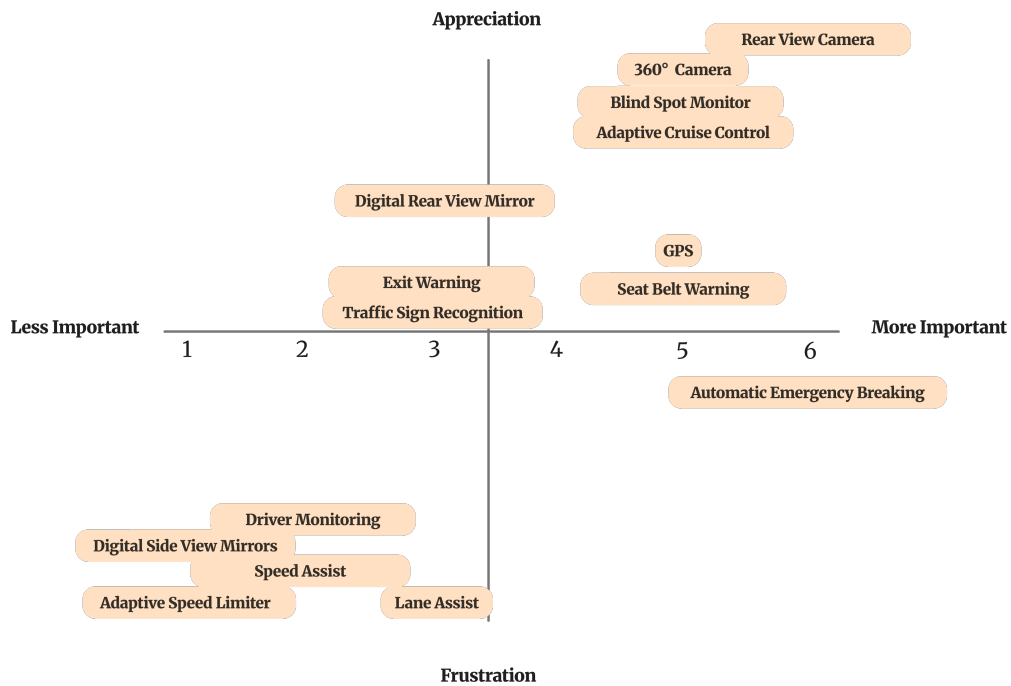


Figure 6.2: Graph Mapping Analysis: Importance vs User Appreciation

The majority of irritation was due to false positives from a system or to the fact that the system restricted the driver. As a result, respondents tended to turn off these systems the most, rendering the systems useless.

"It becomes something I want to turn off because it is annoying"

— Pilot Interview Participant ¹

The interviews aligned with the results of the questionnaires, raising new perspectives on the importance of awareness systems and potential gaps of current solutions. Participants expressed a lack of trust in the same systems that provoked irritation in the questionnaires, where there can be a connection between drivers' trust towards systems and false positives. The more expressive systems, with feedback that is considered intrusive, would in case of false positives result in more irritation and decrease in trust than that of discrete system.

¹Translated from Swedish.

"Then like a time when I was merging and I got a false positive on the breaking, you know, that definitely made my heart pound."

— Interview Participant 3

6.3 The Context

Many of the respondents were regularly commuting in heavy traffic during which demanding situations occurred frequently. Some of the prominent situations mentioned were lane changing on a multi-lane highway during rush hour, city crossings with limited visibility, or road users located behind the A-pillar or in the blind spot. Driving in this type of context for a long period of time lead to cognitive load, making the driver feel distraught. Respondents raised concerns about not paying as much attention to details and a general lack of awareness about surrounding traffic in these situations.

Several of the participants in the interviews expressed difficulty handling poor weather and light conditions. Awareness of their surroundings significantly decreased with the reduced vision and increased cognitive load caused by these conditions. There were respondents who stated the need for an expanded comprehension of the traffic situation. There are currently vehicles that provide an overview of traffic situations as a graphic representation on the center display. Although this was appreciated because it offered an extended view that they could not otherwise achieve, the need to divert attention from the roadway to the center display was deemed to be highly problematic.

"I think the risk is greater that people will look at the screen instead of looking out the window, so I feel that it reduces safety rather than increasing it."

— Interview Participant 1 ²

6.4 Human-vehicle Interaction

Research suggests that user acceptance of vehicle interventions is positively correlated with system reliability. Specifically, a reduction in the false-positive rate tends to increase driver trust, leading to a higher tolerance for automated steering or braking actions. On the other hand, there are some cases where the driver does not prefer the vehicle's interference in the driving even if the action is correct. For

²Translated from Swedish.

example, users preferred warnings on speed limits rather than automatic braking, as they wished to not feel limited by the vehicle.

With the situations mentioned above, the majority preferred to get information and then make the driving decision themselves, rather than the car taking the decision and doing something automatically. This appears to be linked to the wish of being in control, but also to not be underestimated by the car. Many users saw prestige in being a good driver and did not state having any problems being aware. When asked about their best awareness system, one participant very clearly answered:

“My eyes”

— Questionnaire Respondent 1

Still, many users later admitted that they can zone out while driving or have occasionally missed surrounding vehicles. In both interviews and questionnaires, the desire for additional support, not for restriction, were mentioned. Most importantly, users want to be able to keep focus on the road.

“If you’re not looking where you’re supposed to be looking, you’re looking at a screen instead of the roadway, that’s a distraction.”

— Interview Participant 6

Given that false positives are a major source of frustration for many users and negatively affect their perception of the system, frequent false alerts not only create irritation but also reduce trust in the system’s reliability. As a result, some drivers choose to disable the system entirely or feel the need to double-check its feedback.

While driving, attention is vital and distracted drivers are a big risk increasing factor. One prominent aspect of distraction mentioned in the interviews were the screens, primarily the center display. This is especially the case when there is a lot of information simultaneously, which can range from navigation information to notifications from phones. The interviews revealed that users first and foremost wish to keep their eyes on the road while driving, not on the display. Furthermore, a demand of action from the driver, such as disregarding notifications while driving, was considered highly inappropriate.

“And it made me dismiss that by hand and then it popped up another notice that I also had to dismiss by hand. This is taking my attention off the road and I don’t like that.”

— Interview Participant 3

User studies demonstrated that intrusive systems with loud noises was thought of as most irritating. Loud noises can increase an already stressful traffic situation, meaning the cognitive load can become too high for the user. In contrast, visual elements such as symbols and camera feeds were perceived as less intrusive. However, camera feeds require the driver to divert attention from the road, which was also viewed as dangerous.

Increasing amounts of awareness systems and automated driving systems has introduced shifts in driver behavior. The increasing amount of vehicle intervention results in less driver engagement, allowing the drivers attention to be diverted to non-driving related tasks. Multiple respondents expressed concerns related to a decline in driving ability across the general population. This results in a distrust of other road users ability to be aware of the traffic situation, and alert enough to make critical decisions.

"Your ability of maintaining straight line and forcing your car to stay within the lane will be gradually compromised the more you use lane assist."

— Interview Participant 5

6.5 Gaps and Requirements

The goal of this project was not to solve the problem of lack of driver awareness in one specific traffic situation. Instead, it was to develop a concept that enhances the perception of the vehicle's surroundings in a more comprehensive way. Multiple situations can occur in one zone, and one situation can occur in multiple zones. Potentially hazardous situations that can occur in the 10 different zones around the car, visualized in Figure 6.3, is listed in Table 6.1.

Table 6.1: Examples of Problem Situations in Zones

Situation	Zone
Approaching a slower moving object ahead or oncoming vehicles.	1
Vehicle crossing the roadway at an intersection.	2 & 8
A vehicle traveling alongside in an adjacent lane.	3 & 7
A vehicle traveling alongside during an overtaking maneuver.	3
A vehicle overtaking alongside the host vehicle.	7
Vehicle located within the blind spot area.	4 & 6
A following vehicle engaged in tailgating.	5
A pedestrian at a crosswalk obscured by the A-pillar.	9 & 10

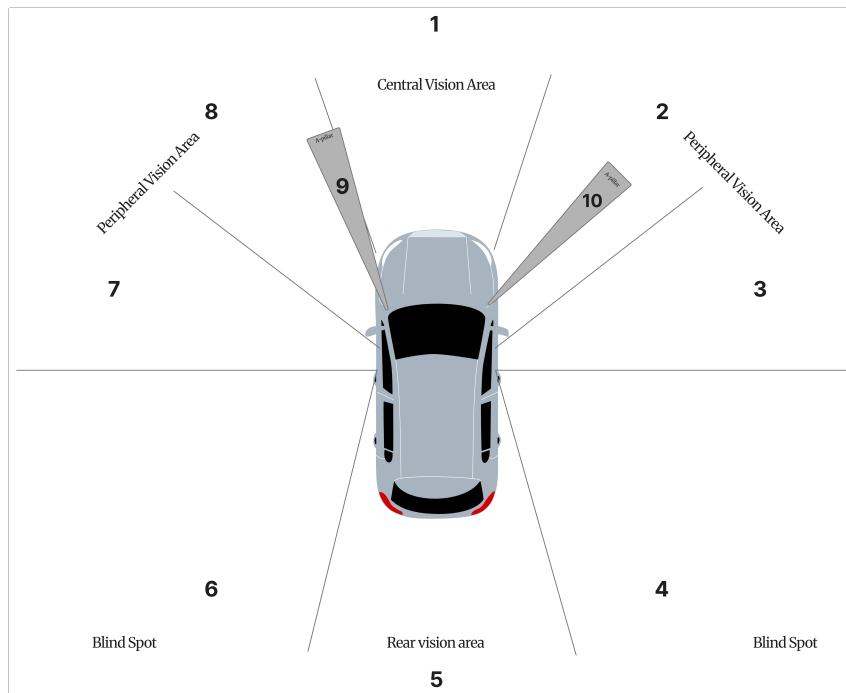


Figure 6.3: Driver's Field of Vision, Illustrating Zones Mentioned in Table 6.1

Identified Gaps

Several gaps were identified in today's market of current awareness systems, one of the main being a more comprehensive understanding of the surroundings while driving. This problem arises from limited visibility caused both by the vehicle design, especially the A-pillars, and by external factors such as other vehicles and surrounding infrastructure. The A-pillars were one of the most mentioned problems among users, where a common problem was missing pedestrians or other vehicles at crosswalks or in roundabouts. This might be enhanced while driving in poor visibility conditions.

