DESIGNING FOR ENHANCED TRUST THROUGH FEEDBACK MECHANISMS FOR TAKEOVER SCENARIOS IN SEMI-AUTONOMOUS VEHICLES.

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ABSTRACT

DESIGNING FOR ENHANCED TRUST THROUGH FEEDBACK MECHANISMS FOR TAKEOVER SCENARIOS IN SEMI-AUTONOMOUS VEHICLES

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With advancing technology, autonomous systems that perform tasks with little or no human intervention based on environmental perception have emerged. In semi-autonomous vehicles, the transition of control between user and vehicle is critical for trust and safety. Appropriate perceived trust is essential for successful takeovers, and feedback mechanisms play a key role. Previous studies focused on technical aspects like timing or feedback modalities. This thesis explores how feedback design affects users' perceived trust and safety during unintentional takeovers in critical situations. User research included think-aloud sessions on an itinerary and semi-structured interviews to gain deeper insights. Findings were compared with the literature to identify factors supporting appropriate trust and adoption. By focusing on user needs rather than only the vehicle's actions and implementing more implicit feedback design approaches, the interaction between the user and the system can be improved. This leads to more accurate, calibrated trust, preparing users to respond effectively during critical takeovers and enhance overall perceived trust and safety.

Keywords: Autonomous Vehicles, Perceived Trust, Feedback Mechanisms, Takeover, User Experience.

ÖZ

YARI OTONOM ARAÇLARDA DEVRALMA SENARYOLARI İÇİN GERİ BİLDİRİM MEKANİZMALARI ARACILIĞIYLA GÜVEN İÇİN TASARIM

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Teknolojinin gelişmesiyle, çevresel algıya dayalı olarak çok az veya hiç insan müdahalesi olmadan görevleri yerine getirebilen otonom sistemler ortaya çıkmıştır. Yarı otonom araçlarda kullanıcı ile araç arasındaki kontrol geçişi, güven ve emniyet açısından kritik öneme sahiptir. Başarılı bir devralma için uygun düzeyde algılanan güven gerekir ve geri bildirim mekanizmaları bu süreçte önemli rol oynar. Bu tez, kritik durumlarda gerçekleşen istemsiz devralmalarda geri bildirim tasarımının kullanıcıların algılanan güveni üzerindeki etkisini incelemektedir. Kullanıcı araştırması, belirli bir rotada yapılan sesli düşünme protokolü ve yarı yapılandırılmış görüşmelerle yürütülmüştür. Bulgular, güveni ve benimsemeyi destekleyen faktörleri belirlemek amacıyla literatürle karşılaştırılmıştır. Araç odaklı yaklaşımlar yerine kullanıcı ihtiyaçlarına öncelik vererek ve örtük geri bildirim stratejileri kullanarak, kullanıcı-sistem etkileşimi geliştirilebilir. Böylece, daha dengeli ve doğru bir güven oluşur; bu da kullanıcıların kritik devralma anlarında daha etkili tepki vermesine ve güven algısına katkı sağlar.

Anahtar Kelimeler: Otonom Araçlar, Algılanan Güven, Geri Bildirim Mekanizmaları, Devralma, Kullanıcı Deneyimi.

To the future self

may this journey be a reminder of today's effort and tomorrow's growth.

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LIST OF ABBREVIATIONS

ABBREVIATIONS	
ACC	Adaptive Cruise Control
ADAS	Advanced Driver Assistance
AEB	Automatic Emergency Braking
aHMI	Automation-Focused HMIs
AI	Artificial Intelligence
AP	Automatic Pilot
AVs	Autonomous Vehicles
dHMIs	Dynamic HMIs
DDAW	Driver Drowsiness and Attention Warning
DM	Driver Monitoring
DMS	Driver Monitoring Systems
eHMI	External HMIs
GM	General Motors
HCI	Human-Computer Interaction
HMIs	Human-Machine Interface Systems
HUD	Head-Up Display
iHMI	Driver Interaction HMIs
IoT	Internet of Things
ISO	International Organization for Standardization

LDWS	Lane Departure Warning System
LIDAR	Light Detection and Ranging
LKA	Lane Keep Assist
LRR	Long-Range Radar
LVDA	Lead Vehicle Departure Alert
NHTSA	US National Highway Traffic Safety Administration
ODTUİAEK	Applied Ethics Research Center of the METU
PA	Park Assist
RCA	Radio Corporation of America
RCCA	Rear Cross-Traffic Collision Avoidance Assist
RVC	Rear View Camera
SAE	Society of Automotive Engineers
SRR	Short-Range Radar
SVC	Surround View Camera
TJA	Traffic Jam Assist
TOR	Takeover Request
TSR	Traffic Sign Recognition
UI	User Interface
UTAUT	Unified Theory of Acceptance and Use of Technology
UX	User Experience
vHMI	Internal Vehicle HMIs

CHAPTER 1

INTRODUCTION

With the advancement of technologies, autonomous products and systems capable of completing tasks with no or limited human intervention by their perception of the surrounding environment have been developed (Zhang et al., 2023). These developments affect the automotive sector as well, with research and development efforts towards fully autonomous vehicles. While they create a more comfortable experience for the driver and passengers, they also ensure safety and security of the vehicle and its surroundings.

Autonomy levels vary according to the features and equipment of the vehicles. Although fully autonomous vehicles, classified as level 5 according to the J3016 standard of the Society of Automotive Engineers (SAE) (SAE International, 2021), are not ready to be on the roads today, we can see semi-autonomous vehicles widely. Although the autonomous features in these vehicles are significantly advanced in terms of software and hardware and can perform certain tasks on their own, trust in these systems that the vehicle will complete tasks successfully is a crucial factor and should be based on appropriate trust-building (Ekman et al., 2018). Because in sudden adverse situations and critical conditions, the vehicle's awareness, reaction, and the way and time of warning the driver are important to avoid possible accidents. Especially in semi-autonomous vehicles, where the driving tasks can be performed by the vehicle to a certain extent, but the driver should not be completely disengaged with the driving experience, there may be a request to give control back or for the driver to takeover. For an unintentional takeover, feedback mechanisms should be effective to support the driver's perceived trust and safety towards these systems.

The safe integration of autonomous driving systems into our lives is strongly related to users' trust in the system. However, this trust should be at an appropriate level.

While trusting the system less than necessary can create inefficient results, trusting it too much can also cause some problems. For example, if the driver, who should not be completely disengaged from the driving activity, quits the driving task with excessive trust, there may be a delay in regaining control in the event of a possible accident or system failure, and preventable accidents may occur.

Although the advanced features of autonomous vehicles (e.g., advanced driver assistance-ADAS, adaptive cruise control-ACC, lane keep assist-LKA, etc.) may increase the user's trust in the system, this does not mean that they will directly offer a safe driving experience. The users' perceived trust, built on the interaction between the user and the vehicle, is a significant factor for ensuring safe driving experience and should be calibrated for effective results (Walker, 2020). Previous studies support that users' trust levels should be at an appropriate, optimal level (Lee & See, 2004). The definition of appropriate trust has been approached from different perspectives across disciplines. Some studies emphasize the importance of matching users' perceptions with the actual capabilities of the system by fostering accurate mental models (Yang et al., 2020), while others focus on quantifying trust through users' behaviors and performance metrics so that trust can be measured and compared (Wang & Yin, 2021). Despite methodological and terminological divergences, the underlying consensus highlights the importance of maintaining an effective relationship between the trustor and the trustee. A common understanding is that the abilities users believe the system promises should align with what the system can actually deliver. When the system's abilities fall short of user expectations, over-trust occurs; when they exceed user expectations, under-trust arises (Wischnewski et al., 2023). Various theories and metrics have been developed across disciplines to measure and evaluate appropriate trust.

The vehicle's feedback, especially in critical situations, is important for users regarding the sustainability of trust. The studies assessing user trust in automated vehicles (e.g., Gold et al., 2013) primarily reveal the effects of existing feedback designs for takeover situations on users' perceived trust and safety. However, they

often limit the scope of their studies to very specific attributes of user interface (UI) or feedback design. For example, one study (e.g., Schneider et al., 2021) deals with modality types, while the other (e.g., Faltaous et al., 2018) only examines continuous visual feedback. Therefore, research is also needed to determine how the feedback should be designed holistically to enhance the user experience (UX).

This thesis is not focused on how trust is measured, but on what factors are effective in building perceived trust and safety, and how these factors can be integrated into an effective feedback design and improve the driving experience.

1.1 Aim and Objectives

This thesis aims to explore how to enhance trust through feedback mechanisms for takeover scenarios in semi-autonomous vehicles, particularly in critical conditions such as adverse weather, sudden pedestrian/obstacle crossing, and risky environments.

While pursuing the aim, the objectives of the research are:

- Understanding and revealing the factors that affect users' perceived trust and safety of vehicles with autonomous features.
- Identifying the design attributes playing a role in shaping perceived trust and exploring how they may be integrated effectively into the feedback design for the designers.
- Determining design intervention areas and offering design strategies to enhance perceived safety and trust through feedback design.

1.2 Scope of the Study

The research focuses on the perceived trust and safety of users towards semi-autonomous vehicles through feedback designs and UX. It includes a field study that requires active participation in a driving experience on an itinerary involving phases that might share similar challenging conditions with potential takeover scenarios. The participants are expected to have a driver's license for at least 2 years and semi-autonomous driving experience. The scope of the autonomous cars is limited to SAE level 2 vehicles (see literature section 2.2 SAE Levels of Autonomous Vehicles) with partial automation, involving features such as ACC, LKA, and a variety of sensors. The experiences and perception of trust of the participants examined by applying user research methods to reveal insights for how effective feedback mechanisms should be designed to enhance users' perceived trust and safety.

Research Questions

Considering the aim and objectives mentioned previously, two main research questions were addressed.

- What are the main dimensions that affect user trust in semi-autonomous vehicles during unintentional takeover scenarios?
- What are the design considerations for effective feedback mechanisms to increase perceived trust, enhance users' ability to regain control, and make informed decisions in critical, unintentional takeover situations in autonomous vehicles to foster positive user experiences?

1.3 Structure of The Thesis

The thesis consists of the following chapters.

Chapter 1, *Introduction*, provides a brief background about the research, gives information about the problem statement and how it is addressed, presents the aim and objectives of the research, followed by the scope of the research and research questions that will be addressed throughout the study.

Chapter 2, *Literature Review*, examines autonomous vehicles and their autonomy levels according to the SAE classification, UX, and UI of vehicles with autonomous features, users' perceived sense of trust and safety, and feedback design in autonomous vehicles under separate subheadings.

Chapter 3, *Methodology*, presents the methodology and research setting of the study. The research includes a think-aloud protocol implemented during a field study, semi-structured interviews, and thematic coding in examining the data collected from the participants.

Chapter 4, *Findings and Discussions*, presents and discusses the findings of the user research with reference to the literature.

Chapter 5, *Conclusion*, summarizes the study by integrating the findings and analysis results. It revisits the research questions and provides answers. Additionally, it offers design strategies and recommendations on key factors to consider for the effective design of feedback mechanisms, which play a crucial role in enhancing users' perceived trust and safety.

CHAPTER 2

LITERATURE REVIEW

Technological innovations allow complex tasks to be performed more easily and safely in many areas, such as communication, transportation, daily tasks, and environmental interaction, increasing our quality of life. Russell and Norvig (2021) state that artificial intelligence (AI) enables systems to perform tasks that normally require human intelligence, such as perceiving the environment and reasoning. In this context, technology has succeeded in automating tasks and facilitating decision-making processes by adapting to human needs and desires, supported by developments in areas such as the Internet of Things (IoT) and machine learning. It can be seen that the effects of AI are in diverse fields of our lives, including more critical areas such as business, management, and transportation. Although its impact is largely important for its users, it also provides benefits from a broader perspective, such as social and economic terms.

Autonomous systems can perform various tasks with their decision mechanisms without the need for human control. They are equipped with various technologies to see, understand, and interpret their surroundings, and take action accordingly (Endsley, 2017b). These systems can examine existing information or situations, analyze new ones, and take appropriate actions. As autonomous systems become more competent and reliable, their role in daily life will expand, and they will be able to perform certain tasks entirely autonomously. One of the most significant applications of autonomous systems is autonomous vehicles (AVs). AVs are equipped with various technologies such as sensors, AI-supported decision-making systems, and automated control units that allow them to perceive their environment and take action by making decisions accordingly (SAE International, 2021). These systems are divided into automation levels according to the level of need for human

control regarding the autonomous features they have. They are categorized into six classes, ranging from requiring complete human control to fully autonomous (SAE International, 2021).

According to Berg Insight (2024), an independent market research and analysis company specializing in automotive technologies, the adoption and sales of autonomous vehicles have increased over time and are expected to grow exponentially in the near future. Although its widespread use has increased with its improved features, it also raises concerns about trust and safety, particularly in critical situations that require user intervention. Trust in automation can be defined as the belief or attitude that autonomous systems will assist users in achieving their goals in uncertain and/or risky conditions, such as complex traffic scenarios or adverse weather (Lee & See, 2004). In this context, perceived trust plays a crucial role in shaping users' willingness to adopt autonomous systems and rely on their capabilities. While numerous software and hardware advancements have been introduced in the field of engineering to support perceived safety and trust, the level of users' knowledge and motivation to learn may not always be sufficient to comprehend these developments directly. Perceived safety is a subjective feeling that one will be safe and protected when interacting with autonomous vehicles shaped by trust, comfort, and confidence in the system's ability (Nordhoff et al., 2021). Since users interact directly with vehicles, they need methods that will make them feel safe at first hand. Feedback mechanisms that communicate the vehicle's status and intended actions to the user play a key role in supporting users' perceived trust. The importance of feedback is crucial, especially in critical conditions where the driver needs to take control of the vehicle. Effectively and understandably designed feedback mechanisms can convey the real capability of the system to the user, keep them ready to take action when necessary, and can be a pioneer in improving perceived trust and safety. For this reason, this thesis investigates how the feedback given by the vehicle in critical conditions in terms of takeover can be designed to improve users' perceived trust and safety. In this chapter, information will be given

about autonomous vehicles, their features, perceived trust and safety, UX, and UI in autonomous vehicles.

2.1 Autonomous Vehicles

One of the most effective application areas of the innovations and ease brought by AI is the automotive industry, and its support is used especially in the development of autonomous vehicles (AVs). As Faisal et al. (2021) stated, the development history of autonomous vehicles can be divided into four main periods. First, in the 1950s, General Motors (GM), Radio Corporation of America (RCA), and Sarnoff Laboratory were the pioneers of research in this field. Towards the 1980s, Ohio State University became one of the leading institutions in research focused on areas such as road safety. In the third period, until 2003, the focus was on vehicle functions and innovative developments, and studies were conducted on automatic vehicle control. Finally, in 2004, research began under the leadership of the DARPA Challenge, which included the actions of vehicles depending on environmental factors, significantly accelerated real-world AV development, and made autonomous driving a central focus of transportation innovation. Since the 2010s, these vehicles and technologies have begun to be tested on the roads (Chen et al., 2022).

AVs are equipped with various technologies such as advanced sensors, radar, lidar, and image processing on both interior and exterior (Zanchin et al., 2017) (See Table 2.1). These features allow the vehicle to perceive its environment, improve the driving experience, and even make its own decisions and take action if it has sufficient technological equipment. Although studies on autonomous systems increased towards the 2000s, studies on AVs progressed rapidly after the 2010s, with advances seen in technology's different areas (Faisal et al., 2021) (See Figure 2.1). In the 2010s and later, major tech and automobile companies began working on their autonomous vehicles, paving the way for today's developments and future goals (Chen et al., 2022). AVs, which have specified levels of autonomy depending on their features, offer improvements in efficiency and safety. They help ensure the

safety not only of the vehicle and its users but also of other vehicles, pedestrians, and the other living beings with which it interacts. While the tests and studies of advanced AVs continue, the integration of fully automated vehicles into our lives is long-term because sufficient technological development and infrastructure have not been provided, and the appropriate public awareness should be formed accordingly.

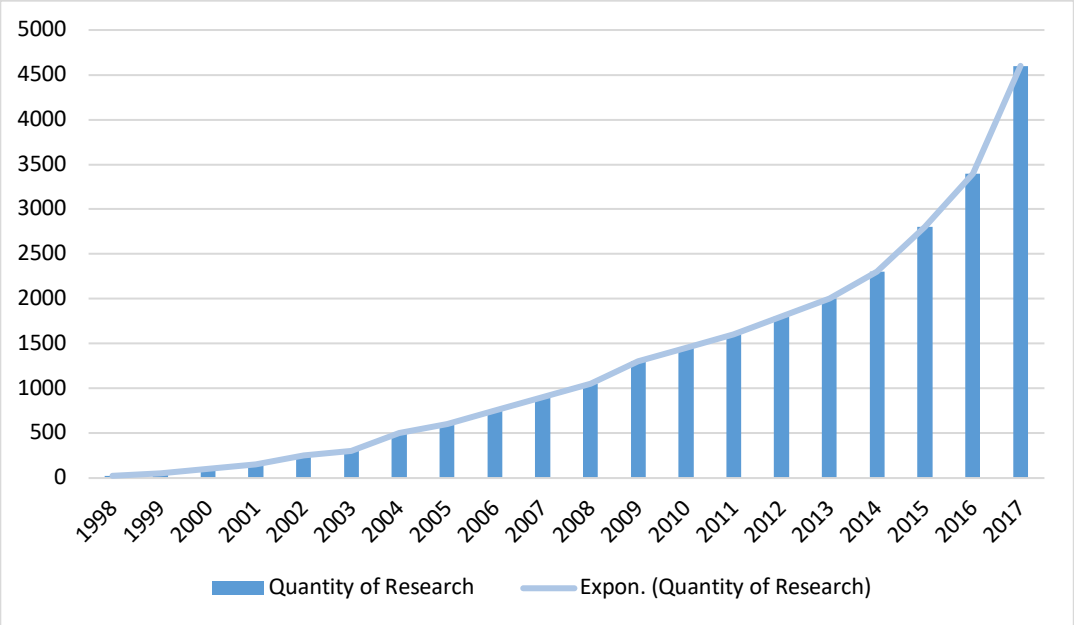

Figure 2.1 Growth in Research Quantity by Years (Adapted from Faisal et al., 2021, p.50)

2.1.1 SAE Levels of Autonomous Vehicles

This part of the thesis aims to provide information about the classification of vehicles in terms of autonomy levels and the criteria they meet according to these classes.

Autonomous driving systems are being developed in the automotive industry to improve safe driving and increase efficiency by reducing user intervention. These autonomous driving technologies are classified into levels from Level 0 (No Driving Automation) to Level 5 (Full Driving Automation), six levels in total, according to the J3016 standard of the Society of Automotive Engineers (SAE) (SAE

International, 2021). Although other organizations have developed their classifications, SAE is the most commonly accepted classification, and some organizations, such as the US National Highway Traffic Safety Administration (NHTSA), have subsequently adopted SAE's classification (Zanchin et al., 2017). The SAE standard outlines the scope of automation by levels and clarifies the roles of the user and the vehicle. This improves the interaction between vehicles and users, creating a safer driving experience. Developments in Level 5 full driving automation are continuing (Litman, 2025). As technology advances, artificial intelligence (AI) and technical developments are needed for its manufacturing and use in traffic. For vehicles at this level to be used, they must be able to adapt to road and weather conditions fully autonomously, how they will behave with non-or partially autonomous vehicles needs to be tested, and regulations must be arranged within this scope. These conditions also show that more time is needed for this level to develop and become widespread. Testing processes are proceeding for the Level 4 high-driving automation (McKinsey & Company, 2024). Pilot studies are being conducted on vehicles in certain regions and under certain conditions. However, due to today's technological developments and regulatory restrictions, they are not yet ready for general use. Today, the most common autonomous technologies in vehicles are at Level 2 partial driving and Level 3 conditional driving automation. While different features assist the user in the driving experience at these levels, the user must actively participate in the driving and be ready to takeover control in critical situations. Sudden obstacles such as unexpected objects or pedestrians, complex traffic conditions, adverse weather conditions, and system failures can be given as examples of critical situations. For each level, the features of vehicles and the technologies that enable the use of these features vary. As the level of autonomy increases, new features are added to the features of the previous level or there are software improvements in the quantity of technologies used and their use together. In the Table 2.1 below, features and their technologies can be seen by according to the SAE levels of autonomy. Additionally, Figure 2.2 represents the placement of key features within the vehicle.

Table 2.1 List of Features and Technology

SAE Levels	***Features****	***Technology****
Level 0 No Driving Automation	-Basic Features	-Basic Technology
Level 1 Driver Assistance	-Active Cruise Control (ACC) -Lane Departure Warning System (LDWS)	-Ultrasonic Sensors -Long-Range Radar (LRR) Sensors -Surround View Cameras (SVC)
Level 2 Partial Driving Automation	-Lane Keep Assist (LKA) -Park Assist (PA)	-Short-Range Radar (SRR) Sensors
Level 3 Conditional Driving Automation	-Automatic Emergency Braking (AEB) -Driver Monitoring (DM) -Traffic Jam Assist (TJA) -Advanced Driver Assistance (ADAS)	-Infrared & Thermal Sensors -Long Distance Camera -Stereo Camera -Light Detection and Ranging (LIDAR)
Level 4 High Driving Automation	-Automatic Emergency Braking (AEB) -Driver Monitoring (DM) -Traffic Jam Assist (TJA) -Advanced Driver Assistance (ADAS)	-Combination and quantity of technologies -Software developments and algorithms
Level 5 Full Driving Automation	-Automatic Pilot (AP)	-Combination and quantity of technologies -Software developments and algorithms

*Features and technologies added cumulatively at each level.

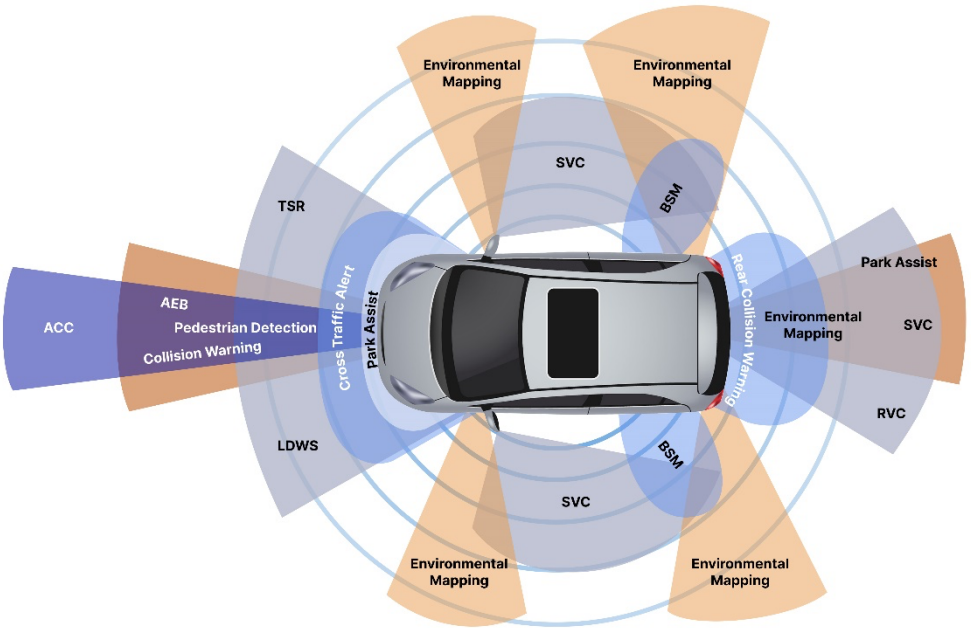

Figure 2.2 Placement of Key Features Within the Vehicle

2.1.2 Features of Levels

As mentioned above, the classification consists of 6 levels as seen in Figure 2.3 (SAE International, 2021). Each has its own level of driver participation and autonomous features.

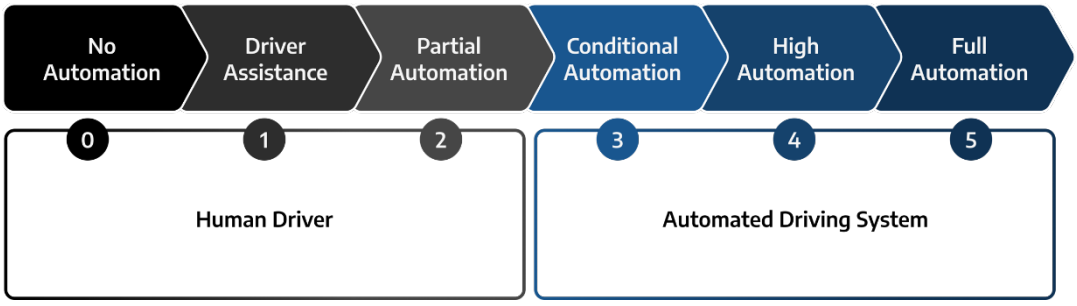

Figure 2.3 Levels of Autonomous Driving (Adapted from SAE International, 2021)

Level 0 – No Driving Automation: The vehicle is fully controlled by the driver. It does not have active autonomous features, but it may include passive safety measures.

Level 1 – Driver Assistance: Some autonomous features are included in the system, but the driver must be in control during the entire drive.

Level 2 – Partial Driving Automation: The vehicle can perform functions such as steering and accelerating simultaneously. However, the driver must remain engaged throughout the trip and cannot completely give up control.

Level 3 – Conditional Driving Automation: The vehicle can perform all driving tasks autonomously under certain conditions. Even if the driver may not be fully engaged in driving, must be ready to takeover control in critical situations.

Level 4 – High Driving Automation: In areas specifically designed for it, the vehicle can perform driving fully autonomously. Driver intervention is not required.

Level 5 – Full Driving Automation: The vehicle performs all driving tasks completely autonomously under all conditions. It does not require a driver, everyone in the vehicle can be considered a passenger.

As the vehicle's level of autonomy increases, AI applications, which have been developing significantly in recent years, are also used to achieve the level of technology it needs to have. For the vehicle to perceive environmental conditions and drive autonomously, it must be able to perceive the environment it is in and interpret it enough to take the relevant actions with the help of artificial intelligence-supported features.

2.1.3 Takeover in Autonomous Driving

With the development of autonomous driving technologies, the interaction between humans and systems has begun to play a significant role in trust, safety, and user experience. This role is particularly evident in Level 2 and Level 3 vehicles.

Although these vehicles have advanced driving support capable of performing specific driving tasks, the need for human interaction continues, and users must be able to regain control at any time. As Xin et al. (2019) stated, at Level 3 conditional driving automation, the driver is not required to remain fully focused on the driving task and may engage in non-driving-related activities; however, if the system encounters a temporary condition such as the loss of road markings, obstruction of sensors or cameras, or a system malfunction that prevents continued operation, the driver is prompted to take back control through various channels. The process of shifting control of the vehicle back to the driver, called takeover in autonomous driving (Xin et al., 2019).

Takeover is one of the most important and critical processes in the experience in partially automated vehicles, which is referred to in the thesis as semi-autonomous driving experience. It is essential to create an effective, stable, and error-free takeover process to create a safe driving experience, prevent possible accidents, and ensure the continuity of user trust in the system.

There are many factors that help a driver successfully take control of a vehicle, including reaction time, environmental complexity of conditions, level of situational awareness, and the effectiveness of feedback design (Radlmayr et al., 2014; Hong et al. 2022). In a study conducted by Gold et al. (2013), it was predicted that while it may take 7 seconds for drivers to successfully takeover from a vehicle in autonomous mode while they were completely distracted and involved in secondary tasks, the effective time may be 10 seconds or higher. Because if the driver is forced to takeover in a shorter time while completely distracted, the reactions may cause the situation and the environment not to be fully analyzed, and dangerous situations may arise. This study is a good example of the reaction time, and the need to increase drivers' situational awareness. Another study shows that, in adverse weather conditions, takeover situations are more likely to fail, such as an unexpected obstacle collision, than in normal weather conditions (Li et al., 2018). According to the study of Zeeb et al. (2016), feedback designs that appeal to more than one sense enable a safer driving experience by reducing the time the driver takes to take action.

As the effectiveness of the takeover process directly impacts the user's perceived trust and safety, it is important to design feedback mechanisms in semi-autonomous systems by holistically examining all relevant factors, such as timing, contextual elements, type of warning, and the user's awareness.

2.2 UI in Autonomous Vehicles

The user interface (UI) is the primary point of interaction between the user and a product, whether physical and/or digital, and can be graphic, text, visual, audio, or video-based (Nacheva, 2015). As Nacheva (2015) summarizes, the UI can be defined in general terms as how a product communicates with itself, the system it interacts with, and the user.

The UI in autonomous vehicles is the tool that allows the driver and passengers to exchange information with the vehicle. It allows them to react and provide information to each other through various ways, such as visual, auditory, and sensory. While the traditional vehicles' UI is more manual and analog, as the autonomous features of the vehicles increase, UI designs have started to become more technological and cognitive.

In autonomous and semi-autonomous vehicles, the UI covers a significant part of the experience. As the level of autonomy increases, control gradually shifts from the user to the vehicle, and users must place trust in the system and comprehend what the vehicle is doing or intends to do. For this reason, the UI begins to function as a tool that facilitates cooperation between the user and the vehicle, beyond merely providing information. The notifications and feedback provided by the interface allow the driver to maintain awareness of the current situation, understand the limits and capabilities of the system, and take control in a timely and effective manner if necessary (Norman, 2013; Flemisch et al., 2012).

There are several types of human-machine interface systems (HMIs) in autonomous vehicles, depending on the need and variety of information, without serving a single

purpose or being presented to the user from a single area (Bengler et al., 2020). Bengler et al. (2020) name these systems as internal vehicle HMIs (vHMI), driver interaction HMIs (iHMI), automation-focused HMIs (aHMI), external HMIs (eHMI), and dynamic HMIs (dHMIs); it is important to integrate these systems as needed to communicate effectively with the user and ensure that the proper actions are taken in complex traffic scenarios.

In addition to providing information about the status and actions of the vehicle, UI has an important role in the process of establishing, maintaining, and calibrating users' trust in the system. Especially in takeover situations in critical conditions, the transparency and clarity of the information provided determine how the user takes action and enables the correct intervention (Endsley, 2017b).

In such scenarios, the user's cognitive and physical state should also be taken into account because factors such as distraction and stress can affect users' desire to takeover, so a holistic design approach should be followed in interface designs by considering the user, in-car interactions, and the vehicle's interactions with the environment; otherwise, perceived trust and safety of the users' may be disrupted (Bengler et al., 2020). Therefore, UI is not only a visual design and beauty element of the vehicle, but also a determinant of the user's perceived trust and safety.

2.2.1 Parts and Features

The vehicle interface is structured according to various physical areas and the functions offered through these areas to provide information to the user and direct the driver's attention. UI components are generally classified as primary, secondary, and tertiary according to their location in the vehicle, based on the priority of information and the frequency of interaction with the user (Geiser, 1985, as cited in Tönnis et al., 2006) (See Figure 2.4).



Figure 2.4 Classification of Primary, Secondary and Tertiary Areas / Tasks (Adapted from Tönnis et al., 2006)

Each section has different characteristics based on its function. For example, the instrument cluster provides information such as speed, driving mode, distance, and basic warnings that are directly related to driving. Different colors and symbols are used in a way that enables the driver to comprehend the information as quickly as possible. The infotainment system is the area where information related to driving—but not directly affecting it—such as maps and system settings, is presented, and entertainment systems, such as music, are integrated. Some sensory feedback, such as vibration and light, is delivered through the steering wheel to help draw the user's attention to the intended information. In addition, audible and light-based warnings and commands can be presented to the user from various areas of the vehicle. In some vehicles, the head-up display (HUD), positioned between the windshield and the instrument cluster within the driver's line of sight, and in some cases integrated as a secondary transparent layer on the instrument cluster, helps effectively convey

information such as system status, speed, and critical warnings without causing distraction.

As Tönnis et al. (2006) explain, primary tasks include functions directly related to driving and are positioned close to the windshield, which is the most reachable area for the driver. Secondary tasks are functions not directly related to driving but that increase driving safety; they are frequently used during driving and positioned in easy-to-reach areas within the driver's field of vision. Finally, tertiary tasks are functions that are not directly related to driving but provide comfort, such as entertainment and information systems. These are located in the middle area of the vehicle's dashboard and require less attention from the driver.

These placements may differ in vehicle designs that have adapted to advanced technology and evolved over time. For example, Tesla's electric vehicles have a display positioned in the middle of the dashboard, close to the driver, and all tasks are performed from this single area (See Figure 2.5).



Figure 2.5 Interior Design of Tesla New Model Y (Tesla, 2025)

As seen in another example in Figure 2.6, the dashboard layout of the TOGG T10X features two separate screens positioned on the upper and lower sections. The upper

screen functions as four lengthwise-aligned displays. Among these, the section behind the steering wheel contains driving information, while the remaining three sections offer user customization and enable access to various applications and features such as navigation, entertainment, and non-driving-related functions. The lower screen provides control over vehicle- and system-related features and functions.



Figure 2.6 Dashboard Layout of TOGG T10X

2.2.2 Design Elements of UI and Feedback Mechanisms

The automotive UI provides the user with information about the vehicle's status and the decisions it has made or will make; in other words, it provides feedback. As Bengler et al. (2020) stated, the type and intensity of the information provided change as the user's role in the vehicle evolves. In particular, as the level of autonomy increases, the driver's role and attention level—such as the balance

between tasks directly related to driving and non-driving-related tasks—change significantly. For example, in the experience of Level 2 partial driving automation, the user's attention is mostly focused on the road and primary tasks. However, as the level of autonomy increases to Levels 3, 4, and 5, the vehicle begins to takeover the driving tasks, allowing the user to engage in secondary tasks. In critical situations, different information and notifications may need to be provided to invite the user to resume control.

In such scenarios, feedback mechanisms designed to convey information and warnings about the vehicle's status to the user form the basis of effective communication regarding how, when, and where to contact the user. These mechanisms are built upon fundamental design elements that play an active role in determining how the user perceives and processes the given information or warning, and how they respond to it. Well-designed feedback mechanisms effectively support the driver's situational awareness and contribute to increased perceived trust and readiness to takeover control (Gold et al., 2013; Endsley, 2017b).

To establish effective system-user interaction in autonomous vehicles (AVs), foster adoption of advanced automation, support perceived trust by enhancing environmental and situational awareness, and ensure the safety of both occupants and the surrounding environment, a variety of feedback mechanisms has been developed (Lee & See, 2004; Endsley, 1995). Early-stage AV systems with low automation levels primarily relied on basic warning symbols and indicator lights. However, as vehicle autonomy increased, more complex decision-making necessitated sophisticated and diverse feedback forms. Beyond the content of warnings, factors such as modality, spatial location, and information type have gained critical importance (Petermeijer et al., 2017).

The following design elements are commonly used in UI feedback to communicate system status, warnings, and requests.

Color is one of the most effective elements in enabling information and warnings related to vehicle status to be perceived quickly and clearly, thereby optimizing

reaction time (You et al., 2021; Jouhri et al., 2023). According to the ISO 2575 (2021) standard, red indicates a dangerous situation that requires immediate action; yellow or orange signals a condition that needs attention and suggests taking precautions whereas green and blue are used to indicate system status—green shows that the system is operating correctly and is in good condition, while blue typically reflects system mode changes or status updates.

Textual inputs are critical for enabling the driver to read information quickly and at a glance, without distracting from the primary driving task. It should be designed with optimized typography, font size, and display duration to balance the driver's cognitive load. Textual messages are often used in conjunction with color codes to help the user perceive the severity and urgency of warnings or notifications as efficiently as possible (Phongphaew & Jiamsanguanwong, 2024).

Icons and symbols are essential elements of visual communication. When effectively designed, they help reduce the cognitive load of the information the system aims to convey, enabling users to comprehend the situation more quickly, easily, and efficiently compared to text-based notifications (Chen & Kuang, 2022). As noted by Chen and Kuang (2022), it is crucial to establish a clear and meaningful relationship between the functions and the intended meanings of icons and symbols. For instance, they should be associated with real-world objects to evoke a sense of familiarity for the user. In cases where no direct real-world equivalent exists, icons should clearly represent the intended technical meaning, as this familiarity allows users to interpret and respond to the information more consistently and intuitively.

Visual feedback is one of the most common types of feedback. It provides users with information such as the vehicle's status, mode, and environmental awareness through displays or HUDs. Various icons, symbols, and illustrations are color-coded to show the importance of the information. According to Yang et al. (2020), visual feedback helps users understand the information more clearly and fosters perceived trust.

Audible cues are especially critical in autonomous driving modes, where the driver is more likely to be distracted. According to Bazilinskyy and De Winter (2015),

audible notifications can serve as directional guides by indicating what the warning concerns and where it is relevant, and they can attract the driver's attention more effectively than other feedback modalities due to the use of tones or verbal cues.

Auditory feedback is commonly used alongside visual warnings. Delivered through beeps, tones, or voice messages, these auditory cues are considered safety-critical, particularly when the user's attention is diverted or visual alerts are insufficient. The use of audible cues is particularly effective in capturing the driver's attention and refocusing them on driving, especially during sudden collisions or takeovers (Bazilinskyy & De Winter, 2015). Additionally, using auditory feedback in combination with other modalities can enhance driver reaction times.

Haptic cues provide users with immediate physical alerts through vibrations in tactile interaction points within the vehicle and are typically delivered from many areas but especially via the steering wheel, pedals, and driver seat (Lee et al., 2004; Campbell et al., 2007). Depending on the urgency and content of the information, these signals may vary in intensity and frequency.

Haptic feedback are particularly effective in regaining the driver's attention in situations of complete distraction, including drowsiness or sleep (Manawadu et al., 2016). It effectively improves driver response performance, shortens reaction time, and reduces cognitive load in situations where visual or auditory cues may be missed or when more urgent warnings are required (Petermeijer et al., 2015; Väänänen-Vainio-Mattila et al., 2014).

These design elements are typically not used in isolation. Instead, multimodal feedback designs are employed, in which multiple elements such as color, auditory cues, and haptic signals are combined depending on the nature of the information being conveyed. Multimodal feedback can also be distinguished based on its level of expression, explicit interaction which conveyed directly perceivable information, and implicit cues that rely on interpreting user behavior and cognitive context (Ju, 2015). Furthermore, feedback that explains why the system behaves as it does, rather than only what it does, significantly affects user trust (Hoff & Bashir, 2015). Thus,

feedback mechanisms can be examined also in terms of their semantic transparency and interpretability. According to Hong et al. (2022), the use of such feedback significantly reduces the reaction time required for takeovers and enhances driving performance.

The clarity, timing, and appropriateness of the content presented through these design elements are critical for the driver to perceive the message and respond effectively. Poorly designed feedback mechanisms can increase the user's cognitive load, cause distraction, and consequently reduce trust. Therefore, feedback designs should be carefully calibrated not only according to the level of automation and the context of the information but also in alignment with the user's mental model.