There is a lack of systems that provide a comprehensive overview of the surroundings while allowing the user to keep their visual attention on the road. As mentioned in Table 3.1, some current systems provide an animated overview of the surroundings presented on a screen. However, this distracts the driver's attention from the road. Additionally, different types of feedback are not very evenly distributed. Much information is presented through sounds and through visuals on screens, which can become both annoying and demanding of attention. This type of feedback can often be explicit and quite aggressive.

Identified Requirements

Based on the problem situations stated in Table 6.1 and on the results presented above, the following insights regarding user requirements were summarized. Users:

- Prefer receiving informative support over experiencing reduced control
- Want to not feel underestimated by the system
- Prioritize keeping their visual attention on the road
- Prefer systems that do not demand excessive attention or direct interaction
- Prefer subtle and context-aware feedback over intrusive alerts
- Seek systems that support rather than replace their own driver awareness

To address these challenges, the following design guidelines were derived to guide the development of the awareness system. An awareness system should:

- Maximize visual attention on the road
- Minimize false-positives and/or make the false positives less irritating
- Have a balanced intrusiveness related to the severity of the situation
- Support driver control rather than replace decision-making
- Function well regardless of the visibility conditions
- Support long-term driver trust through reliable and predictable behavior
- Be intuitive without a steep learning curve

7

Concept Development of Awareness System

With the results and insights presented in the previous chapter, concepts of awareness increasing systems were developed.

7.1 Concepts

The exploratory nature of this project paved the way for the development of various conceptual directions. These were iteratively evaluated to determine the most viable path to reach the goal of advancing toward an all-around awareness system. The results were synthesized into three primary concept areas, which are presented below.

Extended Vision via Cameras

Extended vision via cameras is a theme of ideas that broaden the drivers vision beyond the current capability with the use of cameras, see Figure 7.1. The idea of extended vision was primarily based on insights from the interviews, in which it became clear that drivers trust what they see the most and appreciate the sense of control.

One part of this theme includes Frontal Side View Cameras. When entering a cross section or exiting a narrow parking spot, lateral visibility may be blocked by foliage, buildings, or other vehicles. Ensuring that the path is clear to perform a safe exit can be difficult, forcing the driver to creep into the situation to expand their field of view. The Frontal Side View Cameras allow the driver to get a *sneak peek* and ensure there is no transverse traffic without having to creep into the road. Two cameras, placed on each side of the front of the car, display a live camera feed onto screens inside the vehicle upon the drivers desire, visualized in Figure 7.2. It is accessible with a simple push of a button on the steering wheel, avoiding unnecessary cognitive load from constant feeds.

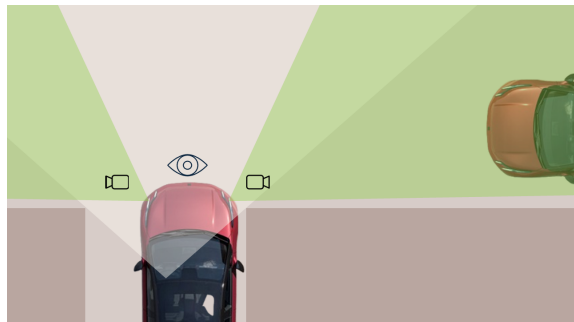


Figure 7.1: Illustration of Frontal Side View Cameras

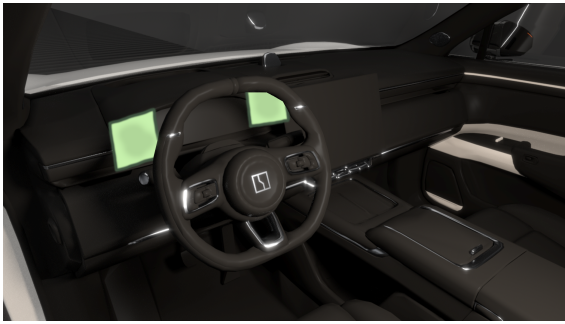


Figure 7.2: Illustration of Camera Feed
direct driver attention to the critical camera feed.

The screens for extra vision are multi-purpose with several camera feeds for the different blind spots of the car, both the standard blind spots and to widen the view of the current reversing camera. Equivalent to the Frontal Side View Cameras, these are turned on upon the drivers desire, whenever there is a need for an expanded vision. In situations where there is a lack of driver awareness, the vehicle uses this system to di-

Prioritization and Reconstruction of Feedback

User studies showed that a large amount of feedback from the vehicle is perceived as intrusive and irritating. This is something that often results in the system being turned off. Therefore, this area focuses on rethinking how feedback is given. The concept consists of making the intrusiveness proportional to the severity of the situation, while still ensuring equal effectiveness. This concept allows existing systems to be used as intended while reducing the cognitive load of intrusive feedback to achieve greater driver awareness.



Figure 7.3: Speed Limit Alert, Reconstruction Concept

The speed limit alert were one of the most frequently mentioned systems regarding intrusiveness and irritation. To avoid this, the concept includes a modified speed limit alert that mainly uses visual feedback, where the speed indicator on the dashboard turns red and increases in size if the speed limit is exceeded. In combination with visual alert, the haptic resistance on the gas pedal increases when the speed limit is exceeded, as seen in Figure 7.3. The resistance is subtle and do not interfere with the driver control and safety. It is

only provided during the short period when the driver exceeds the speed-limit and does not limit the driver to exceed the speed limit in situations such as overtakes. To ensure safety, the speed limit alert still exclaims an audial warning when the exceeding is deemed serious enough.

The industry standard in today's vehicles includes a large and comprehensive infotainment screen in the center of the dashboard. To reduce screen distraction while driving, this concept transitions the infotainment screen into a sleep or stand-by mode while the car is driven, visualized in Figure 7.4. The brightness and contrast of the screen is reduced while still displaying the time and other necessary information. In addition, the layout of the infotainment system is static, which means that the same information and controls can always be accessed at the same location. This will allow the driver to memorize the location of features and interact safely with them while driving, for example, climate control. A proximity sensor reengages the screen before the user touches it, avoiding the extra interaction to *wake up* the system, ensuring a safe interaction with the screen while driving.

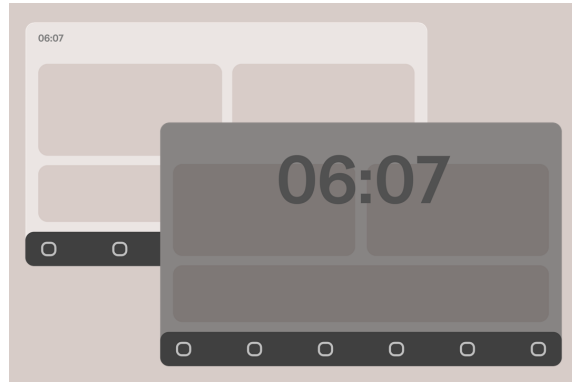


Figure 7.4: Sleep Mode on Screen

Existing driver monitoring systems suffer a lot from false positives and can therefore be perceived as irritating, resulting in users deactivating them. To avoid this, the feedback should be less intrusive barring severe cases. By implementing a feedback hierarchy depending on the level of needed interference, the driver can be alerted just enough to increase focus without feeling agitated. The initial feedback level received is a brief seat vibration for minor distraction. The second level is seat vibration combined with a soft sound that informs the driver that their focus is diverted from the road. Finally the third level introduces seat belt tension with a few quick pull motions. This is deemed as very intrusive feedback hence only used in the severest of cases, such as nodding off. In combination with the audial and haptic feedback, a symbol or text on the screen should inform the driver about why the feedback is triggered.

Spatial Awareness via Light

The interior lights of the car provide the driver with an immersive experience and spatial awareness of their surroundings. This approach provides an increased understanding of the relative position and speed of surrounding cars. The core idea is to provide the driver with subtle visual cues, where they can keep their eyes on the road and still be aware of approaching cars in their peripheral vision. The lights are similar or integrated with the ambient lighting that is already incorporated in many modern cars today. By assigning a functional role to ambient lighting and expanding its use, the system can provide non-intrusive feedback with minimal acclimation, since drivers are already familiar with ambient lighting in vehicles.



Figure 7.5: Early Stages of the Concept Spatial Awareness via Light

The conceptualization of this theme includes lighting placed along the front doors and on the A-pillars, see Figure 7.5. While maintaining the aesthetic profile of the interior ambient lighting, these lights serve a functional role by providing real-time spatial data regarding the driver's surroundings. The lights along the door will provide an understanding regarding relative position and speed of cars in the blind spot, via a light pulse that moves along the light strip. The A-pillar light will activate when something is hidden in the A-pillar blind spot.

In addition to the existing light sources within the vehicle interior, see Figure 7.5, an additional light bar was integrated into the rear view mirror. A soft light will activate in the rear view mirror when the distance to the car behind is too narrow relative to the speed. This serves as a warning to avoid sudden braking and thereby reducing the risk of rear-end collisions.

7.2 Concept Selection

The concept of Prioritization and Reconstruction of Feedback was considered the most fragmented concept with vastly different ideas and did not effectively contribute to an all-around awareness. After the concept evaluation phase, it was concluded that the theme did not form a coherent system in itself, but rather functioned as a way to reduce distraction and improve existing systems. As a result, it was not regarded as the most compelling concept. Instead, extended vision via cameras and spatial awareness via light were the two main areas further iterated and included in the design decision process.

A decision matrix regarding potential for future development, realistic incorporation, level of increased awareness, and cognitive load was used to decide which of

the concepts was the optimal way forward for the project. Based on the decision matrix, see Appendix F, spatial awareness via light achieved the highest score and was therefore chosen as the final concept. The concept showed potential for further development, had an interesting take and was a certain step toward all-around awareness. Since it is based on ambient lighting, which already exists in many modern vehicles, it was deemed realistic to develop and incorporate both functionally and economically, while still being exploratory and providing a unique experience while driving. Furthermore, compared to Extended Vision via Cameras, it allows for a more continuous feedback without requiring active interaction from the driver. However, the functionality of the Frontal Side View was adapted into the concept by using light sources positioned in the lower corners of the windshield. These activate when crossing objects are detected at a distance.

As a further development of the chosen concept, a light bar was positioned near the lower edge of the windshield, providing visual feedback when the driver is following the vehicle ahead too closely. The concept, as developed at this stage, is shown in Figure 7.6.



Figure 7.6: Spatial Awareness via Lights, Prior to User Testing

7.3 User Evaluation of the Final Concept

User testing resulted in further iteration of the concept of spatial awareness via light. The tests consisted of a concept model with led light strips placed in a car, see Figure 7.7. Four participants gave their thoughts and evaluated whether or not they understood the lighting placement related to their function. The tests showed that users generally understood what the light placements and pattern meant, although the tests were done outside the traffic context, which would have provided a

greater understanding of the function relative to the situation. However, the light's intuitiveness varied and as did the amount of irritation they resulted in.



Figure 7.7: Concept Model Used During User Tests

On a scale from 1 (low) to 6 (high), all lights received median averages between 4 and 5, see Table 7.1, when asked about how certain they were regarding their guess for the specific light's functionality. This was strictly based on the feedback presented without any realistic context. After an explanation of the function behind the light sources, the systems received between 5 and 6 regarding perceived clarity of the functions.

The rated irritation level received points between 1.5 and 3.5, on a scale from one (low) to 6 (high). One reason behind the higher scores were thought to be the fidelity level of the model. The lights were described as too bright and the red color as intense, resulting in the lights diverting more attention than intended. One user highlights this problem in relation to the rear view mirror:

"It would probably light up too often, which would be more of an annoyance to me than a help"

— Evaluation Participant 2 ¹

The two lights that received the most complaints were in the front and rear view mirror. Users highlighted that they might be more distracting than helpful while driving:

¹Translated from Swedish.

"I can't control how other drives and if it was so I could move a bit, I don't really see the point"

— Evaluation Participant 1²

This since the areas covered are the two with the best direct vision currently, resulting in users needing less assistance in these areas.

Table 7.1: Summary of User Testing Averages

Light placement	Rated Confidence (Median Average)	Rated Clarity (Median Average)	Rated Irritation (Median Average)
Front Door	4.5	5	1.5
A-pillar	5	6	3.5
Corner View	4	5.5	2
Frontal	4	6	3.5
Rear View	4	6	3.5

The results indicate that spatial light-based feedback for awareness has a strong potential to communicate surrounding information in an intuitive way. However, the level of irritation suggests that careful calibration of brightness, color, and placement is necessary. In particular, reducing intensity and size or avoiding strong red tones may improve user acceptance. Furthermore, feedback in areas already within the driver's direct field of vision, such as the frontal and rear regions, should be reconsidered or minimized, as the added value appears limited compared to the risk of distraction.

With this in mind, the rear view mirror was excluded from the final concept, since users generally found it more distracting than helpful. Furthermore, the action possible for the drivers when alerted by this is limited, meaning directed extra awareness was deemed as unnecessary. On the other hand, the front windshield light, although also somewhat questioned by users, is included in the final concept. This is based on the possibility of accident prevention, since tailgating contributes to one third of all car accidents, as mentioned in 3.3, Tailgating-Related Accident Statistics. However, it is extra important for this light to be smoothly integrated in the car, to avoid irritation.

²Translated from Swedish.

8

Argus

In this chapter, the final concept *Argus* will be presented, which is the result of the concept development phase. After the evaluation of concepts, a few adjustments were made to create the final concept.



Figure 8.1: Overview of the Final Concept

8.1 Concept Description

This project's main result is the final concept *Argus*, developed to increase driver awareness, illustrated in Figure 8.1. Similar to the greek mythological giant from which the concept takes its name, see 3.6 *Argus: the 100-Eyed Guardian*, it can be said to have a *hundred eyes*, as it continuously monitors the surroundings of the vehicle. Many awareness systems today demand the driver's direct visual attention, which impairs their ability to keep the eyes on the road. On top of that, both the vehicle itself and external factors such as infrastructure and surrounding traffic, can obstruct critical areas of the driver's field of vision. At the same time, users express a desire for additional support and information, given it does not reduce their sense of control but gives the driver the opportunity to choose how the vehicle will operate. In familiar driving situations in particular, awareness of the surroundings can decrease

as the driving becomes more automated. This highlights the need for a solution that supports and enhances the driver awareness without increasing cognitive load. The goal of this concept was therefore to enhance spatial awareness by enabling the driver to subconsciously receive real-time information about the surrounding traffic environment.

Argus provides increased spatial awareness through ambient light. The system is based on integrated light sources located in the front doors, on the A-pillars, and at the front of windshield. Through subtle light patterns that correspond to external events, the system communicates information about the surroundings in an intuitive and non-intrusive way, since it can be perceived in the peripheral view. This allows the driver to remain visually focused on the road while still receiving information of nearby traffic and surrounding vehicles.

8.2 Functions

The concept is built on strategically positioned lighting on the front doors, A-pillars, and at the front of the windshield, where the light sources are placed in an intuitive way that correlates to what zone around the vehicle it is informing about, see Figure 8.1. Depending on the surrounding situation, these light sources illuminate or change their lighting patterns to enhance driver awareness.

Front Doors

While modern vehicles provide blind spot warnings in the side mirrors, these systems are typically binary and does not include information about relative speed and positioning. Argus complements this by introducing continuous ambient light feedback integrated in the front doors, enabling a more intuitive understanding of surrounding traffic (see Figure 8.2 and 8.3). This light uses a sweeping pulse within the ambient lighting to communicate the relative position and speed of vehicles in the driver's blind spot. The light strip on the door continuously illuminates, as it is part of the ambient lighting in the car, with the moving pulse achieved by adjusting the brightness of each individual LED sequentially.

When asked what systems are appreciated in interviews and questionnaires, one of the prominent systems was the blind spot warning light within the side view mirror. In the developed concept where light is a central part of the solution, the side mirror blind spot detection light will work together with the front doors, as they serve similar purposes in two different ways. Multiple systems build trust, however the different approach on the problem prevents the information from feeling superfluous. The blind spot light serves as a reminder to be aware of your blind spot while the light strip on the door is a way to subconsciously be aware of the surrounding vehicles' position and speed.



Figure 8.2: Ambient Light Source on Front Door



Figure 8.3: Sequence of a Sweeping Pulse Representing a Car Doing an Overtake

A-pillars

The light bar on the A-pillar serves not only as an indication that an object is obscured in the blind spot area behind the A-pillars, but also as a warning for objects approaching from the side. Both situations require similar response from the driver; slowing down and maintaining awareness of the surroundings, which is why they are integrated within the same light element. However, to support a clearer understanding of the situation, the feedback is differentiated through separate segments that activate depending on the context.

When an object is hidden in the A-pillar blind spot, the segment placed directly on the A-pillar will be lightened (see Figure 8.4), similar to the blind spot warning in the side view mirror. This is most relevant in lower speeds, such as at crosswalks or roundabouts and require the driver to slow down and look behind the A-pillar (see Figure 8.5). The vertical straight light of this segment represents the A-pillar itself and is perceived as more static, to signal that the relative speed in these situations is low.



Figure 8.4: Light Source on the A-pillar



Figure 8.5: Sequence of Light that Illuminates When an Object is Detected

A different segment of the same light bar activates in the corner bend when a fast-approaching object is detected from the side but might be in an obstructed field of vision (see Figure 8.6). This may occur, for example, at intersections or when wildlife approaches. The curved light signifies the movement and direction the object is approaching by. The curved segment gives a dynamic feel, signifying that the relative speed in these situations is high as well as the direction of the object signaled about (see Figure 8.7).