Notifications can be categorized as explicit or implicit depending on how the information is conveyed. Explicit notifications typically involve direct and understandable messages about what the vehicle is doing or what the driver should do. In contrast, implicit notifications, including gradual braking, smooth acceleration, or subtle lane corrections, are embedded within the system's actions and do not require verbal or visual cues. The effectiveness of implicit feedback is further enhanced when the system is also capable of interpreting user behaviour. This mutual understanding between the vehicle and the user fosters a more intuitive interaction, supports a positive user experience, and enhances trust in the system (Stampf et al., 2022).

Studies focusing on individual modalities emphasize their respective strengths; however, the effective combination of multiple modalities according to the vehicle's current condition and the context of the information is essential for fostering a positive user experience and supporting trust calibration. When multimodal feedback is delivered with accurate timing and appropriate spatial placement, it results in clearer communication, improved comprehensibility, and increased user trust (Schneider et al., 2021; Yang et al., 2020).

Table 2.2 provides a summarized overview of the types of feedback mechanisms and their corresponding design components discussed earlier.

Table 2.2 Overview of The Types of Feedback Mechanisms

Types	Components	Explanation	Examples	References
Visual	-Icons -Symbols -Color -Written -Lights/ ambient lighting -Animations/ illustrations -HUDs	-Provides system status, alerts/ warnings, and situational/environmental cues via visual channels -Helps maintain situational awareness -Enables quick recognition -Critical for takeover situations	-Drowsiness warning with text and icons -Lane lines in different colors to show lane keeping status	(Chen & Kuang, 2022; Phongphaew & Jiamsanguan wong, 2024; Jouhri et al., 2023)
Auditory	-Beeps -Spoken messages -Tonal warnings -Directional/Spatial audio cues	-Conveys warnings and confirmation via sound -Creates a sense of urgency and priority by varying pitch, rhythm, and duration -Supports quick attention shift -Effective when attention is away from visual cues	-Providing distance info from loudspeakers via spatial distribution -Mode changes -High - pitched beep for collision warning	(Bazilinskyy & De Winter, 2015)
Haptic	-Vibrations through steering wheel or seat -Force feedback on pedals/steering Wheel	-Conveys urgency directly -Effective under high cognitive load and/or visual and audio stimuli are overloaded -Critical for extreme fatigue or sleep	-Steering wheel vibration when leaving the lane without control	(Petermeijer et al., 2017)

Table 2.2 (Cont'd)

Multimodal	-Combined use of two or more modalities	-Enhances perception of critical issues through multiple senses	-Red colored symbol and beep sound for blind spot detection -Steering wheel vibration and audible cues for takeover	(Hong et al. 2022)
Explicit	-Directness of information	-Directly given information via visual, auditory, haptic, or multimodal feedback -Clear and direct communication	-System's mode status via colors -Text-based obstacle or collision warnings	(Ju, 2015)
Implicit	-Contextual cues and behavioral information	-Indirectly gives the state or intention of the system with gradual variables -Requires user interpretation based on experience or expectations -Natural but may be susceptible to misunderstanding	-Ambient lighting color change -Direct the vehicle slowly towards the middle when approaching the lines in lane centering	(Ju, 2015)

According to Lee and See (2004), trust is an attitude toward achieving goals in situations that involve uncertainty and risk. In the automotive context, perceived trust refers to the user's confidence in the vehicle's capabilities, the alignment between its promised features, and the user's reliance on automation. As levels of autonomy increase, perceived trust becomes particularly critical, as vehicles begin to takeover control from the driver. In these situations, the design of the vehicle's UI and its feedback mechanisms play a key role in fostering trust.

How the system communicates its status and intended actions through modality, timing, and placement directly conveys the vehicle's competence and reliability. Therefore, effective feedback supports the user's sense of control and trust in the vehicle's decisions. Each design element within these mechanisms, such as color, audio, text, or haptic cues, influences how drivers perceive and respond to information. When presented appropriately and in timely combinations, these elements help the driver maintain situational awareness and readiness to act, especially during takeover scenarios (Gold et al., 2013; Endsley, 2017b).

Conversely, feedback that is vague or poorly designed can confuse the user, hinder proper responses, and ultimately diminish perceived trust, especially in high-risk or time-critical situations. Therefore, thoughtful and well-structured UI and feedback design are not only essential for effective communication but also fundamental in shaping users' perceived trust in automated driving systems.

2.3 UX in Autonomous Vehicles

According to ISO 9241-210 (2019), user experience (UX) encompasses all aspects of a user's perceptions and responses to a product, system, or service before, during, and after use. While it is commonly associated with the functionality and performance of the product, UX also includes users' emotional responses, expectations, and the entirety of their interactions with the system (Hassenzahl, 2010). As Pettersson (2018) emphasizes, UX is a multifaceted concept and must be approached holistically. Its multidimensional nature reflects its dynamic nature, which is influenced by external factors such as space and time, as well as internal factors such as users' emotional states, which are central to the human experience and directly influence how users relate to and interact with a product (Pettersson, 2018). A well-designed UX not only facilitates the user's understanding of the product and its context of use but also fosters positive emotional engagement. Clear communication of how the product functions and what it intends to do supports users' trust and encourages adoption.

In the context of autonomous vehicles, UX plays a crucial role in shaping the relationship between the product—the vehicle—and the user—the driver. As the level of autonomy increases and users shift from being active controllers to passive observers ready to takeover control, the nature of interaction changes and the experience itself evolves (Riener et al., 2022). Accordingly, the importance of a well-designed UX becomes increasingly evident. In these scenarios, trust in the vehicle's capabilities is built largely through the user's experience. If a highly capable system fails to effectively communicate its functions to the user, the quality of interaction, and thus the UX may suffer. This can diminish perceived trust in the system and hinder the adoption of autonomous technologies. Therefore, within the automotive context, UX serves as a key factor in balancing perceived trust and safety, ultimately shaping users' confidence in automation.

2.3.1 Takeover Situations and Examples

One of the most critical moments in the UX of AVs is the takeover situation. As discussed earlier, in semi-autonomous vehicles, users must be ready to take back control of the vehicle whenever the vehicle becomes insufficient for the driving task, and they must not completely disengage from driving. It is therefore essential to design warnings and feedback mechanisms that can prompt them to regain control within a sufficient timeframe, even if they are engaged in non-driving tasks. Poorly managed takeover scenarios can lead to confusion, stress, and even worse, serious accidents.

We can better understand from real-life examples why the takeover and the vehicle-driver interaction are critical. Unfortunately, the first pedestrian death from an accident involving a semi-automated/partially automated car was believed to have occurred in Tempe, Arizona, in 2018, when the takeover process malfunctioned (Griggs & Wakabayashi, 2018). The car was a Volvo XC90 used for Uber in autonomous mode, and according to the information obtained from the cameras in the vehicle, the driver was completely distracted and not focused on driving tasks.

The vehicle did not notice the cyclist passing in front of it in the dark of the evening and did not take action on emergency breaking in time. The driver was not able to take control in time because he was not looking at the road, and the vehicle did not give him an effective notification. The cyclist tragically lost her life.

A similar accident, reported by the National Transportation Safety Board (NTSB, 2017), involved a Tesla vehicle operating in autopilot mode that lost environmental awareness due to intense sunlight, failed to take necessary action, and collided with an oncoming truck, resulting in the driver's death. It was noted that the driver was not holding the steering wheel; however, this incident demonstrates that the system failed to provide accurate and timely feedback to the driver and was unsuccessful in executing the takeover.

According to BBC News (2018), another example involves a Tesla vehicle operating in Autopilot mode that failed to slow down after losing lane tracking, resulting in a collision with a barrier, a subsequent fire, and the driver's death. Although Tesla stated that a warning was issued to the driver to regain control and maintain contact with the steering wheel, the system did not provide sufficient time for the driver to refocus attention on driving, and a successful takeover was not achieved.

These accidents demonstrate how dangerous it can be to have over-trust in the autonomous system and the vehicle's ability to take all necessary actions at the right time under all circumstances. Users' trust level should be at the appropriate level, so they can engage with the driving task and takeover at a proper time. Especially in critical conditions, unintentional takeover processes need an optimum level of trust (Ekman et al., 2018).

2.4 Perceived Trust and Safety

Trust is a concept that has long been researched and discussed across various disciplines and contexts, making it difficult to establish a single universal definition. It is commonly conceptualized as comprising emotional trust, which involves

feelings toward the trusted person or system, and cognitive (rational) trust, which is based on evidence and reasoning (Komiak & Benbasat, 2006). Kohn et al.'s (2021) comprehensive review of trust in automation not only includes these two dimensions but also introduces the concept of behavioral trust, which encompasses users' actual trust and compliance behaviors toward automated systems.

According to Kramer (1999), although it may be interpreted differently depending on the disciplinary perspective, there is general consensus that trust is fundamentally a psychological state, involving perceived uncertainty or risk that depends on the actions of others with whom individuals are interdependent. Hoff and Bashir (2015) state that, trust not only shapes the core of human relationships on an individual basis but also shapes the interaction of larger structures such as society and communities. In addition, trust also plays a significant role in shaping the ways people interact with technology (Hoff & Bashir, 2015).

As technology advances, systems' capabilities increase, paving the way for autonomy. With the growing prevalence of autonomous systems in daily life, trust in these technologies has become an important subject of research. User trust in these new features and capabilities is a key factor in the adoption of technology and automation. Based on Lee and See's (2004) basic definition of trust, trust in automation can be defined as the belief or attitude that autonomous systems will assist users in achieving their goals in uncertain and/or risky conditions, such as complex traffic scenarios or adverse weather.

As Miller (2022) also mentioned, people's trust is divided into what they show and what they say, as demonstrated trust and perceived trust, respectively. When examining trust, it's important to define the type of trust being examined clearly. Numerous studies have been conducted to measure trust, and various methods have been developed. However, the trust people feel and act upon when experiencing a product in real life or a simulated environment is different from the trust they hypothetically give to questions about the product and its use. This highlights the need to consider whether the trust being studied is perceived or demonstrated.

Demonstrated trust, especially in critical situations such as takeover scenarios in AVs, may not always be measured by what users report. Therefore, perceived trust research in UX studies could make the results more reliable (Miller, 2022).

In this context, perceived trust refers to the user's confidence in the system's ability to function effectively, while perceived safety reflects the user's sense of physical and emotional security during interaction (Nordhoff et al., 2021). Perceived safety is inevitably related to trust. Based on this relationship, the primary focus of this thesis is on perceived trust, as it plays a central role in fostering perceived safety and promoting the appropriate use of autonomous systems.

Wischnewski et al. (2023) emphasize that early research on trust in autonomous systems primarily focused on how trust is established, particularly addressing disuse, resulting from underestimation of the system’s capabilities, and misuse, stemming from overreliance on the system. Both conditions compromise the system’s effective usability: either users fail to benefit fully from the service provided, or they overestimate the system’s abilities, potentially leading to risky, even fatal, errors. Therefore, the user's trust in the system must be calibrated, that is, be at an appropriate level. In autonomous systems, appropriate trust is critical to ensuring both user and system safety (Hoff & Bashir, 2015).

Appropriate trust is the correspondence between perceived and actual system performance (Lee & Moray, 1994). According to Mehrotra et al.’s (2024) research, there are several ways to measure appropriate trust and some factors that are effective in achieving it. Questionnaires, interviews or similar reporting tools have been used for measuring perceived trust since it relies on users' self-reflections whereas simulator or live studies have been conducted for 'demonstrated trust' to understand actual thoughts of the participants. These methods were deemed insufficient on their own to establish appropriate trust, prompting the use of a mixed-methods approach as an additional means of measurement, and participants’ trust levels before, during, and after the simulation-like study were examined using a combination of the

previously applied methods, aiming to achieve a more holistic and accurate assessment of trust (Mehrotra et al., 2024).

As further emphasized in Mehrotra et al.'s (2024) review, factors such as system performance, user expertise, reliability, task complexity, feedback, type of explanation, transparency, and context all influence the establishment of appropriate trust.

2.4.1 Relevant Studies in Autonomous Vehicles

Studies on perceived trust in autonomous vehicles have been conducted using a variety of experimental approaches, each offering valuable insights into how users perceive, develop, maintain, or lose trust across different scenarios (Hoff & Bashir, 2015; Mehrotra et al., 2024). Investigating the factors that influence perceived trust, particularly in takeover situations within semi-autonomous vehicles, is especially important, as establishing and sustaining appropriate trust under risky conditions is critical for ensuring a safe driving experience (Wischnewski et al., 2023; Gold et al., 2013). These experimental studies are commonly conducted through driving simulations or real-world driving scenarios (Radlmayr et al., 2014; Wilson et al., 2020), alongside survey-based and self-report methods that help capture users' retrospective experiences (Mengel et al., 2025; Kenesei et al., 2025).

Simulation-based studies are a widely adopted method in autonomous vehicle trust research, as on-road experiments are often constrained by safety concerns and the limited availability of controlled environments (Morales-Alvarez et al., 2020). These studies aim to replicate real-life and in-vehicle conditions by simulating environmental factors, thereby providing participants with realistic driving experience. The simulation environment also allows researchers to systematically control and manipulate test conditions to examine specific factors under consistent and repeatable scenarios.

For instance, in a simulation-based study, Gold et al. (2013) investigated drivers' takeover performance by assigning participants to an autonomous driving condition with secondary task engagement. It aimed to assess the time required for drivers to regain control in response to a critical situation, such as an accident. Findings revealed that shorter takeover request (TOR) times led to quicker driver reactions; however, the quality of these takeovers was often compromised, potentially resulting in hazardous outcomes for both the driver and the environment. Conversely, longer TOR intervals increased the likelihood of delayed reactions, reducing the effectiveness of timely intervention. Based on these findings, the researchers recommend a multi-modal notification strategy, delivered at optimal intervals, to enhance situational awareness and facilitate safer, more efficient takeovers.

Similarly, Radlmayr et al. (2014) conducted a high-fidelity driving simulator study to investigate how takeover performance is influenced by varying traffic conditions. Participants were assigned to three experimental groups, each exposed to identical non-driving-related tasks but differing traffic densities. To gain deeper insights, participants' subjective experiences were also assessed through questionnaires administered during and after the experiment. The results indicated that higher traffic complexity and density significantly impair takeover performance. Moreover, engagement in non-driving-related tasks was found to reduce situational awareness, leading to delayed response times and a decrease in the overall quality of takeover.

On-road studies provide a more realistic understanding of how users experience and trust autonomous systems in real driving situations. As highlighted by Miller et al. (2016), there can be a discrepancy between the trust individuals report in hypothetical scenarios and their demonstrated trust when confronted with those situations in real driving contexts. This underlines the value of on-road studies in capturing more nuanced, experience-based insights into users' perceptions and behaviors. However, despite their advantages, on-road experiments remain relatively rare in the domain of semi-autonomous vehicle research due to safety concerns and regulatory limitations. Additionally, the inability to reliably reproduce identical

driving scenarios for all participants presents further methodological challenges (Wilson et al., 2020).

Morales-Alvarez et al. (2020) conducted an on-road study in which participants drove a semi-autonomous vehicle within a closed-off environment for a specified period. During the drive, they were assigned secondary tasks such as reading or texting that diverted both visual and cognitive attention from the road. Following the drive, a questionnaire was conducted to assess participants' situational awareness and perceived trust. The findings revealed that the nature of the secondary task significantly affected reaction time during takeover situations; tasks demanding greater cognitive load, such as texting, resulted in delayed responses. Moreover, participants reported higher levels of trust on smooth and predictable roads, indicating that perceived trust was significantly influenced by road complexity. Overall, the study underscored that user trust and attention are closely shaped by task demands, environmental awareness, and driving context.

In another on-road study, Wilson et al. (2020) had participants drive in semi-autonomous mode on a traffic-free highway under controlled conditions. To better understand user trust, researchers measured perceived safety, ease of use, and usefulness with questionnaires administered before and after the drive. Participants who drove the first part of the route manually and the second part in autonomous mode reported a notable increase in perceived trust and safety. However, during takeover scenarios, some users were unaware of the current driving mode and experienced confusion. The study shows that the way the vehicle communicates its current state is crucial. Mode confusion presents a serious safety concern, and the findings suggest that feedback mechanisms must be designed more clearly and effectively.

Based on these examples, it can be argued that on-road studies are essential for developing user-centered and effective feedback designs that enhance situational awareness and help users respond appropriately during critical takeover scenarios in semi-autonomous vehicles.

Surveys and self-report studies are commonly used in quantitative research with large sample sizes to gather insights into individuals' attitudes and perceptions. These studies typically analyze responses through statistical methods, using numerical data to identify relationships and draw generalizations. In the context of AV trust research, such tools are frequently used to evaluate user attitudes, expectations, and willingness. However, they may not always capture actual user behavior. When trust is assessed based on hypothetical scenarios rather than real-time driving experiences or simulations, discrepancies may emerge between perceived trust and demonstrated trust, particularly in situations where timing and potential risks are critical (Miller, 2022).

An example of a survey-based study on trust in AV adoption is presented by Choi and Ji (2015), who examined ten trust-related factors (including items like perceived usefulness, system transparency, and technical competence) identified in the literature. Using a 7-point Likert scale, 552 participants evaluated these factors. The analysis revealed that vehicle usability had a greater influence than ease of use. Most notably, trust emerged as the strongest predictor of both perceived usefulness and behavioral intention. The main determinants of trust were system transparency, technical competence, and situation management. These findings suggest that clear communication of vehicle status and actions can enhance user trust, thereby facilitating technology adoption. Overall, the study highlights trust as a central construct in the AV domain, particularly critical for the adoption and successful integration of autonomous systems.

In a recent study, Kenesei et al. (2025) applied the Unified Theory of Acceptance and Use of Technology (UTAUT) model to examine how trust and perceived risk influence the adoption of AVs. The researchers developed an online questionnaire for the context of Level 5 autonomous vehicles. A total of 938 participants rated seven factors derived from the literature using a 7-point Likert scale. These factors included perceived risk, trust, performance expectancy, effort expectancy, social influence, facilitating conditions, and intention to use. The findings showed that

strengthening these factors significantly supports trust development, and trust and perceived risk play a central role in adoption decisions. The study also emphasized that design clarity, clear system communication, adequate user support, and feedback design, especially for first-time users, are essential in fostering perceived trust and encouraging adoption.

Taken together, the reviewed literature indicates that experimental and survey-based methodologies offer complementary insights into the development and calibration of trust in AVs. Simulation-based and on-road studies reveal users' actual behaviors and responses in real-time driving contexts, while survey methods provide a broader understanding of attitudes, perceived risks, and intentions toward AV use. Combining these approaches can support the design of feedback systems that enhance perceived trust by addressing real-world user needs, supporting safe takeover performance, and encouraging the adoption of semi-autonomous technologies.

2.4.2 Factors of Trust Building

Studies have examined the factors that shape the establishment and maintenance of user trust. The Table 2.3 below presents the factors that play a significant role in perceived trust across autonomous, semi-autonomous, and manual vehicles, together with their descriptions, relevance to trust, and representative references. Similar categories from different studies have been combined into a single factor.

Factors influencing users' perceived trust are categorized into three main groups:

1. **User-related factors**, which concern individuals' internal states and personal dispositions
2. **System-related factors**, which pertain to the system's characteristics and capabilities

3. **Interaction & contextual factors**, which involve the communication, interaction, and situational context in which the user and system operate.

Table 2.3 Trust Related Factors

1. User-Related Factors

Trust Factor	Description	Relevance to Trust Building	References
Self-confidence	Users' belief that a person can understand AV features and intervene successfully when necessary.	May enhance takeover quality.	(Hoff & Bashir, 2015)
Situational Awareness	The user's awareness of the vehicle's state and environmental factors.	Higher awareness allows one to interpret the situation and be prepared to take the necessary actions.	(Endsley, 1988)
Intention to Use Technology and Technology Readiness	Users' motivation or readiness to adopt and interact with automated systems.	Positive intentions are predictors of trust and adoption.	(Becker & Axhausen, 2017; Parasuraman, 2000; E. Hong & Park, 2023)
Mental Model	Users' insight into how the system works and its capabilities.	Accurate mental models are effective in calibrating trust.	(Zhang et al., 2025a)
Level of Knowledge	General understanding of autonomous vehicles.	Provides the appropriate level of trust by balancing expectations.	(Körber et al., 2018)
Level of Knowledge: *Past Experiences*	Feelings and thoughts arising from past interactions with systems.	Directly affects the trust that is placed in the system, whether in immediate or future experiences.	(Endsley, 2017a)
Level of Knowledge: *Initial Learned Trust*	Established trust during the first interaction with autonomous systems.	First impression to build and keep trust.	(Zhang et al., 2019)

Table 2.3 (Cont'd)

2. System-Related Factors

Feedback	Mechanisms for communicating system status or warnings (e.g. takeover time).	Reduces uncertainty by informing the user and supporting trust.	(Ekman et al., 2018; Walker, 2020)
Customization:	User-controlled personalization of interface or features.	Increases comfort and gives a sense of control over the vehicle-strengthens trust.	(Saffarian et al., 2012)
Transparency	System's ability to clearly communicate its intentions, reasoning, and limits.	Transparency fosters understanding, reduces confusion, and increases trust.	(Valentine et al., 2021; Kunze et al., 2019)
Transparency: *Error Information*	Explanation of the causes and consequences of system errors.	Reduces uncertainty by informing the user and supporting trust.	(Stanton & Young, 2000)
Transparency: *Explainability*	Explains why the system behaves in a certain way.	Supports the user's understanding and mental model development.	(Valentine et al., 2021)
Transparency: *Justification of Decisions*	Logic or rationale behind AV's decisions.	Reinforces system competence and persuasiveness.	(Valentine et al., 2021)
Automation Capability	The actual performance, scope, and reliability of the AV system.	Directly impacts trust via system competence.	(Helldin et al., 2013)
System Confidence Level	Technical capability of the system itself	When shown to the user, it helps build trust and prepares them for a potential takeover.	(Miglani et al., 2016)
Predictability	Degree of alignment between the system's capabilities and the user's expectations of the system	Enhances trust and reliability.	(Walker, 2020)

Table 2.3 (Cont'd)

Anthropomorphism	Human-like attributes or cues (voice, face, name).	Can increase familiarity, and trust.	(Forster et al., 2017)
Adaptive Automation	Adaptation of system behaviour based on context or user profile.	Increases comfort, and perceived trust.	(Saffarian et al., 2012)

3. Interaction & Contextual Factors

Communication	Conveying AV capabilities and constraints.	Reduces uncertainty and mismatched expectations.	(Valentine et al., 2021)
Communication: *Company–User Communication*	External communication (ads, manuals, press) by AV manufacturer.	Influences users' initial perception and reliance.	(Valentine et al., 2021)
Communication: *AV–User Communication*	Ways of interaction of AVs with the user.	Important for trust building and successful takeover.	(Okamura & Yamada, 2020)
Brand Identity / Reputation	Perceived trustworthiness and reputation of AV manufacturer.	Well-known or AV-expert companies have a positive effect on trust.	(Lin et al., 2018; Carlson et al., 2014)
Common Goals	Alignment between user's goals and AV system behaviour.	Sense of shared goals and intentions supports perceived trust.	(Davidsson & Alm, 2009; Hoff & Bashir, 2015)
Common Goals: *Misuse*	Overreliance on the system	Overestimation of the system's abilities, potentially leading to risky, even fatal, errors.	(Wischnewski et al., 2023)
Common Goals: *Disuse*	Underestimation of the system's capabilities.	Users may fail to benefit fully from the service provided.	(Wischnewski et al., 2023)

2.5 Importance of Feedback Design in AV

When people interact with a product or system, feedback refers to the information the system provides about its current state, actions, and outcomes (Norman, 2013). Norman (2013) emphasizes that well-designed feedback is essential for users to interact with the system effectively and meaningfully. In contrast, poor or insufficient feedback can lead to misunderstandings, critical errors, or a decline in user trust by reinforcing incorrect mental models. In the context of autonomous vehicles, this highlights the crucial role of feedback design as automation levels advance, ensuring safe driving and fostering trustworthy interaction between users and systems.

In semi-autonomous vehicles, particularly in SAE Level 2 and 3, drivers are required to remain engaged in the driving task and be ready to intervene when necessary. Therefore, well-designed feedback mechanisms play a critical role in keeping the driver informed, maintaining engagement with the primary task, and ensuring readiness to take control when needed. In such systems, feedback not only conveys information about the vehicle and its actions but also enhances their situational awareness and helps calibrate their trust in the system (Lee & See, 2004; Endsley, 1995). Properly designed feedback ensures that the system's actual capabilities match the user's expectations, reducing the risk of misuse or disuse and providing the appropriate level of trust (Wischnewski et al., 2023). In AVs, feedback should be timely, understandable, and consistent with the user's mental model, striking a balance between cognitive load and clarity. As Mackay et al. (2019) noted, providing users with more information may negatively impact trust by increasing their cognitive load rather than increasing their trust in the system.

Feedback can be categorized into distinct design elements, including visual components (e.g., color, text, icons, symbols), auditory alerts (e.g., tones, spoken messages), and haptic cues (e.g., steering wheel or seat vibrations). Additionally, it can be categorized as explicit or implicit based on the mode of interaction: presenting notifications clearly and intentionally in a way that users can directly perceive is

considered explicit feedback, whereas delivering information based on interpreting user behavior at a more cognitive level is classified as implicit feedback (Ju, 2015). These elements are essential for shaping a positive user experience. To ensure effective interaction, support appropriate levels of trust, and enable the driver to successfully take control, feedback should be delivered through a multimodal approach that aligns each modality with the type of information being conveyed (Hong et al., 2022).

2.5.1 Effect of Trust in Feedback Design

Although various types of feedback mechanisms have been developed to enhance users' environmental and situational awareness and to inform them about the vehicle's status and intentions, users' perceived trust in these systems significantly affects how such feedback is received, interpreted, and acted upon. The way the vehicle communicates with both the user and its surroundings through these mechanisms also plays a vital role in shaping perceived trust and safety. This becomes especially critical during sudden changes or risky situations, such as when automation fails to fulfil its driving function. In these moments, the clarity and communication style in which the vehicle conveys information or requests to the user are essential for ensuring a safe, effective, and trustworthy takeover process.

In semi-autonomous vehicles trust serves as a bridge between the user and the system. When established at an appropriate level it facilitates both the adoption and effective use of these technologies. Well-designed feedback mechanisms not only communicate the vehicle's capabilities but also play a central role in calibrating user trust. Accordingly, trust is not only shaped by feedback design but also informs how such mechanisms should be developed. As feedback designs, supported by different modalities depending on the type and importance of information, begin to reflect user intentions and preferences rather than conveying system status or issuing requests they contribute to more effective and positive user experiences. Ultimately

this fosters greater acceptance and supports the continued advancement of semi-autonomous vehicle technologies.

The interaction between users and semi-autonomous vehicles is best understood within the framework of human-computer interaction (HCI), which defines interaction as a goal-oriented process (Hassenzahl, 2010). Within this framework drivers do not merely operate the vehicle but continuously engage with it by interpreting feedback and responding accordingly. Hassenzahl's (2010) three-level goal hierarchy offers a valuable structure for understanding this interaction. At the base of the hierarchy motor goals relate to how a function is executed. The middle level, do goals, refers to what is being done, while the top level, be goals, addresses why an action is taken by uncovering the users' underlying intentions.

In the context of automated vehicles, the motor level includes physical actions that control the vehicle. The do level covers the functional operations that enable specific tasks to be performed. The be level provides insights into the user's intentions, such as perceived safety, sense of control, and trusting the system (See Table 2.4). According to Hassenzahl's (2010) approach, when designing feedback for semi-autonomous vehicles, the harmony of all these levels should be considered. Especially as the level of autonomy increases, goals play an important role in aligning the implicit intentions of the system and the user for ensuring continuity of trust while creating a meaningful user experience.

Table 2.4 Hierarchy of Goals (Adapted from Hassenzahl, 2010, p.12)

Hierarchy of Goals	**Question Of...**	**In semi-autonomous vehicles**
Motor Goals	How?	Physical actions that control the vehicle.
Do Goals	What?	Functional operations that enable vehicles to perform specific tasks.
Be Goals	Why?	Insights into the user's intentions, such as perceived safety, sense of control, and trusting the system.

Understanding the underlying reasons behind user trust enables more accurate trust calibration and the design of effective feedback. When users develop mistrust toward the system, they may become more distracted or ignore critical warnings. To prevent this, feedback should be designed to effectively capture attention and reinforce the user's sense of control, particularly in semi-autonomous vehicles. This approach is especially important for ensuring safe and efficient transitions during unintentional takeover situations. On the other hand, if the user develops distrust, their attention should be supported through more combined, multimodal, and implicit feedback, aiming to gradually rebuild trust to an appropriate level.

In addition to system performance and the vehicle's technological capabilities, the timeliness, clarity, and appropriateness of the language used in feedback significantly impact user trust in semi-autonomous systems. For instance, delivering a critical situation alert too early may lead the user to perceive the warning as inaccurate or unnecessary. Alongside timing, the use of multimodal feedback is especially important in critical moments to effectively address both the driver's needs and the environmental context.

Clarity and transparency in presenting information through various design components and communication channels help users better understand the system's limitations. This not only facilitates the establishment of trust but also supports maintaining it at an appropriate level. Framing plays a central role in this process (Keren, 2007). Whether the feedback is conveyed through text, visuals, or sound, the tone used, whether supportive, neutral, or commanding, influences how the user interprets the situation and determines their response. For example, when a non-critical takeover is required, a message like "TAKEOVER NOW!" may induce unnecessary urgency, causing the driver to react abruptly and make unsafe manoeuvres without fully assessing the environment. In contrast, a softer prompt such as "Please takeover, a potential obstacle has been detected." encourages a calmer and more informed transition.

As technology and artificial intelligence continue to evolve, adaptive feedback systems that assess both the driving environment and the driver's behaviour and needs will become essential for establishing an implicit communication channel that reinforces perceived safety and trust. Ultimately, while each factor contributes to user trust, none alone is sufficient. Feedback mechanisms must be designed with a holistic, user-centred perspective that integrates these elements seamlessly.

Poorly designed or ambiguous feedback mechanisms can cause users to react too early or too late, especially in critical takeover situations. Therefore, all types of feedback mechanisms and their elements must be considered together to create a comprehensive user experience. This approach can positively improve drivers' environmental and situational awareness, perceived trust in the system, and overall driving experience. Previous studies have addressed different aspects of feedback design, showing how each factor should be structured. However, a holistic approach is needed to examine all factors collectively to determine how feedback should be designed to ensure appropriate levels of perceived trust and safety. As a result, this thesis explores how feedback designs can be tailored to users' actual thoughts and needs by analyzing the relationships among all components to achieve these goals.

CHAPTER 3

METHODOLOGY

The chapter focuses on the research methodology and helps to reveal what factors shape users' perceived trust in the driving experience of partially autonomous vehicles. It presents participant selection criteria, venue and equipment, data collection tools, the procedure for the think-aloud protocol and semi-structured interviews, and the overview of data analysis. The procedure of this research was approved by the Applied Ethics Research Center of the Middle East Technical University (0620-ODTUİAEK-2024) (See Appendix A).

3.1 Overview of the Field Study

The study consisted of two phases (See Table 3.1).

In the first phase, a three-part online questionnaire was conducted to reach potential participants whose license and vehicle specs met the study's requirements, what potential participants think about partially autonomous vehicles and their features, and their level of knowledge, and to give detailed information about the continuation of the study to invite them.

The second phase consisted of two stages: a think-aloud protocol conducted during a driving itinerary, followed by a semi-structured interview. The protocol aimed to effectively understand the participants' thoughts and feelings towards the vehicle's autonomous features in certain- critical- conditions. The second stage was completed by interviews with questions about the topics that could not be answered or that needed to be raised in more detail during the protocol.

Following the first two phases, the analysis was carried out on the collected data through thematic coding, enabling categorization in line with the research questions and literature findings.

Table 3.1 Overview of the Study

		Method	Aim
Phase 1	**Call for Participants**	Online Survey	-Reaching target participants -Specifying the autonomous features that their vehicles have -Restoring their knowledge of their vehicles' features and preparing for the next stage
Phase 2	**Field Study** *Stage 1*	Think Aloud Protocol	-Conveying experiences through active driving
	Field Study *Stage 2*	Semi-Structured Interview	-Focusing on topics that were not answered or that needed more detail during the think-aloud protocol

3.2 Study Setup

This section describes the participant sampling and recruitment, as well as the venue and equipment used for the field study.

3.2.1 Participant Sampling and Recruitment

This qualitative research aimed to obtain in-depth insights and detailed information from participants regarding the subject matter. According to Patton (2014), unlike quantitative studies, where data collected from large, randomly selected samples is statistically generalized to the broader population, qualitative research involves selecting a smaller number of participants who are expected to serve as strong sources of relevant information. This approach helps to get more in-depth and detailed information with fewer participants. The responses and reactions of the participants to what they feel, and experience are more important than the statistical

results, meaning that the researcher obtains results by interpreting the outputs (Schreier, 2012).

To achieve effective gathering of detailed outputs, the selection of a sampling method is critical. Sampling methods are categorized into probability and non-probability sampling (Etikan et al., 2016). In probability sampling, participants are randomly selected, ensuring that each individual has an equal chance of being chosen. In contrast, non-probability sampling lacks randomization, and the likelihood of selection is not equal, instead being based on criteria set by the researcher. Given that the objective of qualitative research is to gather in-depth information on a specific topic, non-probability sampling is typically employed. The most commonly used types include convenience sampling, which involves selecting participants who are easily accessible to the researcher, and purposive sampling, where participants are chosen based on predefined criteria, expertise, or the specific purpose of the research (Etikan et al., 2016).

Accordingly, purposive sampling was employed in this study as the participant selection method. Participants were strategically divided into two categories based on their level of knowledge about the topic. Those with a professional background in automotive software engineering were classified as having a high level of knowledge, whereas individuals from other occupational fields who lacked detailed knowledge of autonomous vehicle technologies, but had driving experience with autonomous features, were placed in the lower level of knowledge category. Although the main aim of the study was not only to explore the effects of the expertise levels on the UX of autonomous features, this sampling strategy made it possible to explore how different levels of subject-matter knowledge might influence perceptions of autonomous vehicle technologies alongside other factors and inform the design of more effective feedback mechanisms.

To reach individuals who have fully gained competence in driving under the regulation, participants were selected according to the following criteria: individuals who have had a driver's license for at least two years and are actively driving, and

who own a vehicle with partially autonomous driving features or have experienced such vehicles. The expectation regarding two years of experience in driving was determined based on the “candidate driver” definition specified in the Highway Traffic Regulation published in the Resmi Gazete dated April 17, 2015, numbered 29329. The regulation states that newly licensed drivers will be evaluated as candidate drivers for the first two years (Resmi Gazete, 2015). Therefore, the participants were recruited from the drivers who have had a license for more than 2 years as they have completed their “candidate driver” status.

To reach the targeted participants, digital announcements (See Figure 3.1) were shared on the researcher's social media accounts (i.e., Instagram, LinkedIn, Facebook, WhatsApp), announcement posters were left on vehicles with features suitable for the research needs, and verbal announcements were made to the researcher's network.

The announcements included information about the researcher and the study, the participant recruitment criteria, expectations from the participants, the theme-related visual, and a questionnaire link designed to gather data on respondents' vehicle features, attitudes toward autonomous technologies, and personal details to assess their eligibility. Participants who wanted to participate in the research and met the requirements were reached through their preferred communication channel.

In total, 73 individuals were initially contacted, either verbally through the researcher’s personal network or via the distributed form. Among these, 19 individuals were excluded at the outset as they verbally indicated that they did not meet the recruitment criteria. Of the 54 individuals who completed the form, three declined to participate, while 32 were found not to meet the eligibility requirements. Additionally, eight eligible individuals could not be included in the study due to scheduling conflicts that prevented arranging a common time and location.

The study involved a total of 11 participants, comprising five individuals with a high level of knowledge based on their profession and technology, and six participants who regularly use vehicles but do not possess in-depth knowledge of the automotive

industry, including vehicle features and feedback mechanisms. Table 3.2 presents an overview of the participants and their vehicles, including participants' levels of knowledge and the key features of their vehicles.

When the first phase of the study, the questionnaire, which consisted of ten questions, was completed, they were given detailed information about the second phase, which was the think-aloud protocol followed by semi-structured interviews, and re-invited.



Figure 3.1 Social Media Announcement Poster

Table 3.2 Overview of the Participants and Vehicle Information

Vehicle/ Model	Opel Corsa Ultimate	TOGG T10X	Chery Omoda 5	Peugeot e-308	Mercedes C200	Hyundai Ioniq 6	Renault Clio	Tesla Model Y
Participants	***P0**	P1, P3, P5	P2, P10	***P4**	***P6**	***P7**	***P8**	P9
**Key Features	LKA, ACC, Collision Warning, AEB, RVC, SVC	LKA, ACC, DMS, ADAS, Blind Spot Monitoring, Collision Warning, AEB, RVC, SVC	LKA, LCA, ACC, DMS, ADAS, Blind Spot Monitoring, Collision Warning, Parking Assistant, AEB, RVC, SVC	LKA, LCA, ACC, DMS, ADAS, Blind Spot Monitoring, Collision Warning, Parking Assistant, AEB, RVC, SVC	LKA, Collision Warning, Parking Assistant, AEB, RVC, SVC	LKA, LCA, ACC, DMS, ADAS, Blind Spot Monitoring, Collision Warning, AEB, DDAW, LVDA, TSR, RCCA, RVC, SVC	LKA, LCA, ADAS, Collision Warning, Parking Assistant, AEB, RVC, SVC	LKA, LCA, ACC, DMS, ADAS, Blind Spot Monitoring, Collision Warning, Parking Assistant, AEB, RVC, SVC

*Participants who have a higher level of knowledge on Avs

**Feature definitions are available in Appendix F.

3.2.2 Venue and Equipment for Field Study

As the field research included the participants' active driving experience and involved passing through points where critical conditions could be observed, they were warned and asked to avoid any action that may endanger themselves and their surroundings.

The first phase of the study, the questionnaire, was taken online via Google Forms, a tool that is more familiar and accessible to the researcher and participants. Think-Aloud protocol and semi-structured interviews were planned face-to-face and the protocol included active driving experience in participants' vehicles. The itinerary of the protocol was pre-determined by the researcher and limited to 5 km/10 min, with action points that may occur as critical conditions (See Figure 3.2).

As can be seen in Figure 3.3, these action points represent areas where the participants can observe the environment or traffic-related challenges that may be encountered along the route. For example, *the campus area*, a pedestrian-priority zone, involves high pedestrian density, frequent uncontrolled intersections, and speed bumps, making it where sudden crossings are common. *The off-campus area* includes transitions through security gates and merges into the main road, requiring careful speed adjustment and high awareness. *The uncontrolled intersection* is particularly complex, with numerous entry and exit points and no traffic signals, significantly increasing the risk of collision. *At the sudden turn joining the main road*, drivers must make a sharp right turn immediately after exiting an interchange, which demands rapid decision-making and limits visibility. *The traffic lights zone* contains controlled intersections and pedestrian crossings, necessitating sustained attention and compliance with traffic signals. In *the school area*, the presence of multiple schools results in high pedestrian activity, particularly by children, which introduces unpredictability and requires extreme caution. Lastly, *the endpoint* marks the conclusion of the route, where drivers are expected to decelerate and complete the driving task safely. At the end of the ride, participants were kindly invited for a

cup of coffee at the last point where the interviews were taken, mostly in a coffee shop.