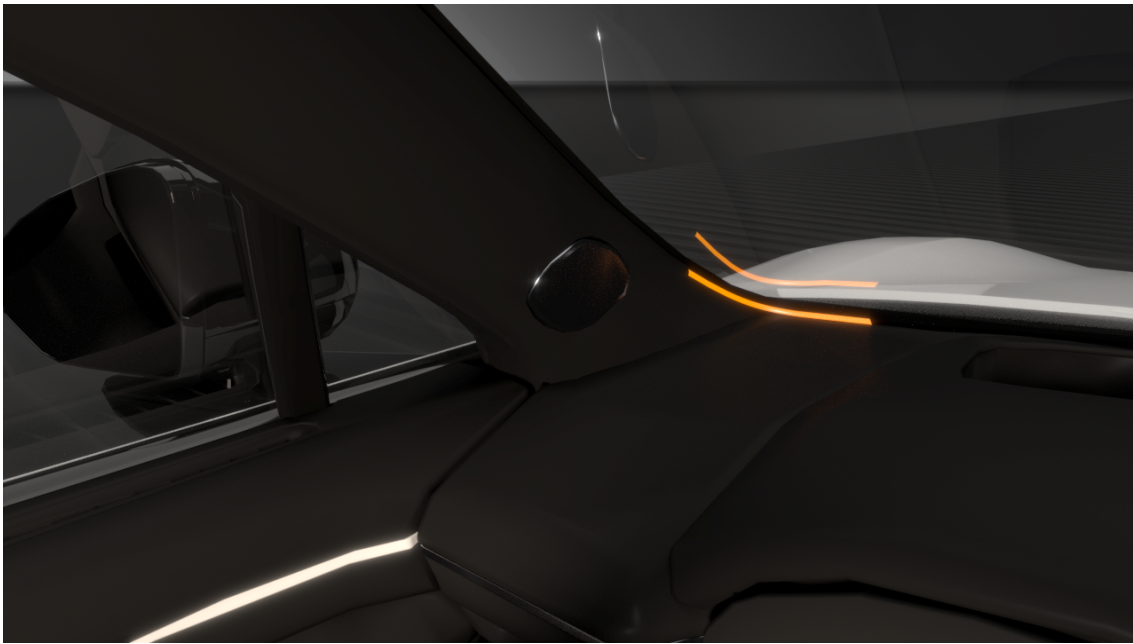


Figure 8.6: Light Source in the Corner Bend of the Windshield

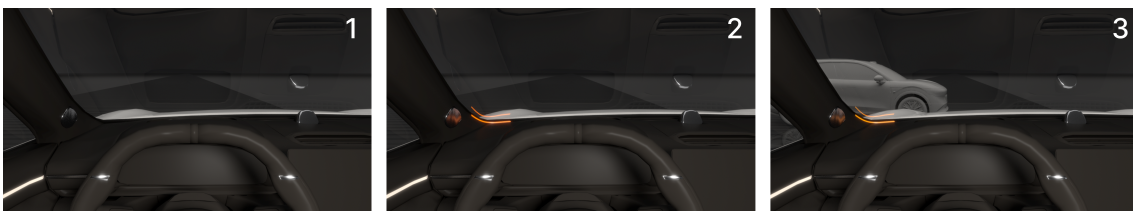


Figure 8.7: Sequence of Light That Illuminate When an Object is Detected

Front of the Windshield

Distance estimation is a key aspect of driving, where maintaining an appropriate distance to preceding vehicles according to the three-second rule plays a vital role in accident prevention. A subtle horizontal light bar is positioned at the center front beneath the windshield (see Figure 8.8). Illumination originates in the center and progressively extends outward along the LED strip as the distance between vehicles decreases, acting as a visual alert for tailgating behavior (see Figure 8.9). The light thereby functions as a proximity indicator, informing the driver if the distance between the operated and preceding vehicle becomes insufficient for the current relative speed, indicating an increased risk of collision.

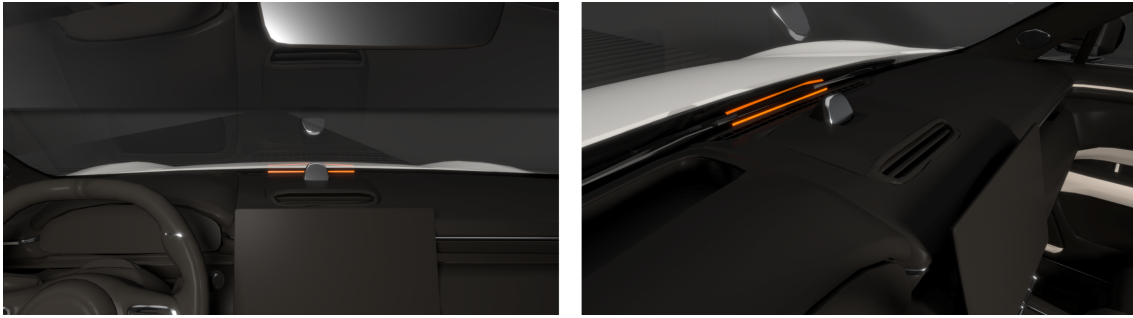


Figure 8.8: The Light Bar When Illuminating



Figure 8.9: Sequence of Light That Illuminate When Tailgating

8.3 Technical Description

This subchapter describes the more technical aspects of the concept, including a description of how the system works together, how the detection of objects should be, and the light presentation in the car.

System Overview

The core goal with the system is to enhance spatial awareness about the surrounding. The concept is designed to feel as a cohesive all-around system, rather than functioning as separate light sources. This allows a single object to be shown across multiple zones. For example, first through the front doors, and later via the A-pillar if it is hidden behind it.

Since the system is distributed across different light sources mapped to its surroundings, no single element is prioritized over another. If a vehicle is present in the blind spot while the distance to the car ahead is too small, both lights will light up, indicating the need for extra attention.

To make the system feel as one, a consistent color is used across all light sources. An important aspect while driving is to feel comfortable within the car's interior environment, to avoid unnecessary distractions and cognitive overload. The spatial ambient lighting that constitutes the final concept Argus has the function of increasing driver awareness while also providing an integrated aesthetic experience. As the concept is intended to be integrated into the interior ambient lighting, the colors can be customized to suit individual preferences. According to the theoretical background 3.5 Vision and Visual Feedback Systems, color of lighting significantly

affects the driver. Depending on the color, it can affect the drivers emotions as well as problem-solving skills.

In addition, similar movement patterns are used to encourage intuitive learning and promote the subconscious understanding of the correlation of outside events to interior lighting patterns. For example, variations in speed and distance are shown through different light intensities in similar ways across the different light sources.

Sensitivity

Factors that play an important role in the activation of the system include relative distance and speed, the visibility of the object to the driver, the approach angle, and object classification. The functionality of Argus is summarized in Table 8.1 with the corresponding zones visualized in Figure 8.10.

Based on existing awareness systems presented in Table 3.1, the underlying technologies required for this concept appear to already exist or be feasible with current developments. The primary difference between the information provided by Argus and systems such as Tesla’s live traffic visualization lies in how the information is presented to the user, rather than in the detection capability itself. This suggests that the concept is technically possible, as environmental sensing and object detection are already available.

Table 8.1: Argus: Overview of LED Function

Name	Position	Pattern	Purpose	Zone
Side Door	Upper Side door, (L/R)	Sweeping pulse	Provides a peripheral cue of passing vehicles’ movement and their relative position within the blind spot.	3, 4, 6, 7
A-pillars	Lower Wind-shield Corners (L/R)	Constant light	Indicates the presence of road users (pedestrians/-cyclists) obscured by the A-pillar and also a subtle awareness of objects approaching from occluded views.	2, 8, 9, 10
Windshield Front	Center-base of the windshield	Expands from the center as the vehicle approaches another vehicle or obstacle ahead.	Provides a peripheral cue for front-end proximity, aiding the driver’s sense of depth and clearance.	1

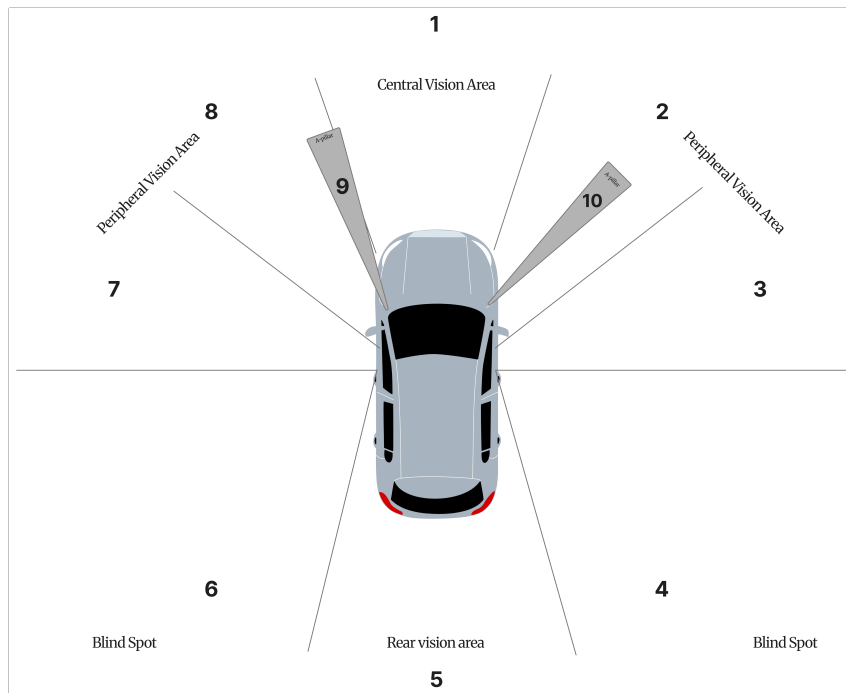


Figure 8.10: Driver's Field of Vision, Illustration of Zones in Table 8.1

Integration

The light strips will adapt their intensity based on light conditions to ensure visibility without causing glare. As the light is informative rather than a warning, it fades in gradually to not trigger an emergency response without first looking. However, the fading is still quick since some situations require a quick response. Since many detection-based systems are prone to false positives, it is important that the feedback remains non-intrusive and ambient in nature, reducing potential irritation when occasional false activations occur. The visual output is therefore scaled, ranging from subtle illumination in informational states to increased pulsing frequency in higher-risk scenarios. Calibration of systems should be designed to avoid abrupt or intrusive signals, instead prioritizing continuous, low-distraction awareness.

The lights integrated into the front doors are part of the ambient lighting, meaning they are always illuminated, but emit a brighter pulse to represent vehicles in the blind spot. However, the remaining lights are not visible while not alerted. These will be integrated seamlessly in the car. On the A-pillars, they are placed beneath fabric, meaning they are only visible when lightened. The front light are placed integrated in the car by an indentation that makes the light subtle and not too intrusive.

9

Discussion

In this chapter, the delivery of the objective, the project process, sustainability, ethics, and future development will be discussed.

9.1 Argus

Through the final concept Argus, the project fulfills the objective of the project, which was to develop a user-centered system that improves driver awareness without increasing users' cognitive load. Although the concept Argus does not cover all possible situations regarding awareness, it does offer increased awareness in the majority of the areas around the vehicle. This means that the concept is a step towards an all-around awareness system.

According to the theoretical background Section 3.1 Defining Driver Awareness, driver awareness consists of perception of the elements in the environment, comprehension of the current situation, and projection of future status. Argus gives an increased perception of the elements in the environment by lights that signal that an object is present as well as in movement. By the information being mapped out on areas corresponding to the zone it informs about, the feedback becomes more intuitive facilitating comprehension. The projection of future status is assisted by showing objects placement before they are visible from the driver's natural field of vision. For example, the corner windshield segment warns the driver about crossing objects that are not visible to the driver. The front doors alert the driver of passing vehicles through a light pulse before they enter the blind spot. This means that the concept assists and increases the driver awareness on all three levels. However, the extent of the increased awareness and how much safer the drive would be is difficult to quantify. Still, due to its relatively straightforward implementation and low cognitive load, the relative increase in awareness can be considered a justified amount.

Because of the limited time frame, a summative evaluation on the final concept after refinement was not conducted. This means the main standpoint for users perception of Argus, is based on the initial formative test. Based on their inputs regarding the concept model, it was established that the integration and aesthetic look of the lights would be a key factor in appreciation and acceptance of the system. By simple descriptions of the concept as a compliment to the concept model, the general acceptance and appreciation was high, indicating potential of including it in a final concept as well. Additionally, the concept is built on the idea that it

should be integrated as a part of the ambient lighting in the car. This is present in most modern cars today, meaning that it would not be a significant change to the interior of the car. Warning lights, such as the side mirror blind spot, are also well established and further support the acceptance of users.

The results of this project were anticipated in relation to the theoretical framework. Since Argus builds on existing technologies for traffic analysis as well as interior lighting, the concept outcome aligns with these systems. The user studies confirmed known industry and traffic challenges stated in Section 3.3, Car Accident Risk Factors, such as visibility issues caused by blind spots and tailgating behavior, which validated the direction of the concept. The solutions contains technical aspects present in existing systems, but displays it in a more immersive way. This means the concept's content is relatively expected compared to existing theoretical framework.

9.2 Research Result

To guide the project and initiate the concept development, the research questions were formed. This was referenced throughout the project and set the path for the work.

Driver Awareness

One of the results from this area concluded that some of the new technologies are not very inclusive. Modern vehicles place more and more information on screens, both infotainment but also as of recent, the digital rear view mirror. At the same time, some users highlighted difficulties with depth perception in screens, potentially excluding a portion of the population. Another interesting perspective concerns the role of the systems when the driver becomes overstimulated. This raises the question of whether systems in demanding situations should provide additional warnings and information, or instead be scaled down to allow the driver to focus maximum attention on the surrounding environment. The intention of Argus is to be discrete to avoid cognitive overload even in demanding situations. The concept should feel as part of the surroundings and simply bring the spatial perception inside the vehicle to make it more comprehensible to the driver.

Existing Systems

Driven by significant investment and rapid technological development, the automotive industry undergoes constant transformation as new systems and brands enter the market each year. When researching awareness systems that exist or have existed, the vast amount of data to be processed is impossible to cover. New systems were discovered throughout the entire process and identifying gaps that had not already been covered was a difficult task. Since the industry is driven by competition, there is high confidentiality regarding solutions and development processes. The ideas that reach the market are only the tip of the iceberg compared to the ideas

tested or evaluated by brands behind closed doors. This results in the research and development of new systems being highly inefficient for external parties, as failed systems and dead-ends are never made public, impeding the collective progress of the industry.

The research conducted regarding existing awareness systems raised a prominent concern about false positives. Balancing the threshold for activation is challenging, where a sensitive system may result in an increase in false positives, which according to interviews can result in the driver turning the system off, rendering it useless. However, an insensitive system venture the safety of the driver by not alerting them accurately. It is important to consider this when implementing feedback in an awareness system. Intrusive feedback is often intrusive for a reason, critical situations demand a fast reaction. The risk of being regarded as irritating can be a small trade-off for ensuring the driver's safety.

Context

Defining a clear context for the project was a challenge. For instance, a driving route can be widely different depending on the context. Driving during rush hours differs vastly from driving when the traffic is lighter. This means that the driver's needs and preferences for awareness systems vary. Therefore, restricting to a specific context seemed inappropriate and a simplification of how the car is actually used.

The interviews were conducted with users from different countries to cover a variety of contexts. Despite differences in countries and city sizes, similar problems were identified. Traffic situations tend to occur in similar ways, although with varying levels of severity. Argus reflects this by being a concept that can be applied across a wide range of contexts.

Human-vehicle Interaction

As mentioned in Section 6.4 Human-vehicle Interaction, a majority of respondents in both the interviews and questionnaires indicated a preference for receiving information and then making the driving decisions themselves. However, contradicting this, the same respondents later reported situations where they tend to miss surrounding traffic or *zone out*. This sense of pride regarding driving ability may be particularly prominent among the researched demographic, but it is not uncommon in the general population. This presents a new perspective for the development of awareness systems: creating a system that assists subtly, ensuring safety without appearing to underestimate the driver's abilities.

Distraction consumes the driver's awareness. The use of the center screen is becoming more and more tempting, with the accumulation of function controls and new features. Eliminating distractions might therefore improve awareness more than any new awareness system. However, the presence of mobile phones greatly complicates the situation. Controlling the use of mobile phones while driving goes beyond what awareness systems can do without sacrificing attractiveness on the market.

Interaction with awareness systems in today's vehicles often require direct attention and interpretation from the driver. Diverting the attention of the driver from the road counteracts the true purpose of an awareness system; to enhance awareness of surroundings, not direct attention to feedback and away from the road. Discrete feedback signals can make use of subconscious cues to increase awareness without directing the attention away from the initial source. With a good layout of the feedback, the amount of processing needed can be minimized.

Gaps and Requirements

As mentioned previously, the constant development of the automotive industry meant a challenge in finding unexplored topics. The main gaps found are regarding limited visibility in relation to the A-pillars and the issues with feedback that is often presented through sound or on one of the screens. To increase overall driver awareness, a standpoint for the project was to try to combine multiple problem solutions into a single system. This is represented in the concept development process, where a solution to one problem was developed and then explored in reverse to investigate the possibility to cover multiple gaps and increase awareness on multiple fronts with the same solution. The process reflects the way the project explored the possibilities of an all around awareness system and ways to increase awareness, rather than a specific problem to be solved.

The insights gathered were of a broad nature, ranging from a situational description of the driving context to insights regarding how feedback should be presented to drivers. This means that there was no detailed list of needs and requirements in the traditional sense that would typically be necessary for the development of a final product. Instead, the insights can be applied to the development of various types of awareness systems. Although many of the requirements may appear quite intuitive, several existing awareness systems do not fully adhere to them. Therefore, the findings remain relevant, as they provide an overview of important aspects to consider when designing an awareness system.

9.3 Project Process

This section discusses how well the project process supported the fulfillment of the purpose and objective of the project.

Literature Studies

The literature studies were primarily done as a way to benchmark existing research and technologies. This established a wide foundation as well as enabled the possibility of identifying gaps in existing technologies. This can be seen in the final concept that combines solutions to multiple problems into a single system. However, the wide scope also resulted in a less detailed investigation of the technologies. A more narrow scope could have strengthened the technical feasibility of the concept, but would most likely have resulted in a more limited width of the concept itself.

Participatory Observation

Participatory observations were conducted through visits to car dealerships as well as driving a selection of vehicles. The purpose of these observations was to develop a broader understanding of the current market offerings and the project's subject. In order to experience extreme driving situations without risking damage or compromising safety, a study visit to Tenstar Simulation AB was conducted. However, the simulations were of less fidelity than expected and were not able to contribute with specific insights regarding awareness. The most valuable part of the visit was the interviews with expert. Same applied to the dealership visits, were the interviews regarding consumer behavior proved to be the most valuable source of information.

Questionnaires

During the creation and distribution of the questionnaires, efficiency of receiving responses was a key factor. Users tend to respond more frequently to questionnaires that interest them. Therefore, the questionnaire was distributed through car forums and tailored for their members. The use of convenience sampling was an active decision to meet deadlines and make the process more efficient. This might have resulted in a misrepresentation of the driving behavior of the general public as the demographic was not representative.