During the protocol sessions, video and audio recordings were taken simultaneously by both a GoPro Hero 1 and the researcher's smartphone, with the participants' consent. The camera was placed on the left front window of the vehicle and positioned over the left shoulder of the participant or on the vehicle's sunroof to fully capture the intended view so as not to distract the participant while driving (Figure 3.4). The field of view was set to see participants' movements, feedback mechanisms (i.e., dashboard, instrument cluster, screens), and the exterior to understand in which conditions how they act or think. Semi-structured interviews were also voice-recorded by a smartphone.

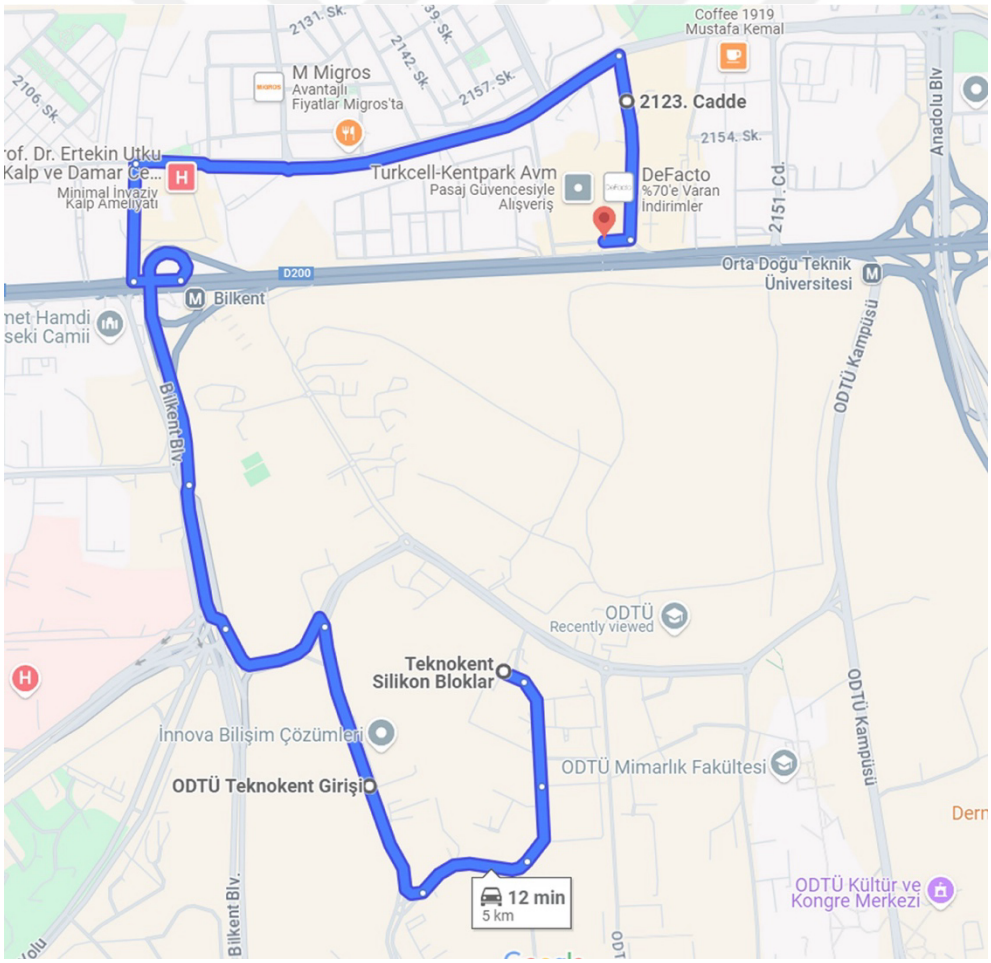

Figure 3.2 Itinerary of the Think Aloud Protocol

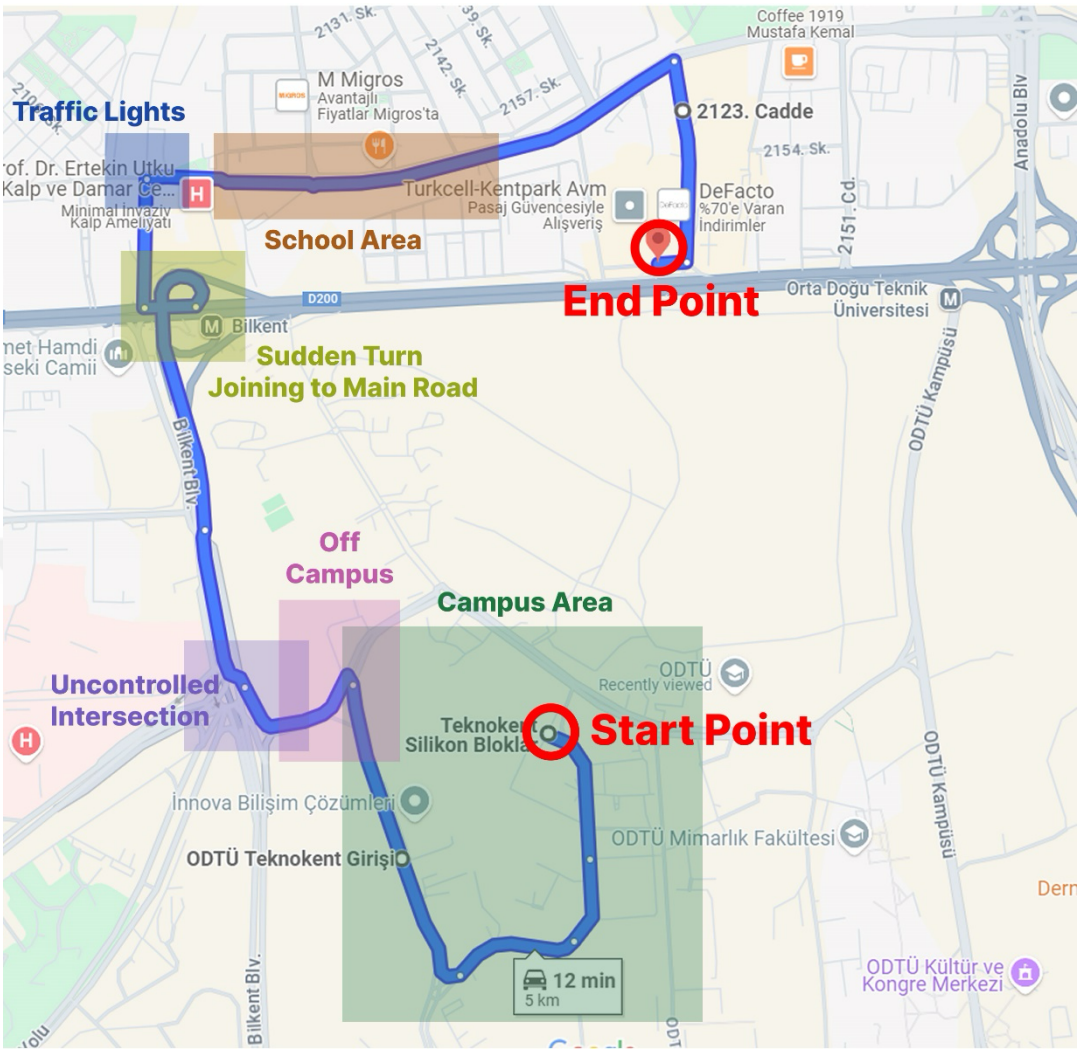

Figure 3.3 Itinerary of the Think Aloud Protocol and Critical Conditions Areas



Figure 3.4 GoPro Placement on the Vehicle's Sunroof and Its Camera View

3.3 Data Collection Methods and Tools

This section describes the data collection methods and tools used in the research, including an online questionnaire, a think-aloud protocol, and semi-structured interviews.

3.3.1 Online Questionnaire

Questionnaires are one of the most common methods used to collect data from participants who meet criteria on a specific topic across various fields (Midena & Yeo, 2022; Rowley, 2014). Since they offer application flexibility across different platforms, they enable people to be reached quickly and are an effective method, especially for reaching participants. Potential participants can be reached with online prepared inquiries, and their compliance with the criteria and the knowledge of the participants about the research topic can be examined. As the first stage of the user research, an online questionnaire was prepared using Google Forms. The questionnaire consists of 11 questions in total (Table 3.3).

- One question about the voluntary participation of the participants,

- Four questions about the features of semi-autonomous vehicles and which features are available in their vehicles,

- Two questions about the general thoughts of the participants about semi-autonomous features and,

- Four questions about the personal information and communication channels preferred by the participants who want to participate in the continuation of the study.

The questionnaire consists of questions that aim to collect different information; thus, different types of questions, such as checkboxes, Likert scales, and short answers, were prepared so that participants could answer comfortably and effectively. Also, it consists of stages, as the participants progress according to their

answers, and those who do not meet the criteria or do not want to participate are directed to the end page without showing the following questions.

Table 3.3 Overview of the Questionnaire

Quantity	Category	Aim
1	Consent	Voluntary participation approval
4	Vehicle Features	Reminding them of the features of their vehicles and investigating the suitability for the study
2	General Thoughts on Features	Warming up and gathering a general impression
4	Personal Information	Obtaining contact information

3.3.2 Field Study (Think Aloud Protocol)

The think aloud method is a research method in which participants instantly share their thoughts with the researcher while performing a task (Charters, 2003). It is one of the most common methods used to obtain the most accurate insights about participants' thoughts without being influenced or directed by another idea or action (Ericsson & Simon, 1980). As Charters (2003) states, applying this method requires designing the process and determining the tasks the participant will perform and the researcher's role. If possible, participants should not need any external influence to convey their thoughts aloud during the process. However, sometimes methods, such as asking research-related questions, can be used to motivate participants who have difficulty in this regard to help them express their thoughts. Concerning that, after the questionnaire, the field study phase was started with the participants who met the criteria and volunteered to participate in the continuation of the study.

The first stage of the field study, the think aloud protocol, involved verbal communication to enable the researcher to get insights into the feelings and thoughts that occur in response to the feedback mechanisms of semi-autonomous features during an active driving experience on an itinerary. The willingness of the participant and the conveyance of all actions and thoughts were important. In cases of hesitation

or topics requiring further clarification, the researcher asked the driver questions without distracting them. These questions were divided into 5 groups (Table 3.4). As Ericsson and Simon (1980) pointed out that even if the protocol is well-implemented, it may not be possible for the participant to convey all their thoughts verbally during the process. In such cases, one of the most common methods used to obtain in-depth information about the participants' thoughts and to make the data collected in the protocol more meaningful is retrospective questioning. When the foreseen conditions along the itinerary did not occur at the specific areas where critical conditions may occur, the researcher asked retrospective questions while conducting the think-aloud protocol by giving examples of situations to benefit from the participant's past experiences.

The sessions began with a question to encourage participants to talk and gain a better understanding of their vehicles. They were asked to briefly introduce their vehicle's interface, dashboard, and explain the areas where the vehicle provides feedback when using autonomous features. The first two groups of questions were asked to understand the impact of autonomous features and feedback mechanisms on the driving experience in general. The remaining questions considered participants' perceived safety and trust regarding the overall experience.

The protocol was planned in line with the findings of the literature research on user trust in semi-autonomous vehicles. The questions were prepared on themes obtained from literature to focus on the unanswered topics during the driving experience.

Table 3.4 Question Groups of Think Aloud Protocol

	Question Groups
1	Vehicle usage
2	Feedback mechanisms and effects
3	Decision making and perceived trust
4	Challenging situations and coping with
5	Overall appraisal and recommendations

3.3.3 Semi-Structured Interviews

Interviews are conducted to gain insight into the personal views and experiences of participants on a specific subject. The focus is not on observing facts or actions, but rather on the answers given by individuals in response to the questions asked. Interviews can be classified as structured interviews, where all questions are known in advance and clear answers are expected; open interviews, where the questions are not predetermined and develop during the conversation; and semi-structured interviews, which involve pre-determined questions but allow for flexibility and development throughout the process (Busetto et al., 2020). Semi-structured interviews, typically conducted with one participant at a time, may include a mix of both open-ended and closed-ended questions, often followed by "why" or "how" questions to obtain more in-depth responses and insights (Adams, 2015). As Adams (2015) states, this approach gives the researcher the flexibility to deviate from the prepared questions when needed, making the conversation more comfortable and helping build better communication with the participant. Additionally, interviews are generally designed to last no longer than one hour to avoid overwhelming the participant and to maintain efficiency.

The continuation of the field research, semi-structured interviews, was designed for subjects that were not answered during the think-aloud protocol or that were aimed to obtain more in-depth insights. The protocol sessions were concluded in front of the shopping mall, which was the last action point of the itinerary, and the participants were invited to the cafe where the interview would be held. The reason for conducting the interviews right after the protocol was to support the participant with sample visuals on the relevant topics while the effect of the experience still lingers. The interview questions consist of five sets, as shown in Table 3.5. In general, feedback types, designs, and their effects on the user were questioned. In the first set of questions, critical condition examples and trust-related feedback designs were emphasized. The questions about design preferences and improvements aimed to highlight the design elements in the feedback mechanism

and their impact on UX, and to gather the participants' thoughts on the existing design and its aspects that could be improved. The interview was completed by asking for general thoughts on semi-autonomous vehicle technologies and feedback designs.

Table 3.5 Question Sets of Semi-Structured Interview

Question Set	Content	Quantity
1	Driving experience	7
2	User experience and comfort	2
3	Design preferences and improvements	5
4	Perceived trust and technology adoption	1
5	Overall appraisal and recommendations	2

3.4 Pilot Study and Its Implications on Research Conduct

The pilot study was conducted to test the research methods, tools, and equipment setups. An engineer working in an automotive software company volunteered to participate in the study. The vehicle was a 2021 model Opel Corsa with some autonomous features, but it did not have functions that would drive completely on its own. Since the primary aim of the pilot study was to test the applicability of the developed methods and interview questions, it was not essential for the participant's vehicle to fully meet the targeted feature criteria. Although the participant had prior experience with vehicles incorporating autonomous functionalities, the level and range of automation in his current vehicle were insufficient to align with the full scope of the study. For example, the vehicle lacked high-level features such as Advanced Driver Assistance Systems (ADAS), Driver Monitoring Systems (DMS), or autopilot; however, it was equipped with basic functions like lane keeping and cruise control. Despite these limitations, retrospective questioning conducted during the pilot study generated meaningful insights that were deemed appropriate for inclusion in the overall dataset.

First, a GoPro was mounted on the vehicle's sunroof with (See Figure 3.4) a vacuum holder with the participant's consent. The dashboard photos of the vehicle were taken for use in the next stage of the study. The voice recording was taken from an Android mobile phone. Starting from the first point of the inquiry, METU Technopolis, the destination was reached within the expected time by applying the think-aloud protocol, and then a semi-structured interview was conducted. Since it was expected during this process and the participant was informed to be careful, risky situations were avoided, and no warning or feedback that the vehicle could give under critical conditions could be observed.

Since the participant was a software developer in the automotive industry, the idea that he might be biased against the research topic was confirmed during the pilot study, and the participant selection criteria were reviewed. For this reason, an arrangement was made to include participants from various professional groups and ages. The level of knowledge people have about the system has an important effect on evaluating the system and the feedback it receives. The participant tended to trust less based on his work experiences when his trust in the system was questioned. For example, when asked about his trust in autonomous features and comfort, he answered, “I trust myself more; we are the ones who make these systems, and I know how it works or where it falls short.” (P0.1, see the original versions in Turkish of all participants' quotations referred to in the thesis in Appendix F.)

In addition, it was observed that the factors obtained from the literature regarding feedback design and users' perceived trust and safety were applicable and overlapped with real usage scenarios. According to the study of Valentine et al. (2021), one of the challenges encountered when calibrating trust is the transparency of the system, and to ensure this transparency, the explainability and justification of design decisions are important. When we consider these as factors, it can be said that these factors are effective in some moments when the participant's trust in the system is negatively affected. For example, the feedback design of the drowsiness warning feature feels inadequate and unclear because this design, which has a gradual representation of drowsiness in bars, does not provide clear information about how

the grades are determined or what exactly each grade means (Figure 3.5). Therefore, the user stated that the feedback design and the reason behind the decision are not explanatory.



Figure 3.5 Drowsiness Warning Feature

In the semi-structured interview, the itinerary diagram and visuals of the participant's vehicle were used (Figure 3.2; Figure 3.6). These were useful in terms of reminding the think-aloud protocol and helped to express himself more clearly when asking questions, and it was decided to use them in the rest of the study. The itinerary included critical conditions (e.g., a school area as shown in Figure 3.8), and each condition was separated, colored, and named as an area in the diagram, making it easier for the participant to give examples (Figure 3.3). When asked questions about his past experiences and critical situations encountered, he shared the thought “The sudden turn area marked in yellow is a very risky place, effective application of the blind spot warning feature is quite useful in such places.” (P0.2) Similarly, he was able to share his thoughts on the existing system and the subjects that could be improved regarding the design and placement of feedback coming from the vehicle,

through the visual classification according to the regions of the vehicle (Figure 3.6; Figure 3.7). He quickly conveyed that road warning signs are given from region A, while the feedback of rear-view camera and sensor-based features is given from region B.



Figure 3.6 Feedback Regions of The Vehicle: Region A - Instrument cluster, Region B - Infotainment System, Region C - Steering Wheel

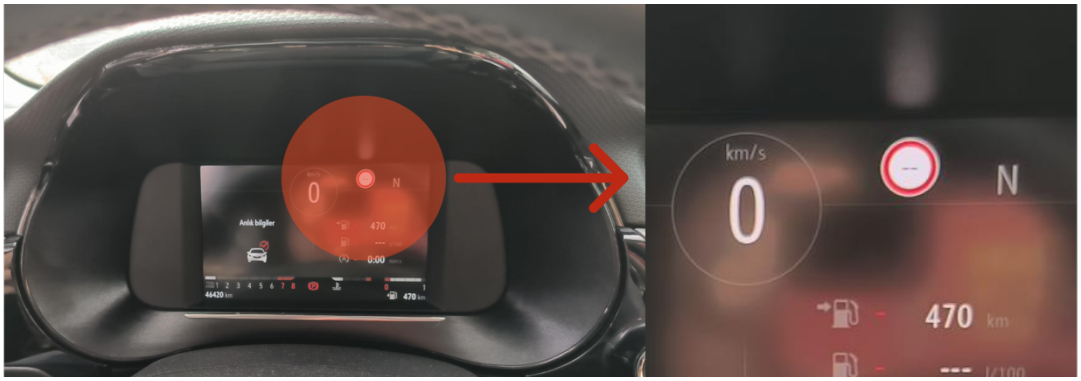

Figure 3.7 Road Warning Sign Example from Region A



Figure 3.8 School Area - Pedestrian Crossing

To gain more in-depth insights from the participants, minor changes and additions were made to the study protocol and the semi-structured interview questions. A comparative question was added in the think-aloud protocol to explore whether participants had prior experience with other vehicles featuring autonomous functions, and if so, what differences they observed in terms of features and feedback mechanisms. Additionally, the interview question regarding potential improvements for user experience was revised to specifically ask which aspects of the information or its presentation they would change to enhance the experience. These revisions enabled the study to consolidate richer data regarding the design of feedback mechanisms.

3.5 The Study

The pilot study was conducted in March 2025, followed by the main study between May and July 2025 with a total of 11 participants. Across these phases, data were collected in the form of photographs of equipment assembly and participant vehicle dashboards, audio and video recordings from the think-aloud sessions, and audio recordings and researcher notes from the subsequent semi-structured interviews.