When conducting questionnaires, ensuring an equal interpretation of the questions between respondents can be challenging. There was one question in particular that was interpreted in two different ways. This was recognized during the interviews where the same question was included but with a verbal explanation. On the scale which current automotive safety systems were rated based on their importance, some recipients answered whether they would want that system in their car or not, and others if the system itself is efficient. This could have resulted in wrongful data, although the interpretations were similar. An example of this was the digital replacement for rear and side view mirrors. They received diverse scores and in the interviews it was expressed that although it is a good system, it is not a necessary one. This aligned with the majority of the respondents' thought processes, despite the different scores as a result of interpreting the question differently.

Even outside of the scale, a handful of responses were contradictory. The same systems received positive and negative responses; a prime example is the digital rear view mirror, where some recipients expressed that it was worse than a regular mirror at night, while others expressed that they thought it was better. Similarly, some thought it was too large, while others would have preferred it even larger.

Interviews

The interviews were conducted mainly with the questionnaire respondents who agreed to participate in an interview. Since the questionnaires were distributed through online car forums, a very similar demographic was noticed in between the interviewed. This led to the majority of the interviews being conducted with car

enthusiasts and tech-lovers. Therefore, interviews with less experienced drivers were used for compensation. Interestingly enough, although car enthusiasts had a lot more tech-oriented responses, the opinions and experiences between the two were very similar, despite the interview guide being tailored for car enthusiasts.

Tech-oriented people risk having an initially critical view toward systems and notice flaws within a system that would go unnoticed to most users. This presents a potential issue with the data received from interviews, as the demographics' threshold for distrusting a system is much lower than that of an average driver. Although distrust may appear sooner, it is not without reason. The advantage of the tech-oriented demographic is that the base knowledge of systems is much higher than the average driver, which enables for elaborated responses and well-formulated preferences for new systems.

The interviews were all conducted digitally with respondents from different regions of the world. The main difference between conducting an interview in person versus digitally is the ability to interpret body language and facial expressions. This can contribute to the understanding of the answers to subjective questions as the interpretation of a verbal expression can differentiate depending on body language or facial expression. Another advantage in conducting interviews in person is the possibility of using mediating objects. The project could have benefited from conducting interviews within a car, as it reminds users of situations and works as a reference.

User Evaluation of the Final Concept

A model of the final concept with relatively low fidelity was developed for user testing and evaluation. The model allowed the users and the project group to get a good sense of how the concepts would be implemented inside a vehicle.

Using methods like Wizard of Oz in combination with the vehicle as a mediating object certainly improved the authenticity of the user test; ensuring a more credible result from the tests with a better understanding of user behavior. However, for safety and financial reasons, it was decided to conduct the tests while the vehicle remained parked. This means that the users' understanding of the system and thus their preferences could change in a real traffic situation, since the light signals are relative to surrounding traffic. It can be argued that users could evaluate the concept differently while driving with their attention divided, which could have changed the direction of the concept development.

The user evaluation included four participants, primarily due to time constraints. This is considered a low amount, and is something that could have been expanded to make sure more possible insights on the concept were gained. However, after the four interviews and tests, it showed that the same opinions were raised and the same problems were mentioned by most of the participants. The general opinion about the concept and understanding of the functions were similar, which is why the user testing was considered enough with respect to the time constraints.

Since the model consisted of regular exposed LED-strips, the brightness, size, and visibility of the lights were far from the expectations intended for the final product. Users expressed a critique regarding these factors, as feedback was perceived as intrusive and more prominent than desired. The feedback was partly disregarded as a fidelity issue, yet still shaped the final light placement. During testing, all lights were bright red, which resulted in users interpreting the lights as a warning and the situation as more critical than intended, further strengthening the case for color customizability.

9.4 Sustainability

A challenging aspect of this project was striking a balance between innovation and longevity, developing something inventive that remains relevant for years to come, while still being feasible to implement within the foreseeable future. This challenge extended beyond the concept itself, as introducing new technologies risks promoting unsustainable consumer behavior.

Consumption patterns in certain markets are highly trend-driven, which has significantly impacted the automotive industry. This has led to continuous releases of new vehicles with shortened development cycles, as manufacturers strive to remain relevant and push new technologies to market. Argus could risk becoming a feature that increases car purchases; a pattern that is not environmentally sustainable. It is therefore the project team's hope that Argus will prove to be a long lasting feature.

The final concept was developed with the intention of adding functionality to an already integrated component of the vehicle: ambient lighting. Although it requires a small increase in the number of light sources, it adds value to the already integrated ones. From a sustainability perspective, expanding an existing system is considerably more resource-efficient than introducing an entirely new standalone solution for driver awareness. In conclusion, Argus represents a sustainable approach to improving driver awareness; one with the potential to remain relevant for many years to come.

9.5 Ethical Aspects

The core of this project has been safety, as the purpose of Argus is to improve road safety and create a more secure traffic environment for all road users. However, technology and systems are rarely flawless and may fail for various reasons, leading to unpredictable consequences. This raises an important ethical question that is relevant across all areas of automation: Who bears responsibility when a system fails? This consideration, together with the questionnaire results discussed in Section 6.1 Driver Awareness, made it clear that the appropriate path forward was a system that provides information without making decisions on behalf of the driver. This approach preserves both control and responsibility with the driver, while still improving awareness.

An important related consideration is the calibration and sensitivity of the system. An overly sensitive system risks generating false positives, which may cause drivers to lose trust, something that was mentioned by users. On the other hand, a system that is not sensitive enough may fail to alert the driver in situations where intervention is needed. Skepticism toward the system might be desirable from an ethical point of view. Since every system might fail at some point, it is important for drivers to feel responsibility in maintaining awareness and not transfer the responsibility on Argus.

9.6 Future Development

This section discusses possible next steps for the continued development of Argus. It includes evaluation, technical aspects, user experience and customization.

Awareness Evaluation

To further develop the concept, it would be favorable to evaluate driver awareness in a high fidelity model in a real driving context. In the theoretical background, see Section 3.2 Measuring Awareness, the two methods SPAM and SART were introduced as approaches for measuring and evaluating driver awareness. Although the methods were originally developed for air traffic control contexts, the principles behind them would still be suitable for future evaluation of the concept. SPAM measures cognitive workload in real time, which is important for evaluating how intrusive or beneficial the system may be in the context. SART evaluates the driver's own perception of focus, where awareness is assessed from the driver's subjective perspective. This combines the more objective time-delay measures of SPAM with the subjective numerical ratings of SART. Driver awareness is highly dependent on the individual, which makes it important to measure and evaluate subjective assessments in combination with performance-based tasks. This would allow a more quantifiable measurement of the concept's potential in increasing driver awareness, and allow for further iterations regarding optimal movement patterns, placement, and overall functionality.

Technical Aspects

The technical solution for the concept is deemed possible since existing technologies in awareness systems process similar information, only displaying it in a different manner. However, to further develop the concept, a deeper investigation of necessary sensors, radars, and cameras would have to be done. Favorably, the system should be able to function based on existing technologies in the car, however, the feasibility depends on the specific car model in which the system will be integrated. Additionally, the calibration of the system would be of high importance. Balancing the activation threshold is of utmost importance to avoid irritation and distrust, while still remaining functional. To achieve a well-balanced calibration, it would be beneficial to use the awareness-measuring methods mentioned above. They could

provide a basis for when an increase in awareness is beneficial for the driver and when it merely adds information to a situation in which the driver is already aware.

The light that is likely the most difficult to calibrate satisfactorily is the A-pillar segment. While driving, there is almost always something located behind the A-pillar, since it continuously blocks a portion of the driver's field of vision. However, by using object-identification technologies and possibly an AI-based system, situations that typically require attention could potentially be detected. For example, the system could identify moving objects that remain hidden from the driver, such as a pedestrian crossing a cross-walk.

User Experience and Customization

A main aspect of Argus consists of the integration with an ambient lighting system. To further develop the concept, it would be necessary to investigate existing ambient lighting systems in varying models and brands of cars. Depending on the characteristics of these ambient lighting systems, adjustments and seamless integration would create a cohesive experience.

Future research should evaluate different colors applied to the concept to determine how spatial ambient lighting affects the driver, based on the theoretical background in Section 3.5, Ambient Lighting as Visual Feedback System. Low frequency colors such as blue and purple, has the advantage of improving alertness and being perceived as more unique, which could enhance driver awareness. High frequency colors such as orange and yellow, on the other hand, have the advantage of being soft and comfortable, which could enhance driver awareness by not being overly intrusive and thus reducing cognitive overload. However, they may also be less noticeable in critical situations. Since the concept alerts the driver to blind spots and tailgating behavior, red can also be considered as a suitable option, as it is perceived as the most intuitive and effective color for alerts. The benefit of color customizability is that every driver has their own preferences regarding what works best for them. Some drivers are more easily stressed and require colors that are not overly intrusive, while others can handle a large amount of information and therefore have different needs and preferences. Another aspect is the selection of color with the aim of strengthening brand identity, but it must be considered that different colors have different effects on the driver, both in terms of awareness and response.

In this project, the scope regarded the moment while driving. This means there are possibilities to expand the concept to a broader scope. One idea for this is to develop an immersive experience with help from the system, starting when the user enters the vehicle. When entering, the light in the car could welcome the driver by lighting up all lights in a specific order. This could create a more immersive introduction to the system and strengthen the driver's connection to the vehicle from the moment they enter the car.