While the audio recordings and transcribed data formed the basis of the thematic analysis and affinity diagramming, the notes, photographs, and video materials served as supportive documentation to enrich and validate the findings.

The think-aloud protocols lasted between 15 and 25 minutes, depending on traffic conditions, while the semi-structured interviews ranged from 35 minutes to 1 hour, varying according to the participants' level of knowledge and willingness to share their experiences.

3.6 Data Analysis

After the participants were determined through the online questionnaire, the video and audio recordings of the think-aloud protocols and interviews were transcribed. Themes were first derived from the literature findings and then enriched with additional themes emerging from the research data. Following this, all the outcomes were divided into themes, and a second coding study was conducted to combine themes from the literature and research to make the obtained data meaningful.

3.6.1 Thematic Coding

In qualitative research, data is typically based on participants' responses; therefore, audio and/or video recordings are transcribed into written text. To enable coherent inference and draw conclusions across all participant responses, the researcher organizes the data by grouping participant outputs through interpretation. The most fundamental unit that forms these groups is the code. In qualitative content analysis, coding refers to the process of assigning labels—typically consisting of one or a few words—that capture and summarize the meaning of longer phrases in a concise and meaningful way (Saldana, 2015). As codes begin to form, it becomes possible to observe their relationships with each other, and thus themes emerge. In other words, according to Gibbs (2018), by breaking long texts into meaningful pieces, codes, a

thematic framework is created, which helps to understand how the ideas that participants frequently mention are connected.

The transcription of audio and video recordings was carried out following the completion of each participant's think-aloud protocol and semi-structured interview. These transcripts were then transferred into MAXQDA software for thematic coding. A separate set of files was allocated for each participant, and participants were assigned a unique number to ensure anonymity. The data were analyzed to understand how users' perceived trust was affected by feedback mechanisms during their driving with semi-autonomous features. From this analysis, the data were sorted into relevant code groups, and themes were identified.

The coding was developed progressively as data from different participants became available throughout the process. The final version consists of themes structured to address the research questions. The main themes are as follows:

- Experience-Related Factors
- Interaction Factors
- Contextual Factors

3.6.2 Affinity Diagram

The Affinity diagram is a common technique used to summarize and visualize large and unstructured data (Gupta et al., 2016; Bondarenko & Janssen, 2005). As mentioned by Gupta et al., this method divides the data into meaningful pieces, allowing them to be visually arranged in a hierarchical order and making the relationships between the units visible. Each heading represents a key factor, while the heading that groups these factors can be referred to as the main factor (Aung et al., 2016).

In this study, the affinity diagram is used to support thematic coding and visualize the relationships between code groups and themes, which were factors related to the

effect of notification designs on user trust. All the data, the researcher's notes, and the code structure created as a result of the individual study were divided into color groups and labeled using the online graphic editing tool Figma. Figure 3.9 illustrates a part of the "takeover" analysis from the Affinity Diagram, showing its connections to other sub-themes.



Figure 3.9 Part of the "Takeover" Analysis from the Affinity Diagram

CHAPTER 4

FINDINGS AND DISCUSSION

This chapter discusses the outcomes of the think-aloud protocol following semi-structured interviews. Thematic coding was carried out simultaneously with user research. After each participant's session, the researcher coded the transcribed data using MAXQDA software, not only focusing on the trust-related factors derived from the literature but also considering the dimensions emerging from the participants to develop and expand the code tree. This process allowed the coding structure to evolve into a coherent whole throughout the analysis, making the connections between codes more evident. Once all sessions were completed, the data and themes were reviewed, and related themes and sub-themes were merged. In addition, frequency overlapping mentions were also examined to understand the relationship between the themes. All sessions were conducted in Turkish, and the quotes used in the analysis were translated into English by the researcher.

While factors related to perceived trust and safety, particularly how feedback mechanisms should be designed for critical situations, were being investigated, participants frequently brought up dimensions that did not fully align with the primary research focus but repeatedly emerged during the analysis. These include usability, ease of use, emotional responses toward systems, and perceived usefulness. Although not explicitly positioned or elaborated within the overall code structure, each of these dimensions has implications for trust. Therefore, their interrelations are discussed in the relevant sections below, alongside the associated code groups.

Thematic analysis revealed three main groups of factors influencing users' perceived trust and safety in the use of semi-autonomous vehicles.

Experience-related factors, which conceptually break down the dimensions of users' experiences and mental models,

Interaction factors, which concern the system and its mode of interaction, and

Contextual factors, which relate to the contextual circumstances of the system in use.

These factors were examined in relation to one another through a holistic approach, enabling a multidimensional understanding of users' experiences and providing detailed insight into how each factor contributes to users' perceived trust.

4.1 Experience-Related Factors

Experience-related factors reflect the user's mental model and overall expectations for semi-autonomous vehicle systems, directly influencing perceived trust and safety. These factors are based on how users interpret the system's purpose, operation, and how well it aligns with their goals. The perceived effects of certain system-related factors discussed in the literature review chapter, such as transparency and predictability, were examined in the analysis and, therefore, presented under experience-related factors. Figure 4.1 shows the thematic structure and sub-code fragments associated with these factors.

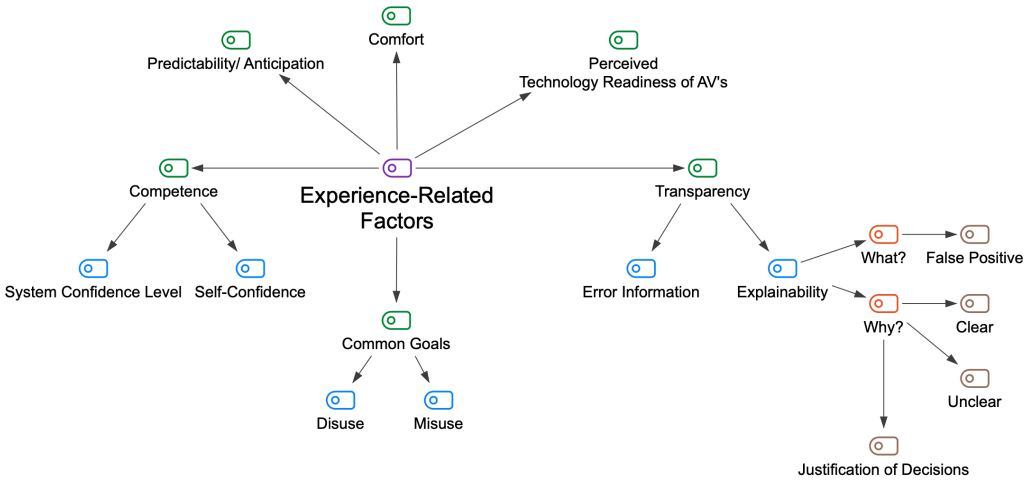

Figure 4.1 Experience-Related Factors of Perceived Trust

4.1.1 Predictability / Anticipation

Predictability refers to the extent to which a system's behavior and capabilities align with users' expectations and their mental predictions about how the vehicle will act in various situations. When users can anticipate the vehicle's actions accurately, it fosters a sense of control and coherence, making the system feel more reliable. In turn, this enhances users' trust in the system, as predictable responses reduce uncertainty. In the context of semi-autonomous vehicles, it is especially critical during takeover situations or in critical conditions, where any unexpected or inconsistent response can undermine trust. Therefore, predictable systems help to enhance perceived trust. (Walker, 2020).

It is observed that other experience-related, interaction-related or contextual factors revealed in the thematic analysis can influence users' judgment of whether systems are predictable. Users can interact more predictably owing to the *level of knowledge* based on *past experiences*. For example, P2 stated that "ADAS doesn't activate in heavy rain anyway. It doesn't activate because it says something is in front of the radar." (P2.1) Having experienced the system's failure and learned the reason, the user's trust in the system was not negatively affected; on the contrary, their reliability towards the system increased.

P9 also supported the idea that being predictable in *takeover* situations could prevent a possible accident in *critical conditions*: "I mean, it made me feel. If something happens that's out of my control, it stops itself. I understood this more clearly that day. It protected me from the accident." (P9.1)

In addition, *system confidence level, explainability of actions, and the way of communication between AV and the user* are supportive factors for predictability. The system's confidence level reflects its actual technical capabilities, and when conveyed *transparently* through appropriate channels and cues, it helps align the user's expectations with the system's true level of competence.

4.1.2 Comfort

Comfort refers to the perception that users feel physically, cognitively, and emotionally comfortable and safe during a semi-autonomous driving experience. It is not limited to physical design and ergonomics but can also be linked to *ease of use*, *transparency,* and *clarity*, which potentially decrease the *cognitive load*. P8 supports this: “It [semi-autonomous driving] definitely increases my comfort. You stop thinking about many things. It ends up doing some things by itself.” (P8.1), thus demonstrating the effect of reducing *cognitive load* on user comfort. Intuitive interaction with the system also supports *technology adoption* and perceived trust. In this context, comfort stands out as one of the basic experience-related factors that both ensure continuity in user interaction with the vehicle and contribute to more effective system use.

The system's confidence level and way of communication, namely feedback mechanisms, also enable the user to have comfortable experience by offering information that would otherwise require drivers' constant attention to process. P9 stated: “All kinds of warnings appear on this one screen on time, especially when necessary. It doesn’t give any unnecessary warnings... It makes me feel at ease. It even detects cars I can’t see, displays them on the screen, and warns me of potential danger accordingly.” (P9.2)

4.1.3 Perceived Technology Readiness of AV’s

Another important factor in calibrating users’ perceived trust is the *technology readiness of AVs*. While it is also influenced by the *system’s confidence level*, which represents the vehicle’s actual technical capabilities and boundaries, technology readiness refers to the user’s perception of how well the system is prepared to handle various scenarios. This perception is shaped by factors such as *past experiences*, *knowledge of technology*, and *situational awareness*, which together influence whether the driver believes the vehicle can or cannot perform a specific action. This

enables users to adjust their expectations regarding the vehicle's current technological capabilities or to take precautions against actions they perceive as not yet fully developed. In doing so, users are able to calibrate their trust accordingly and avoid potentially risky situations.

The need for continuous training and improvement of the system was frequently emphasized by participants, particularly concerning *environmental awareness*. Users expect the vehicle to accurately perceive its surroundings and respond to dynamic traffic conditions and potential errors made by other road users appropriately. As P5 remarked, "This car doesn't know how to avoid the other vehicle on the right. It doesn't know yet. Maybe once it learns, it'll be much better, then it might make sense." (P5.1) This underscores the critical role of environmental awareness in enhancing users' perceived trust in AVs.

Moreover, it was observed that as the system becomes more technologically ready, users demonstrate a higher *intention to use* and engage with it. Participants also associated technological advancement with increased comfort and safety. For example, P1 noted: "A technologically advanced vehicle naturally offers greater comfort and safety." (P1.1)

Nevertheless, in addition to these perceived advantages, some participants expressed hesitations when they thought it was not ready. P3, for instance, pointed out that he does not always trust the actions of the semi-autonomous vehicle, as he believes the technologies it relies on are not yet fully ready. This perceived lack of technological readiness leads to users' distrust in the system.

4.1.4 Transparency

Transparency refers to the system's ability to clearly communicate its intentions, underlying reasoning, and limitations, thereby fostering user understanding, reducing potential confusion, and strengthening trust (Valentine et al., 2021; Kunze et al., 2019).

Throughout the research, system transparency was explored through two dimensions: *explainability* and *error information*. Explainability refers to the system's ability to clarify the reasons behind its specific behaviors, helping users understand and anticipate its actions. Error information denotes its capability to provide cause-and-effect details when it fails to perform a given task, allowing users to reassess their expectations and adjust their trust accordingly. Both dimensions play a critical role in fostering appropriate perceived trust, reducing *uncertainty*, and supporting safer, more confident interactions with semi-autonomous vehicles. In practice, these are most achieved through feedback mechanisms, which serve as the primary channel for communicating the system's intentions, reasoning, and limitations to the user. P7 and P8 stated that, with the feedback provided, they could better understand what the vehicle was doing and why, or what it was aware of in the environment, and therefore they could prepare to react appropriately.

While providing error information benefits the user, not providing it damages their perceived trust. For example, P4 stated, "...sometimes it comes around a bend, just leaves it in the middle, and doesn't let me know." (P4.1) This situation poses a potential accident risk, leading the user to lose confidence in the system and condition themselves to intervene at any time, as if the system were not in control.

In a similar situation, P8 highlighted that the vehicle's environmental awareness should be higher. If it is already at a high level but not readily apparent to the user, this capability should be conveyed more clearly and promptly to the user. For example, in a situation that is too complex or that the system cannot handle, he would prefer to be able to anticipate it and have time to prepare.

In the examples of P7 and P9, it was observed that when the technologies that enable the vehicle to perceive the environment are inadequate, especially in *adverse weather* conditions, the vehicle informs the user by saying that something has come in front of the sensor or radar, and thus the users can understand that the system's capability is limited.

We can best understand the importance of *explainability* on perceived trust in P8's example: “Think of it like a website that works very well but has a terrible interface. The same goes for a car. It might work very well, but if it doesn't convey its full potential or doesn't fully convey its capabilities, it's meaningless. ...Whether it works well or poorly, a system that communicates this effectively will be much better adopted. Therefore, feedback here accounts for 70% of my trust in adoption.” (P8.2)

False positives occur when the vehicle detects an obstacle or potential collision and responds by informing the user and taking action, even though there is no actual threat. In such cases, although the system may correctly answer the question “*what?*” (e.g., the vehicle suddenly breaks while issuing a collision warning), it often frightens users or creates doubt about the system due to the lack of a clear, realistic reason (e.g., there is actually nothing to collide with). Frequent false positives can lead users to distrust the system, believing they are being misled, which may increase safety risks. For example, P7 and P8 reported that the vehicle suddenly emits loud warnings in empty surroundings, brakes unexpectedly, putting the user at risk, or repeatedly warns that the user is tired when they are not. Therefore, false positives, especially in safety-critical features, significantly impact users’ perceived trust.

It is important for the system to communicate not only what it is doing or planning to do, but also *why* it is doing so, as *justification of decisions* significantly influence users’ trust. Aligning with this argument, P0 explained, “The visual emerges here because it has activated a system to prevent skidding. This, of course, makes it feel safer.” (P0.3)

If the justifications are *unclear*, users may become confused, and experience increased *cognitive load*. The *drowsiness detection* feature, which monitors the driver through pedal pressure, steering control, or cameras and sensors, determines whether the driver can continue driving or needs to rest. However, some participants reported that the rationale behind this feature was unclear. They expressed uncertainty about how and on what basis the system evaluates the driver, the meaning of the displayed degrees, and whether the vehicle is confident in its assessment of

drowsiness. P8 suggested that both the label and the solution for the warning should be revised, explaining:

“After long periods of cruise control and autonomous driving, the car shows a coffee icon and warns me to rest, assuming my reactions have slowed. Even if I stop and restart, the warning remains until a set time passes, which is annoying if I’ve switched drivers. In the city, with lane-keeping off, it also warns me about drowsiness during un-signaled lane changes, even after just five minutes of driving. Saying I’m inattentive would make sense but calling me tired is wrong and confuses me about how this feature works.” (P8.3)

4.1.5 Common Goals

Common goals include aligning the user’s objectives and AV system behaviors as well as fostering perceived trust by creating a sense of shared goals and intentions (Davidsson & Alm, 2009; Hoff & Bashir, 2015). If proper alignment is not achieved, users may develop either a lack of trust or overconfidence in the system, which may result in inappropriate levels of trust. As a result, they might either underutilize available features and functions or over-rely on capabilities the system cannot fulfill, which may lead to hazardous situations.

Wischnewski et al. (2023) define disuse as the inability to fully utilize the provided capacity due to underestimating the system's capabilities. The researcher has observed that this situation mostly occurs, particularly under critical conditions or when a potential risk is anticipated. For example, during autonomous driving in the P4 think-aloud protocol, while the vehicle was approaching the car in front of it, the system created a sense that it would fail to slow down at the time and speed expected by the driver and did not provide any notification that it could do so. The driver perceived a risk and, without waiting for the vehicle's response, took over control and braked to a stop.

Misuse, on the contrary, occurs when over relying on the system and relinquishing control to the vehicle even in situations where it is unable to handle it. This can lead to serious risky situations (Wischnewski et al., 2023). Participants' feeling that the vehicle would definitely stop and take the necessary action during a period of drowsiness, sleep, or distraction, often caused by their own actions, supports this factor. P7: "Because when we enable semi-autonomous mode, we generally increase our phone usage. We're more comfortable checking incoming notifications. Deep down, we want to trust the system. There it goes, semi-autonomous. Let me read this message." (P7.1)

In this context, *past experiences* also play a significant role. If a user has experienced a failed or underdeveloped system, distrust is inevitable. However, a habit developed after using highly advanced technology can create misuse when disabling features or using other vehicles, leading to risky situations by unknowingly expecting a feature the vehicle lacks. For example, P8 stated that after driving a vehicle with high levels of autonomy for an extended period, he realized that he was forgetting to brake in his own vehicle because he expected the vehicle to brake, and then break later, thus developing over-trust in the system.

4.1.6 Competence

Competence is the ability to perform a task successfully by an individual or organization. In semi-autonomous vehicles, control is either held by a human or the AV, depending on who is executing the tasks. For humans to take control, the AV requests a takeover, or often influenced by the sense of autonomy, the user voluntarily takes over control. User autonomy mainly correlates with their *self-confidence*, which is a key factor in perceived trust. Nearly half of the participants highlighted during interviews that they should have full control over the system or the option to takeover at any moment. P10 mentioned that having control made him feel more secure.

Competence is divided into two parts: *system confidence leve*l and *user self-confidence*. The system's technical capability and its demonstration to users influence their trust and prepare them for a potential takeover. Users frequently mentioned the impact of the vehicle's awareness and feedback of environmental factors or situational variables related to them on their perceived trust. P1's statement, “My trust increases because it provides information about their environmental situation.” (P1.2) also illustrates the impact of system transparency and explainability on trust.

Furthermore, there are expectations for continued progress in system awareness, allowing vehicles to improve their environmental perception and be trained for various scenarios. Similarly, efforts to enhance drivers’ *situational awareness* and understanding of driving characteristics can enable the system to provide customized autonomous responses. These advancements would support more implicit feedback designs and create a more intuitive user experience without adding *cognitive load*.

Experience-related factors play a central role in shaping perceived trust, serving as the foundation upon which other dimensions are built. While they individually influence trust, they are also interdependent with interaction and contextual factors, both shaping and being shaped by them.

4.2 Interaction Factors

Interaction factors refer to the elements that shape how users engage with semi-autonomous vehicle systems and how these systems communicate, respond, and adapt during operation. These factors encompass the bidirectional exchange of information between the user, the vehicle, and other entities, as well as the customization and design of feedback. They directly influence how intuitively and effectively users can operate the system, thereby affecting perceived trust, usability, and overall driving experience. Some system-related factors discussed in the literature review chapter, such as feedback and customization, were examined in the

analysis under interaction factors, as the primary focus was on how users engage with and respond to these features and mechanisms. Figure 4.2 presents the thematic structure and sub-code fragments associated with interaction factors.