10

Conclusion

In conclusion, Argus represents a significant step forward in the development of spatial ambient lighting and its potential applications in future all-around awareness systems. Argus increases driver awareness through enhanced perception of elements, improved comprehension of the surroundings, and increased support for projection of future status. However, the extent of this improvement should be further evaluated using higher-fidelity models to refine the concept.

During the investigation of existing awareness systems, several consistent user insights emerged. False positives were perceived as highly intrusive and resulted in a distrust toward the system. Furthermore, both perceived and actual control emerged as critical factors for user acceptance. Although users generally desire greater access to information, overly intrusive systems are likely to be disabled. This highlights the importance of the user requirements. If a system is disabled by the user, its potential safety benefits are lost.

Awareness systems that provide information without demanding active driver attention can reduce cognitive load while preserving engagement with the driving task. However, there is a critical balance between assistance and dependency; systems that are too intrusive may be ignored or disabled, while overly passive systems may fail to offer sufficient awareness. Consequently, effective awareness systems should aim to support driver focus rather than replace it, ensuring that attention remains directed towards the driving environment.

The review of existing systems confirms the technological feasibility of the final concept. Accordingly, the system can be considered implementable in the near future, aligning well with the project's objective.

Finally, while the exploratory and initially undefined scope of the all-around awareness was at times overwhelming, it encouraged innovative methods and approaches. The ideation process was largely driven by exploring opportunities rather than solving one single problem. This is reflected in the thematic concepts presented in the development phase. Although the project's focus later narrowed, the vision of all-around awareness remained the core of Argus.

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A

Contextual Analysis

This analysis was conducted to identify external factors with focus on what a driver needs to be aware off while driving. It covers different objects and situations, how probable they are to happen and how predictable they are when they happen.

What to be aware of when driving

Probability

Stationary objects

Buildings
Curtins
Parked vehicles
Road blockage objects
Fences
Nature
Pole
Low objects

IRL information

Road Markings
Traffic Lights
Speed signs
Information signs
Traffic directions
Traffic detectors

Other vehicles

Cars	Emergency Vehicle
Public Transport	Motorcycles
Heavy vehicles	Slow-moving vehicle

Vulnerable Road Users

Bicycles
Pedestrians

Unpredictable vehicles

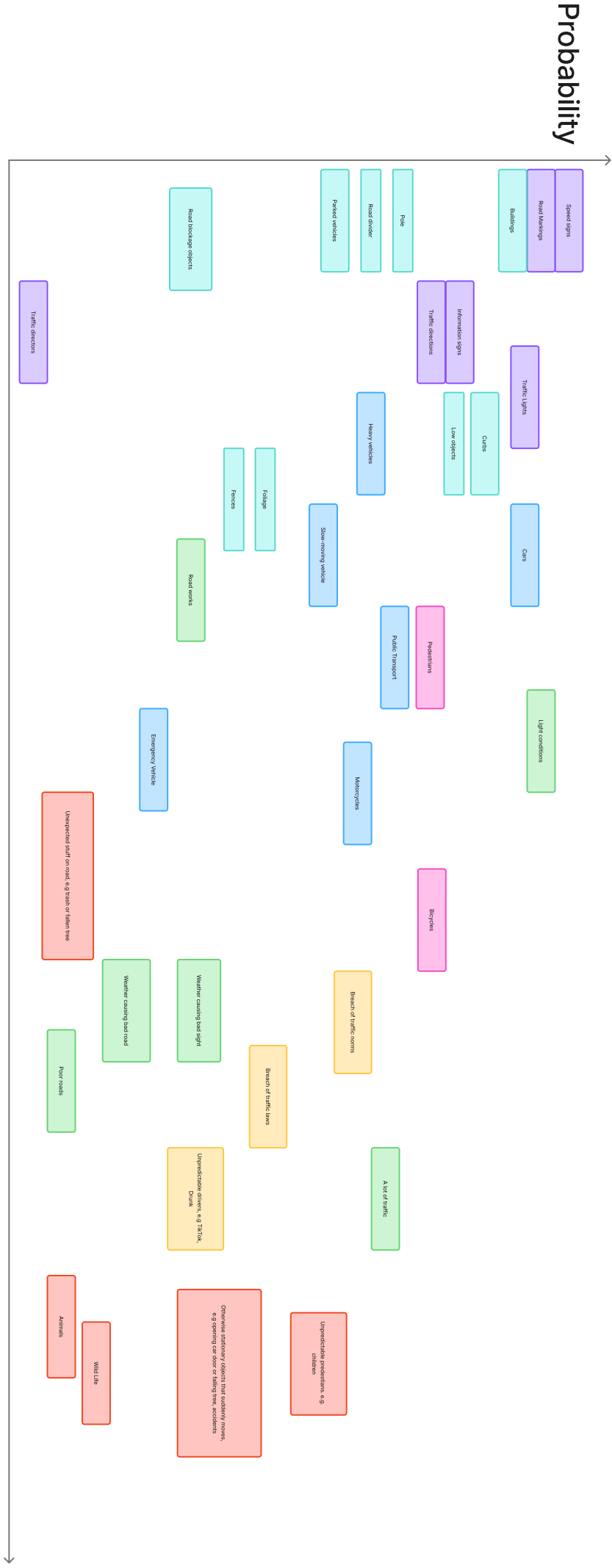
Unpredictable drivers, e.g. Tired, Drunk
Breach of traffic laws
Breach of traffic norms

Unexpected Things

Animals	Unpredictable pedestrians, e.g. children
Wild Life	
Unexpected stuff on road, e.g. trash, fallen tree, accidents	
Otherwise stationary objects that suddenly move, e.g. opening car door or falling tree	

Unpredictability

A deconstruction of “What to be aware of”



Unpredictability

B

What-Where-How

This Appendix contains tree matrices that were used early in the design process to determine, what happens where and how it happens.

C

Surveys

Bellow is one of four slightly different surveys that was sent out during week 10 and 11 in 2026. The different between the different surveys is that two of them contained a question about Polestar 4's digital rear view camera and two does not. Both of theses different surveys was made in both English and Swedish, therefore four different surveys. Theses serverly was distributed in different car forums, both Swedish and globally and the once containing questions about Polestar 4 was distributed in specific Polestar forums, both Swedish and global. The survey that is attached here is the English one that contained questions about Polestar 4's digital rear view mirror.

Questionnaire about safety systems in cars

Bachelor's thesis at Chalmers University of Technology, 2026

This survey is a market reasearch study aimed at investigating drivers' opinions and experiences regarding traffic awareness in different vehicles. If you drive a Polestar 4, your answers will be particularly relevant. The survey is part of a bachelor's thesis in Industrial Design Engineeering at Chalmers University of Technology, Sweden.



* Obligatoriskt

1. Do you own or have driven a Polestar 4? *

☐ Yes

☐ No

2. What kind of car do you drive? Enter the brand, model, and year of your car. *

☐ Annat

5. How important do you consider the following safety features to be? (1=less important, 6 = very important) *

	1	2	3	4	5	6
Lane Assist	☐	☐	☐	☐	☐	☐
360° camera (e.g., when parking)	☐	☐	☐	☐	☐	☐
Speed Assist (warnings when you drive above the speed limit)	☐	☐	☐	☐	☐	☐
Rear view camera	☐	☐	☐	☐	☐	☐
Blind spot monitor	☐	☐	☐	☐	☐	☐
Adaptive cruise control	☐	☐	☐	☐	☐	☐
Adaptive speed limiter (automatically decreases your speed when driving above the speed limit)	☐	☐	☐	☐	☐	☐
Driver monitoring (monitoring fatigue and drowsiness of the driver)	☐	☐	☐	☐	☐	☐
Exit warning (warns about predestin es when opening a door)	☐	☐	☐	☐	☐	☐
Automatic emergency braking	☐	☐	☐	☐	☐	☐
Seat belt warning system	☐	☐	☐	☐	☐	☐
Traffic Sign Recognition	☐	☐	☐	☐	☐	☐
GPS/Navigation System	☐	☐	☐	☐	☐	☐
Digital rear view mirror	☐	☐	☐	☐	☐	☐

6. Are there any systems that you don't find practical? If so, why? *

7. Are there any systems that you don't find practical? If so, why? *

8. Are there any systems that you particularly appreciate? If so, what do you appreciate most about the system? *

9. Are there any systems that you particularly appreciate? If so, what do you appreciate most about the system? *

10. Which systems help you most to be aware of your surroundings and other road users? *

11. Which systems help you most to be aware of your surroundings and other road users? *

12. What do you think of the new camera (digital rear view mirror) that has replaced the traditional rear view mirror in the Polestar 4? Please describe your thoughts in words. *

13. Describe a situation where you tend to miss something in your surroundings when driving. What technology could have helped you in that situation? *

14. Which country have you mainly driven in? *

15. May we contact you if we have any further questions? *

☐ Yes

☐ No

16. Leave your email address and we will contact you if necessary. *

17. Is there anything else you would like to add?

18. I hereby consent to my data being saved and stored in accordance with the GDPR and used within the scope of my thesis work. The data will be stored until 30 June 2026 and will then be deleted. *

☐ Yes

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D

Interview Guide

Bellow is the English version of the interview, a Swedish version were also made.

Interview - English

Bachelor thesis at Chalmers University of Technology, 2026

Target group: Broad target group, covering both extreme cases and normal cases.

Interview duration: 20-30 min

Driving context: Depends on the respondent's commuting route.