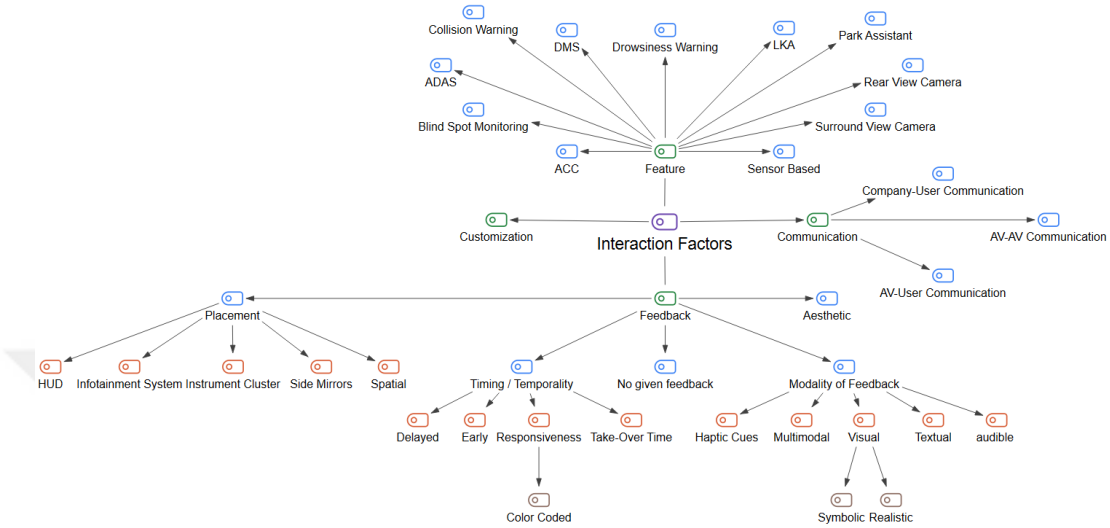

Figure 4.2 Interaction Factors of Perceived Trust

4.2.1 Feature

These code "*features*" was generally used by the researcher to evaluate the features participants stated were present in their vehicles or commented on, as well as the feedback mechanisms related to those features. It includes features like *ACC, ADAS, Blind Spot Monitoring, Collision Warning, DMS, Drowsiness Warning, LKA, Park Assistant, Rear View (RVC), and Surround View Cameras (SVC)*. The *feedback* modalities used for the features and the placement on the vehicle are discussed in detail in 4.2.2.

Collision warning, blind spot monitoring, drowsiness warning, and *LKA* were the most frequently mentioned features by participants. The *DMS* feature was also referred to for its ability to be aware of the user and provide a *drowsiness warning*. Other features mentioned were evaluated by participants for their impact on supporting the driving experience and enhancing *comfort*.

Blind spot monitoring supports user trust by alerting users to vehicles they may have missed or cannot see in their side mirrors, or to be cautious when opening a door while parked. P5 confirmed this by noting, “When changing lanes, especially at high speeds, the blind spot warning system can prevent many accidents. For me, it's a highly trustworthy system.” (P5.2)

Collision warning systems are also beneficial for building trust and participants (e.g., P1, P3, P8) reflected this stance by stating when they were distracted with secondary tasks or not able to see surroundings it helped them to avoid either crashing a car or pedestrian.

Most participants indicated a preference for using the lane-keeping assistant (LKA) feature during *long-distance* trips, such as intercity travel, rather than in urban settings. This preference is due to fixed speed limits, better road quality, and clearly visible lane markings on highways. In contrast, participants tend to disable the feature during *short-distance* trips, such as urban driving, because of the frequent need for sudden lane changes in traffic, disappearing lane markings, and poor road conditions. The system’s tendency to keep the user in their lane if they do not signal, taking control and steering them back into their current lane can pose risks if there are potholes, bumps, accidents, or other obstacles ahead. In addition, this behavior of the vehicle is seen by users as *unnecessary intervention of the system* and creates anxiety.

Although the drowsiness warning may be confusing in some situations, it is found beneficial and trustworthy, especially during long journeys, in terms of takeover when the driver experiences a lack of attention due to tiredness.

Semi-autonomous vehicles have numerous features designed to ensure safety, and these features may increase perceived trust if the system accurately communicates its status to the user. However, a failure to explain the system's status or rationale to the user can hinder this trust.

4.2.2 Feedback

Feedback mechanisms are provided to the user from specific areas of the vehicle through various modalities to communicate about the vehicle's status or warnings, which reduces uncertainty and supports perceived trust (Ekman et al., 2018).

The use of these mechanisms increases users' *situational awareness*, ensuring they are prepared in the event of a potential *takeover*. For example, P1 stated the following regarding the level of his perceived trust and safety: “I would say that most of the feedback from the vehicle truly contributes to safety in a way that is realistic, accurate, and impressive.” (P1.3) While there are varying concerns about the notification types for different *features*, providing feedback is considered more beneficial than not providing it at all. With the assurance that the vehicle will notify users if there is a problem, *cognitive load* is likely to be reduced, and they can have a more comfortable driving experience. This is exemplified in P3's statement, “It used to be entirely human-dependent. Now it's becoming more machine- or AI-focused. While full attention wasn't necessary while driving, now you might not need to pay that much attention. Systems warn you.” (P3.1) The emphasis on the system’s ability to notify the user is crucial, as autonomous features are not appreciated when such notifications are absent. When the vehicle abruptly reduces speed in response to another vehicle entering its path or executes a sudden steering adjustment to correct a perceived lane departure without delivering feedback for the driver to takeover diminishes users’ willingness to engage with these features.

The *aesthetics* of feedback and interfaces emerged as a factor that users didn't consider critical. They were observed to be concerned that a high aesthetic quality would distract them further and considered it solely from a functional perspective. However, participants' understanding of aesthetics here overlaps with beauty, so no overall comment on the use of aesthetics could be made. As the thesis does not primarily focus on aesthetics, this aspect was not explored in depth.

Modality, *placement*, and *timing* are interrelated sub-factors in relation to how feedback is provided. Since the channel through which a warning is delivered, its location within the vehicle, and its timing collectively shape the overall experience, these factors are presented together in an integrated manner.

In *placement*, primary driving tasks are typically presented via the *instrument cluster*, while secondary driving tasks are supported through the *infotainment system*. Blind spot warnings are commonly delivered through both the *side mirrors* and the instrument cluster. Additionally, *HUDs* are also available (See Figure 4.3). Based on participant feedback, broader integration of HUDs could positively influence perceived safety and trust, since the critical information remains within the driver's line of sight around the steering wheel, allowing them to easily monitor essential data without diverting attention from the road.



Figure 4.3 Placement of HUD Content as a Secondary Transparent Layer in Instrument Cluster Area (P4's Vehicle)

Another approach to placement is the *spatial* distribution of feedback, which directs the driver's attention to the specific area of the vehicle where the warning is relevant. For instance, Participant 8 explained: "It has the following advantage: it emits the sound depending on where I'm approaching… For example, if I approach the left

rear, it will emit the sound from the left rear. The sound distribution is very good feedback. It emits it from a location based on the sound." (P8.4)

Timing determines when and how frequently feedback is provided to the driver; this is directly related to the urgency of the input. Sub-elements such as early or delayed warnings, takeover time, and the responsiveness of the cues influence the driver's ability to react in a timely and accurate manner. The delays reported by the participants generally occurred in the notifications of sensor-based features (e.g., RVC and SVC) or warnings that are not directly related to driving but still require attention (e.g., tire pressure and headlights). It was observed that users can compensate for these delays as they become familiar with the vehicle. However, in some cases, when the vehicle's environmental awareness is insufficient (e.g., when it cannot maintain control on a sharply curved road or when lane markings become blurred), the car gives control to the user immediately, yet with delayed feedback. P8 exemplified this situation by saying, "I turned on the speed limiter and lane keeping... the lane ends somewhere ahead, or there is a place where it cannot recognize the lane... I can understand that it cannot find it when the car leaves the lane." (P8.5) In such cases, users stated that the vehicle should have noticed them earlier and informed them; otherwise, if they were distracted in a critical situation, it would be difficult to react to the vehicle's instantaneous response. P10 reinforced this point, explaining that "There may be some early notification or gradual notification. I believe it would be better if there were earlier warning systems that detected a risk rather than immediate critical moments." (P10.1)

The *responsiveness* of the system, whether through the duration or color of the feedback, is crucial. An autonomous system should respond to changes and communicate these to the user incrementally, which also plays a key role in enhancing user awareness. Context-dependent notifications, such as variations in the frequency, intensity, and duration of *audio* cues, or the *color-coding* of *visual* alerts (e.g., yellow and red) based on severity, along with the gradual presentation (e.g., drowsiness warning), enable users to recognize warnings more directly (See Figure 4.4).



Figure 4.4 Camera Sensors and Color-Coded Overlay (P8's Vehicle)

P2 provided an example about color-coding: "If it needs to brake suddenly [collision warning], it is red, its sound is different and louder." (P2.2) P0 also mentioned that he understands the meaning of the warning with colors better: "I understand that yellow means I need to be more careful, and red means I am approaching quickly and there may be a risk of a collision." (P0.4) (See Figure 4.5).



Figure 4.5 Collision Warning Example (Chery Omoda) (@chery.ozpam, 2025)

Takeover *timing* was frequently emphasized by participants as a critical factor. They highlighted that the vehicle should detect potential situations earlier and give timely warnings, enabling drivers to be both physically and mentally prepared to take appropriate action. A primary motivation behind this demand for *early* warnings is to allow drivers to assume control before the vehicle enters a risky situation, enabling a controlled and safe takeover, rather than forcing drivers into sudden and stressful interventions. This need was reflected in P8's statement: "When the lane disappears, it says, 'Oh, I couldn't find it.' It needs to say that before then. At least enough to give me a reaction time. Otherwise, if I'm distracted, I could have an accident." (P8.6)

Modality refers to the channel or channels through which information is conveyed, such as *visual*, *auditory*, *haptic*, *textual*, or a combination thereof. In high-urgency situations, the use of multiple modalities delivered at short intervals is often necessary to ensure timely and effective driver response, whereas in low-urgency scenarios, a single communication channel may be sufficient.

The use of clear and concise text was reported to be beneficial for users, as it minimizes *cognitive load* and enhances comprehension. As P0 emphasized, "The concise imperative form of the language used both prevents confusion and facilitates readability. Therefore, I believe that short, clear, imperative notifications are more accurate." (P0.5) This perspective highlights the importance of brevity in textual notifications, particularly in driving contexts where prolonged reading time can distract the driver. For example, P6 stated that "A long text appears at the top of the infotainment screen, and a single red symbol appears [Park Assist]. It says, 'Your vehicle's speed is limited, touch here to cancel it.' This is a long warning. And someone trying to park quickly won't read it. When you press it, the car returns to normal; if you don't, the car slows down significantly, and it becomes unusable. I think those without experience or who haven't read it will be more likely to panic. They'll probably have a lot of trouble." (P6.1)

Visual notifications are generally presented in either *symbolic* or *realistic* forms. Warnings related to the vehicle's status or malfunctions are typically conveyed through symbols on the instrument cluster. Symbolic feedback is used to provide more immediate information in a simplified way to make it easier to understand. This presentation is designed based on common knowledge, aiming to be understood by users regardless of their prior familiarity with the AVs. It use different color codes depending on the type of alert. Additionally, blind spot warning systems include LED-lit symbols on the side mirrors, which are also displayed on the instrument cluster (See Figure 4.6). When the vehicle detects a potential risk involving an object or vehicle in the blind spot, it simultaneously issues an audible alert. Participants indicated that this type of *multimodal* feedback enhances their perceived trust and sense of safety toward the system.

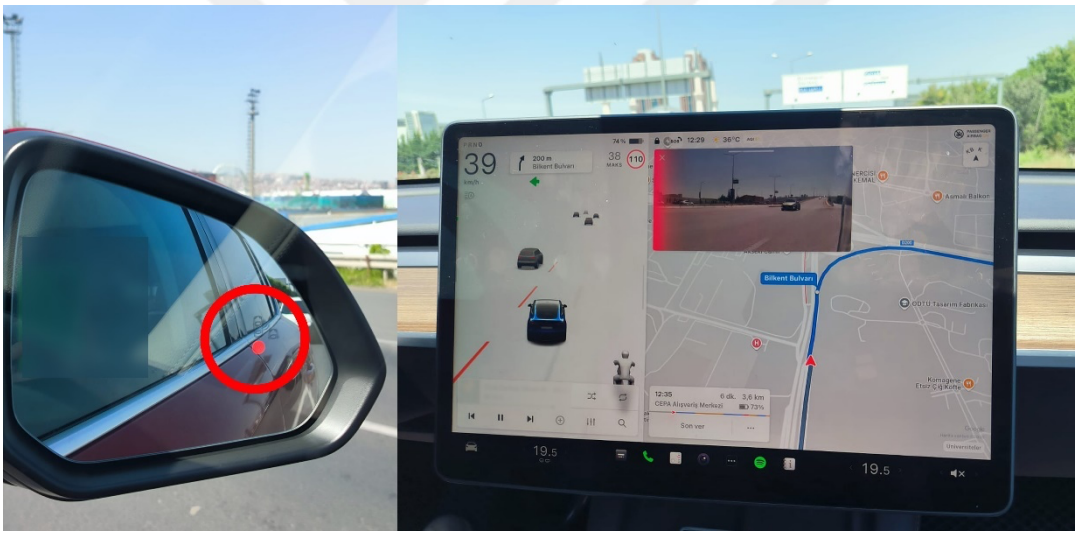

Figure 4.6 Blind Spot Monitoring Warning (P1 and P9's Vehicle)

Realistic feedback examples include the Traffic Sign Recognition feature, which displays exact replicas of traffic signs on the instrument cluster. Additionally, as observed in vehicles like the Chery Omoda 5 and Tesla Model Y, the instrument cluster realistically simulates living beings and objects detected around the vehicle (e.g., other cars, motorcycles, bicycles, pedestrians, traffic cones, and traffic lights) (See Figure 4.7).



Figure 4.7 Realistic Representation of The Environment (P2 and P9's Vehicle)

This realistic representation supports users' trust in the vehicle's capabilities and decisions. Regarding realistic visual feedback, P9 stated: "Whenever any vehicle breaks, it detects that here as well. That's a good feature. It warns you accordingly...This [the brake light of the vehicle in front] turned red; look! They actually applied the brakes...If they open their door, you can see their door opening from here [display]. It detects that too...sees everything, even the traffic light turning green. It sees people walking... I think this system is excellent...it ensures your safety in many ways. So, if you miss something, it doesn't miss." (P9.3)

Auditory notifications emerged as the most useful modality for users and the one that captures their attention most quickly during moments of potential distraction. These cues, typically delivered as *beeps* and *tones*, are *spatially* positioned within the vehicle and as previously mentioned, help reduce *cognitive load* and support user awareness. Especially in situations users classify as critical (e.g., collision risks or high-speed driving), auditory feedback is preferred over visual notifications. For example, P4 emphasized the need to keep attention on the road without constantly checking for visual alerts, finding auditory warnings more effective, and performing a brief visual check only after hearing the sound. Similarly, P6 shared from past experience that, during an *uncontrolled intersection*, the vehicle gave feedback when a car suddenly stopped ahead, and he initially noticed this through the auditory alert.

Presenting feedback through *multimodality* is crucial for supporting users perceived trust and safety, as well as encouraging the adoption of these systems. When these elements are delivered to the user with the right combination and timing, they determine the perceivability and interpretability of the feedback, thereby enhancing the driver's ability to respond safely. For example, an urgent takeover warning that uses a combination of visual, auditory, and haptic cues can significantly improve drivers' perception and reaction times. Supporting the use of multimodal feedback, P5 shared the following insight: "Visual and auditory notifications, combined with steering wheel assistance, are highly effective. The system holds the steering wheel when the vehicle drifts or crosses lane boundaries to prevent potential risky situations. The combined use of these three feedback types is particularly beneficial. Additionally, in more critical moments, safety belt tightening or steering wheel vibration serves as an effective feedback mechanism to alert a drowsy driver." (P5.3)

4.2.3 Communication

Communication is a method for conveying AV capabilities and constraints and helps to reduce uncertainty and mismatched expectations, thus supporting appropriate trust. (Valentine et al., 2021). In semi-autonomous vehicles, communication can be broadly categorized into three types. The first is *company-user communication*, which occurs through channels such as advertising, press releases, and system updates, and influences initial perception and trust. The second is *AV–user communication*, primarily facilitated through *feedback mechanisms* that inform, guide, or warn the driver, which is especially important for trust building and successful takeover. The third is *AV–AV communication*, enabled by *environmental awareness* and technological capabilities that allow the vehicle to detect, interpret, and respond to the actions of other road users.

Companies communicate with their users through various methods. They ensure users understand features and notifications clearly, including initial information during sales and the user manual that comes with the vehicle. However, these

benefits may be limited or unavailable when purchasing a second-hand vehicle. Maintaining continuous communication, through updates, notifications, or accessible support, helps users better understand the vehicle's features and technology, reduces confusion, and supports perceived trust by ensuring they can access clear, reliable information throughout the ownership period. P9 reinforced this point, explaining that "Tesla still receives regular software updates that address customer feedback, and most of the things I wish were like this. I'm really happy with it, as improvements happen automatically and easily. For example, the vehicle's image detail greatly improved after a major update, which even made headlines. It's very professional." (P9.4)

The review of overlapping mentions demonstrate that AV-user communication is mostly affected by *transparency* and *feedback modalities* because *how* the vehicle communicates with the user or *what* is conveyed in this communication are shaped around these two factors. When the system provides feedback to the user with *transparency* and *justification* that meet user expectations, delivered in the right *placement* and with appropriate *modality* combinations, we can consider it successful user communication. This is one of the key factors influencing trust in the AVs. In line with this view, P7 shared "...When the laser pointer appears, it means lane centering, meaning I'm moving you along that laser line. If a car appears in front of that, it also tells you that ACC is engaged. When you use both together, it means the semi-autonomous system is already engaged. It's driving itself." (P7.2)

In the context of AV–AV communication, current systems remain in developmental stages, necessitating substantial regulatory frameworks, technological advancements, and financial investment (Zhang et al., 2025b). Participants suggested that vehicle-to-vehicle communication represents a potential area for development, as indicated that successful implementation could enhance their trust by increasing the vehicle's *environmental awareness*, thereby enabling it to act more *predictably* and autonomously. P3 stated that he does not always trust autonomous features and the actions taken by the vehicle, as he believes the technology has not yet reached a sufficient level. He further emphasized that for trust in these systems to increase,

inter-vehicle communication should be enhanced. Without proper AV-to-AV communication, there is a risk that two vehicles may respond to the same situation with identical actions, potentially creating unsafe scenarios.

4.2.4 Customization

Customization is a user-controlled personalization of the interface or features and increases comfort and gives a sense of control over the vehicle, and strengthens trust (Saffarian et al., 2012). Based on participants' comments, users can benefit from personalized semi-autonomous operation by enabling turning some autonomous features on/off, or they can choose the frequency and intensity of feedback for certain features. Furthermore, offering options such as which screen the windows appear on, the display's appearance, screen brightness, audio cues' tone, and volume creates a sense of connection with the vehicle, increasing user *willingness to use* these systems.

Offering user customization, to the extent permitted by regulations, positively impacts both technology adoption and perceived trust and safety. An example of this perspective comes from P8, who said, “Here in these settings, I can adjust the sounds however I want from the given options. Or you can also personalize it. For example, for a feature's notifications, you can choose to say it never or only say it here. Also, I can select which features will be active. That's the advantage for me.” (P8.7)

As P8 mentioned, customization is sometimes useful to avoid unwanted feedback. For example, constantly being shown a screen that tells the participant how many seconds before it will crash the car in front of them is annoying, so he chooses not to use it from the place dedicated to that warning and has found it more relaxing to receive the same information on a different screen.