* Obligatoriskt

Tips:

- Be silent a little longer and wait for the respondent to think and answer
- Probing, ställ följd frågor och gå in djupare i relevanta områden Probing: ask follow-up questions and go deeper into relevant areas
- Håll dig till tiden, vägled respondenten mot intervjuens fokusområde Probing: ask follow-up questions and go deeper into relevant areas
- Konkretisera; t.ex. R: Hastighetsbegränsaren är jobbig. I: Vad är det som är jobbigt? Ljudet, avstängningen Concretize; e.g. R: The speed limiter is annoying. I: What is it that is annoying? The sound, the deactivation

Introduction and GDPR (1 min)

- **Welcome:** "Thank you for participating! We are investigating how drivers experience safety/awareness systems and their surroundings while driving."
- **GDPR:** "Before we begin, I need your verbal consent to record this conversation and save your data for this project. Everything will be anonymized. Is that okay with you?"
- **START RECORDING.**

Warm-up Questions (3 min), Short Answers

1. How often do you drive, and in what context do you usually do so?

2. How long have you been driving and how much driving experience do you have?

3. Which car do you drive?

4. In what type of traffic environment do you drive the most?

- ☐ Large City
- ☐ Smaller City
- ☐ Countryside
- ☐ Annat

5. Which countries have you driven in?

6. Do you drive to work?

- ☐ Yes
- ☐ No
- ☐ Sometimes

Öppna frågor om Awareness (13 minuter), längre svar

7. How mentally demanding or tiring do you find your commute to work?

8. How much do you notice what's happening around you while you drive? Do you feel fully aware of your surroundings?

9. Do you find yourself focusing on anything else while driving? Please describe.

10. Are there any situations where you find it difficult to spot risks or hazards? (For example, other cars, pedestrians, speed bumps). What would help you in those situations?

11. Can you describe one or more difficult situations that have occurred while you were driving? Did the situation happen during your commute to work?

12. Which part of driving is usually the most difficult? Where and when? (Number of lanes, other road users, road conditions, traffic jams, etc.)

13. What is most important to you in a system that increases your awareness of your surroundings? Is there anything you find annoying? (Alternatively, skip this)

14. What is your understanding of what an awareness system in a car is? Please describe.

15.

	1	2	3	4	5	6	No opinion
Lane Assist	☐	☐	☐	☐	☐	☐	☐
Blind Spot Detection	☐	☐	☐	☐	☐	☐	☐
Driver Monitoring	☐	☐	☐	☐	☐	☐	☐
Traffic-Sign Recognition	☐	☐	☐	☐	☐	☐	☐
Automotive Night Vision	☐	☐	☐	☐	☐	☐	☐
Forward Collision Warning	☐	☐	☐	☐	☐	☐	☐
Side-View Mirror	☐	☐	☐	☐	☐	☐	☐
Digital Side-View Mirror	☐	☐	☐	☐	☐	☐	☐
Rear-View Mirror	☐	☐	☐	☐	☐	☐	☐
Digital Rear-View Mirror	☐	☐	☐	☐	☐	☐	☐
Reversing Camera	☐	☐	☐	☐	☐	☐	☐
Reverse Warning	☐	☐	☐	☐	☐	☐	☐
360° Camera	☐	☐	☐	☐	☐	☐	☐
Head-Up Display	☐	☐	☐	☐	☐	☐	☐
Live Traffic Visualisation (Tesla)	☐	☐	☐	☐	☐	☐	☐
Automotive Navigation System	☐	☐	☐	☐	☐	☐	☐
Speed Limit Alert	☐	☐	☐	☐	☐	☐	☐

16. Notes: Extra interesting responses?

Narrowing questions (3 minutes), short answers

17. Which system or systems do you trust the most?

18. Which system or systems distract you the most?

19. Which system would you like us to improve, and what type of improvement would you like to see?

20. How do awareness systems affect you while you drive? Do you notice any change of driving-behaviour?

Conclusion - GDPR Consent

21. I hereby consent to my data being saved and stored in accordance with GDPR and used within the scope of this bachelor thesis. The data will be stored until June 30, 2026, and will thereafter be deleted. *

☐ I agree

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KJ-method

A KJ-method done with quotes from interviews. Below each category we summarized the information shortly, and tried to formalize some insights gathered from the interviews regarding that subject.

F

Decision matrix

To choose the final concept a decision matrix were used to narrow down from two ideas to one.

Spatial Light (1-6)	Utvecklingspotential	Gymnar projektet	Hur rolig	Realistiskt	Hur uppskattat kan det bli av arbetsgivarna	Hur nära ett all-around awareness system	Utökar awareness	Låg kognitiv belastning
Viktnings	2.5	2	1	2	1.5		3	2.5
Fahim	4	4	6	2	6	3	3	4
Amelie	5	5	6	4	6	5	5	3
Edvin	5	4	6	4	6	5	4	5
Hugo	5	4	5	6	5	5	4	5
Ella	4	4	6	3	5	4	3	3
Gustav	4	5	3	5	5	4	3	3
Total	67.5	52	32	48	49.5	78	63	57.5
630 Sammanslagen tot: 447.5								
Extended vision via cameras(1-6)	Utvecklingspotential	Gymnar projektet	Hur rolig	Realistiskt	Hur uppskattat kan det bli av arbetsgivarna	Hur nära ett all-around awareness system	Utökar awareness	Låg kognitiv belastning
Viktnings (1-3)	2.5	2	1	2	1.5		3	2.5
Fahim	5	4	5	4	5	3	4	5
Amelie	5	4	2	3	3	3	4	4
Edvin	4	3	5	5	4	3	6	4
Hugo	6	4	4	6	5	4	5	3
Ella	4	4	5	2	4	3	4	3
Gustav	4	4	4	4	3	4	5	3
Total	70	46	25	48	36	60	84	55
Sammanslagen tot: 424								

G

User Tests

The user tests were only made in Swedish and in a car where a low fidelity concept were set up.

Mål med test:

- Undersöka vilken typ av *placering* och *rörelsemönster* som signalerar vilken typ av rörelse
- Vad tycker förarna?

Del 1: Undersöka vilken typ av placering och rörelsemönster som signalerar vilken typ av rörelse

Vi gör ett explorativt arbete kring medvetenhet i bilar. Spela in?

Ljus på dörr

Introduktion: Du kör på en flerfilig motorväg med många bilar. Detta händer, vad tänker du att det betyder?

Hur säker är du på det, 1 – 6?

Hur hade du reagerat om detta tändes när du körde?

Visa olika situationer.

Vad tänker du att de olika ljusmönstren betyder?

Vad skiljer sig åt mellan händelserna som varje mönster representerar?

Förklara vad det är

Hur tydligt tycker du det känns 1 - 6?

Hur störande hade du tyckt att det var 1 – 6? Varför?

Var det någon som kändes otydlig eller förvirrande?

Övrig kommentar?

Ljus på A-stolpe

Introduktion: Du kör vid ett övergångsställe. Detta händer, vad tänker du att det betyder?

Hur säker är du på det, 1 – 6?

Hur hade du reagerat om detta tändes när du körde?

Förklara vad det är

Hur tydligt tycker du det känns 1 - 6?

Hur störande hade du tyckt att det var 1 – 6? Varför?

Var det någon som kändes otydlig eller förvirrande?

Övrig kommentar?

Ljus i hörn (Blinkande)

Introduktion: Du kör i en korsning. Detta händer, vad tänker du att det betyder?

Hur säker är du på det, 1 – 6?

Hur hade du reagerat om detta tändes när du körde?

Visa olika situationer.

Vad tänker du att de olika ljusmönstren betyder?

Förklara vad det är

Hur tydligt tycker du det känns 1 - 6?

Hur störande hade du tyckt att det var 1 – 6? Varför?

Var det någon som kändes otydlig eller förvirrande?

Övrig kommentar?

Ljus fram

Introduktion: Du kör på en flerfilig motorväg med många bilar. Detta händer, vad tänker du att det betyder?

Hur säker är du på det, 1 – 6?

Hur hade du reagerat om detta tändes när du körde?

Förklara vad det är

Hur tydligt tycker du det känns 1 - 6?

Hur störande hade du tyckt att det var 1 – 6? Varför?

Var det någon som kändes otydlig eller förvirrande?

Övrig kommentar?

Ljus på backspegel (Av/På)

Introduktion: Du kör på en flerfilig motorväg med många bilar. Detta händer, vad tänker du att det betyder?

Hur säker är du på det, 1 – 6?

Hur hade du reagerat om detta tändes när du körde?

Visa olika situationer.

Vad tänker du att de olika ljusmönstren betyder?

Vad skiljer sig åt mellan händelserna som varje mönster representerar?

Förklara vad det är

Hur tydligt tycker du det känns 1 - 6?

Hur störande hade du tyckt att det var 1 – 6? Varför?

Var det någon som kändes otydlig eller förvirrande?

Övrig kommentar?

Del 2: Undersöka vad förarna tycker om konceptet

Visa skissen

Vad tycker du om systemet i sin helhet?

Är det något du hade uppskattat om det fanns i din bil?

Är det något du hade stängt av om det fanns i din bil?

Är det något särskilt du hade önskat skulle förändras för att det skulle vara ett bra system för dig?

Tycker du det känns som ett futuristiskt system?

Vad hade krävts för att du ska kunna känna tilltro till ett sånt här typ av system?

Tanken är att det ska vara aktivt både vid körning på väg och vid parkering, som komplement till redan existerande system. Är det något av de tillfällena du tycker känns mer eller mindre relevant? Varför?

Övriga kommentarer?



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