4.3 Contextual Factors

Contextual factors include the situational and *other contextual* circumstances that influence how users perceive and trust semi-autonomous vehicle systems during real-world driving. Unlike experience-related or interaction factors, contextual factors reflect the changing nature of trust in response to specific driving scenarios, environmental conditions, and driver-related states. These include critical situations that require takeover (e.g., a*dverse weather, sharp bends, traffic congestion, uncontrolled intersections*), as well as broader *contextual* elements such as *type of driving, environmental setting, and user-related variables like cognitive load, situational awareness, technology readiness, prior experiences, and brand familiarity.* By shaping the level of perceived trust and decision-making, these factors play a decisive role in determining whether users choose to rely on or disengage from automation in a given moment. Figure 4.8 presents the thematic structure and sub-code fragments associated with contextual factors.

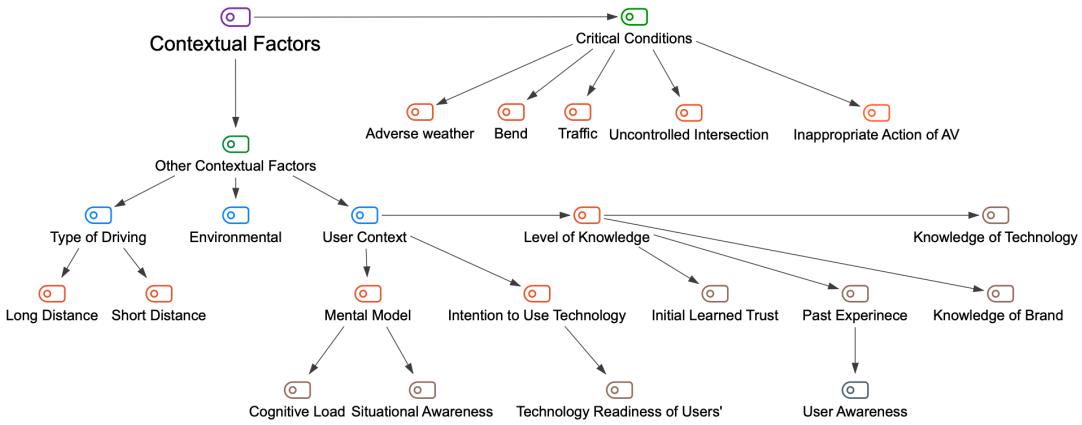

Figure 4.8 Contextual Factors of Perceived Trust

4.3.1 Other Contextual Factors

Other contextual factors refer to elements that directly influence users, such as *environmental conditions, mental states, prior experience and knowledge,* along with *feedback* provided by the vehicle and the actions it performs. Collectively, these

factors are effective in shaping and supporting users perceived trust and sense of safety.

Different usage scenarios significantly influence users' perceived trust. Nearly all participants who highlighted challenging conditions in Türkiye, such as irregular, uneven roads and unclear lane markings, indicated that they mainly use semi-autonomous features during *long-distance* trips. Conversely, during *short-distance* driving, most autonomous functions, especially *lane-keeping assistance*, are turned off. The key factor driving this behavior is environmental conditions. Due to road quality, regulatory restrictions, and the presence of other vehicles, living beings, and obstacles, participants tend to activate these features during *long-distance* drives, where their *environmental* and *situational awareness* may be lower. P4's explanation illustrates this: "In Türkiye, due to other drivers trying to get into the slightest space, it [vehicle] can't function very well in such a variable environment… I use it more for long distances. I leave the control when I'm going to Istanbul and sometimes watch reels on Instagram, etc." (P4.2) Another key reason for using these features on long trips is to decrease tiredness and promote a comfortable journey. Supporting this, P5 said, "Features like adaptive cruise control or lane-keeping assistant are much more useful when I am driving long distances. I feel much less tired when I get out of the car at the end of the trip. That's an advantage." (P5.4) Similarly, P0 stated, "I think using it on long trips increases my comfort." (P0.6)

How the ability to utilize autonomous features in *long-distance* driving supports perceived trust and safety is illustrated by P8's statement: "After a certain period of long driving, a person can enter a state of hypnosis called driving blindness. It's really helpful in these moments. You might drive unsteadily in your lane or drift out of it. In these situations, it takes control." (P8.8)

Providing *feedback* through *multimodality* plays a crucial role in restoring users' *situational awareness*, and higher awareness allows them to interpret the situation and be prepared to take the necessary actions (Endsley, 1988). While driving in autonomous mode, users may focus on secondary tasks but can *takeover* control

through various immediate notifications when their awareness declines. P8 illustrated his successful takeover in a critical situation with the following statement: “For example, one day, I was lost in thought. I was choosing music. Traffic ahead had stopped. I didn’t see it, and a large message appeared on the right screen indicating an obstacle was detected. It braked, so I lifted my head and slammed on the brakes. But if it hadn’t, I probably would have crashed. I was distracted, looking at something else.” (P8.9) P10’s words also contribute to how feedback mechanisms support *situational awareness*: “For example, drowsiness detection with DMS protects us in the event of a collision by providing both audible and vibration warnings, especially during long-distance driving, in the event of any distraction, road hypnosis, or drowsiness. Furthermore, LKA systems keep the car on the road when we drift out of lane during a period of distraction, preventing an accident.” (P10.2)

Although feedback mechanisms support users in many ways, excessive information delivered in short intervals can cause *cognitive overload*. This overload may hinder users from forming accurate *mental models*, leading them to overlook even critical alerts, which reduces feedback effectiveness and may impact trust (Zhang et al., 2025a). Particularly, users tend to be more selective with non-critical notifications. P9 described this situation as follows: “Sometimes it gives different kinds of warnings, but I think they are unimportant, so I don’t pay attention to those notifications. There are too many. If there is a warning related to my safety, I look at it. What is it? If the tire pressure drops, that’s important because the car goes on the tires. Also, if there’s something like an accident, I check it. But I don’t look at every single notification. Having my mind occupied too much doesn’t make me happy either.” (P9.5)

P8 specifically pointed out that the *auditory* cues from the vehicle related to the traffic sign recognition feature can be overwhelming: “The traffic sign recognition is a bit too loud. When I pass a sign and exceed the speed limit, you’ll see it persistently gives me an audio warning. I don’t think this is very ergonomic.

Sometimes the signs can be incorrect, or it may not be appropriate to drive at that speed at that moment." (P8.10)

In addition, users' *cognitive load* can also be related to excessive environmental stimuli, and in such situations, feedback delivered through improper channels or combinations may be insufficient. For example, P6 highlighted this by stating, "In heavy traffic, since we often need to pay attention to many points around us, a visual warning on the cluster alone may not be enough." (P6.2)

According to Körber et al. (2018) general understanding of autonomous vehicles provides the appropriate level of trust by balancing expectations. Supporting this argument, users' *level of knowledge* and *past experiences* with autonomous features have also emerged as important factors affecting their perceived trust and safety towards semi-autonomous vehicles.

For example, P4, an engineer with a strong interest in vehicles and a high knowledge of technology, stated: "I understand the feedback it gives, but can it be as explainable and transparent for someone who doesn't understand much? I can't say for sure... Since I'm an engineer, I'm more familiar with the terminology. I also have some idea of what it can or cannot do, and knowing the technology, I can roughly predict how it will respond." (P4.3)

Additionally, as P7 stated, "There is a tell-tale [symbolic or textual cues about system status or malfunctions] in the automotive industry that indicates drowsiness. I think this is a false positive. It should be an inattentiveness warning, not drowsiness." (P7.3) This reflects how the participant's technological knowledge led him to perceive the system as misclassifying information, which in turn caused reduced trust toward the system.

In addition to *technological knowledge*, *initial learned trust* formed during users' first interactions with autonomous systems is also crucial for establishing an appropriate level of trust and encouraging adoption (Zhang et al., 2019). P6 shared an example of his first unsuccessful experience: "When I first bought the car and was

trying out these [autonomous features], I went on a long trip, and it suddenly braked at a traffic light. It was a bad experience, as it braked unnecessarily at a moment I least expected." (P6.3) If initial trust is established effectively, adoption becomes significantly easier. For example, P9 noted that he struggled during the first ten days of use but eventually adapted, as feedback mechanism was easy to understand and use.

Throughout the study, various retrospective questions revealed that users' past experiences had a significant impact on their perceived trust. This influence may even extend beyond their current experiences, shaping their future interactions as well (Endsley, 2017a). Past experiences also reinforce users' awareness of the systems, enabling them to calibrate their trust more accurately. As P2 explained, "As you use it, you get used to what it can perform successfully or not." (P2.3) Such experiences help users adjust their trust when encountering new features or feedback mechanisms. For example, P3 described his trust toward the vehicle's notifications and actions as follows: "At first, I try to trust it. If there are things [autonomous features] I don't trust or don't like, then I turn them off." (P3.2)

Past experiences also help users understand the *justification of decisions* conveyed through *feedback modalities*. For example, P5, having previously encountered blind spot warnings, was already familiar with the simultaneous *auditory* and *visual cues*. As a result, even if he did not notice the visual warning at that moment, he could still interpret the vehicle's message through the auditory cue, allowing him to inform the researcher about the vehicle's actions during the think-aloud protocol. Similarly, P6 stated that his trust in the system was established after a past incident in which the vehicle took control and *transparently* communicated the reasons for its action, preventing him from hitting a pedestrian at a moment when he had not even realized the risk. Such experiences not only foster trust but also strengthen *users' willingness to rely on the technology* in future interactions.

Users' *knowledge of brands* also influences their trust in autonomous systems. Throughout the interviews, many participants referred to features or communication

methods used by different brands when expressing their views on the systems. For example, several participants cited Tesla as an example when discussing certain features and feedback types, highlighting its strong brand identity in the domain of autonomous vehicle trust. Moreover, P9, who participated in the think-aloud protocol with a Tesla Model Y, often referred to the brand's strong reputation and, through his comments, conveyed that knowing Tesla invests significant resources and expertise in these systems contributed to his trust in using them. Building on the role of *brand reputation*, P8 stated that feedback from reputable brands, which he referred to as premium vehicles, better reinforces perceived trust. According to the participant, the audible cues, beeps, and tonal alerts used in these vehicles are calmer yet effective, whereas in his vehicle, he perceives such alerts as creating tension. This emphasis on brand reputation and its influence on perceived safety and trust is further illustrated by P9's perspective, where he highlights how his trust in Tesla's commitment to safety: "I have a child. Therefore, safety is important to me. I travel with my family most of the time... You know, these guys really care about safety... So, I feel safe. I feel as safe as possible, both for myself and my family." (P9.6)

It was observed that users' knowledge of brands, along with *brand identity* and reputation, facilitates faster adoption by creating a perception of quality, thereby enhancing trust in autonomous systems.

All these factors collectively shape users' *intention to use the technology*. Positive motivation to adopt and engage with autonomous systems has been shown to contribute to perceived trust (Becker & Axhausen, 2017; Parasuraman, 2000; E. Hong & Park, 2023). For instance, P9 described an incident where Volvo's rear collision preparation system detected a rapidly approaching vehicle while stopped at a traffic light, tightening the seatbelts and preparing the occupants for potential impact. Although the collision was avoided, the participant reported feeling impressed and reassured by the system's safety response, noting that such experiences positively influenced their trust in the brand and their intention to choose the vehicle.

In another example from P9, this perspective was supported with the following statement: “From what I have seen in the media, there was an accident involving the Tesla being discussed. I even watched the video footage, where the vehicle experienced an ECU [decision mechanism of an AV] failure and collided with its surroundings. This was just one incident. Out of millions of vehicles, such a case can occur only once. Airplanes can also crash if they are not properly maintained or are operated poorly. In other words, it is a one-in-a-million risk, and therefore, I accept it.” (P9.7)

Furthermore, users' high level of knowledge, especially *technological knowledge*, appears to reinforce their positive attitudes toward emerging and developing technologies. P8, a software engineer in an automotive company with a strong personal interest in cars, noted that these systems have significantly improved in terms of safety, especially over the past five years. He expressed that he finds the capabilities and user interaction mechanisms of newly released vehicles to be successful and stated that he is eager to use them.

As users’ control over the vehicle is limited, such as when certain features intervene to correct or restrict their actions for safety reasons, their intention to use these systems can vary greatly. As noted earlier, when users want to perform more agile driving manoeuvres or quick reactions, they tend to avoid using these features, especially during *short-distance* driving. This demonstrates how autonomy impacts user behaviour, where users may have the skill to control the vehicle, but the restrictions imposed by the system can decrease their perceived freedom and willingness to engage with semi-autonomous functions.

4.3.2 Critical Conditions

Throughout the study, participants were instructed to avoid critical situations, and the itinerary and timings were planned to allow for lower speeds in heavy traffic, so thankfully, no critical conditions were encountered. As a result, takeovers were

mainly observed in situations such as lane markings disappearing or during sudden turns along the route. Additionally, users deliberately took over control when they believed the vehicle could not perform adequately. To gain deeper insights into this aspect, the study focused on participants' prior experiences, and interviews included case-based questions regarding driving under various critical conditions. Among the most common takeover instances were cases where the vehicle assumed control to prevent collisions or tried to return to the lane during uncontrolled lane changes. In adverse weather conditions, it was observed that the vehicle most often alerted the driver to takeover when it was technically unable to handle certain situations, such as when sensors or radar were physically obstructed. During these times, feedback provided properly and through multiple channels supported successful takeovers and helped calibrate users' perceived trust in the system, thereby enhancing their safety.

The importance of road conditions for takeovers and the motivation to use these features were observed during the think-aloud protocol with P2, where multiple takeovers occurred between the user and the vehicle due to various reasons, such as collision risk, lost lane markings, or sharp turns. In such situations, users experience *cognitive overload*, which leads to a tendency to avoid using these features in *short-distance* driving. Additionally, the vehicle's intervention in situations requiring rapid decisions can negatively affect users' perceived safety. For example, almost half of the participants explicitly stated that in such cases, the vehicle assumed control and performed actions that were often either *early*, *unnecessary*, or excessively abrupt. These interventions negatively impacted users' perceived trust and safety, thereby reducing their intention to use autonomous features. To mitigate this, participants suggested that *environmental awareness* of the systems should be improved, respond more accurately and sensitively to potential traffic scenarios, and have enhanced *driver awareness*. In other words, the vehicle should understand the driver and their driving style, interpret the environment accordingly, and leave control to the driver when appropriate, avoiding unnecessary interventions. Based on past experiences and learned real-world accident examples, P0 shared: "Vehicles [semi-autonomous] will react to the first effect [risk factor] they see. Unlike humans, they cannot

simultaneously detect, analyze, and make the right decision before taking action." (P0.7) This illustrates the importance of enhancing the vehicle's environmental and user awareness to support perceived trust in autonomous systems.

Regarding feedback modalities, they are generally presented multimodally, as single-channel notifications often fail to capture users' attention effectively. For example, P7 reported that when the vehicle initially issued a takeover request silently and only visually, he mostly did not notice it; it was only when the alert was subsequently accompanied by an auditory cue that he recognized it and took control. Particularly in *critical situations*, participants emphasized that more salient feedback mechanisms, such as loud audio alerts combined with large visual cues, capable of overriding other stimuli, effectively reinforce users' trust.

4.4 Implications for The Design of Feedback Mechanisms

The findings from this study provide several important implications for the design of feedback mechanisms in semi-autonomous vehicles. Based on participants' experiences, preferences, and responses related to different driving scenarios, design of feedback mechanisms not only affects users' ability to perform successful takeover situations but also shapes their perceived trust and safety. The following presents practical recommendations and design considerations for feedback mechanisms, particularly in the context of takeover scenarios derived from the study's insights.

The most prominent finding for enhancing trust to ensure successful takeovers is that the vehicle's decisions or warnings should not rely on a single modality (e.g., only audible or only visual cues) but should be delivered through well-designed multimodal combinations. Single-channel alerts often fail to attract sufficient attention, which can prevent drivers from regaining adequate situational awareness, especially in critical situations. Considering the importance and urgency of the conveyed information, the combined use of visual, audible, and haptic cues can

enhance takeover performance and foster users' perceived trust and safety in the system.

Visual cues, when designed with simplified yet realistic representations, such as traffic signs, surrounding pedestrians, and vehicles, allow drivers to better understand the system's decisions and capabilities, helping them calibrate their trust accordingly. Feedback should also be given to allow sufficient response time, given the user's accurate reactions. Delayed alerts in potentially risky situations can lead to accidents or undermine users' confidence in the system's capabilities, whereas excessively early alerts may cause confusion if the context is not yet fully apparent. Therefore, both the design and timing of feedback play a pivotal role in shaping and maintaining perceived trust in autonomous systems.

Beyond modality and timing, the spatial distribution of the feedback within the vehicle plays a significant role in how quickly and clearly drivers interpret both the message and its underlying cause. For example, in blind-spot monitoring or parking assistance, placement of warnings in a related part of the vehicle, combined with color coding and audible cues as an object approach, can support faster and more accurate user responses.

Selective provision of feedback is also important. Non-critical alerts, when given too frequently or with excessive intensity, can increase cognitive load and lead to critical warnings being overlooked. Therefore, urgency-based adjustments in feedback intensity and frequency are necessary to help users focus on relevant information and take timely, appropriate actions. Additionally, customization of feedback can support technology adoption and perceived trust, while users' ability to intervene should be limited in safety-critical aspects. That is, customization should not prevent users from receiving essential information, but they may be allowed to choose the tone or channel through which non-critical feedback is delivered according to their preferences.

Transparency and justification of decisions of the system also influence perceived trust. Communicating clearly why the system has taken over or handed back control

fosters a more transparent, explainable, and predictable interaction. In takeover scenarios, short and comprehensible explanations for system interventions have been observed to increase user trust. The user's understanding of the system's capabilities and confidence levels is directly linked to how this information is presented. Vehicles with strong environmental awareness that provide timely and proper feedback can support driver trust during takeovers.

Moreover, unintentional takeovers may be challenging for users to act within the necessary time frame. Therefore, systems should be designed to anticipate risky situations and communicate the potential takeovers in advance, with vehicles leveraging inter-vehicle communication to enhance their environmental awareness. Similarly, improving vehicles' awareness of the driver's state and driving style can foster adoption by making users more willing to rely on the system. For example, a drowsiness warning can enhance both safety and relatedness by indicating that the vehicle is aware of the driver's condition. Ultimately, as systems become more aware of both the environment and the user, and as this awareness is communicated transparently, trust and adoption are strengthened.

With increased environmental and driver awareness, adaptive and personalized feedback designs become possible. For instance, within regulatory limits, allowing users to adjust audible cues' volume and tone or to choose the system's intervention intensity can improve adoption and help calibrate trust. The system may also adapt its interventions based on the driver's attentional state and intended maneuvers. In a scenario where a driver deliberately crosses a lane line to avoid an imminent collision, a system aware of the driver's intentional decision could provide contextual environmental information rather than force the vehicle to keep in its lane.

Brand-user communication can also influence perceived trust. The brand is often the first point of contact before users engage with the vehicle itself, shaping initial trust. If they guide and inform users effectively, provide regular updates and improvements, and remain receptive to user feedback can foster positive experiences with the system.

Taken as a whole, these findings suggest that feedback mechanisms should be multimodal, appropriately timed, and spatially intuitive, with content that is concise, clear, and cognitively manageable. Information should be explainable, making the reasoning behind system actions transparent, yet designed to be quickly perceivable in real-time, avoiding overwhelming the driver with excessive detail. Such feedback allows users to remain informed and situationally aware without cognitive overload, thereby preparing them for potential takeovers and supporting calibrated trust in autonomous systems.

CHAPTER 5

CONCLUSION

This thesis explored perceived trust and safety in semi-autonomous vehicles, with a particular focus on the role of feedback design in takeover scenarios. The literature on autonomous vehicles consistently emphasizes the critical importance of perceived trust and safety in shaping both user acceptance and system effectiveness.

As technologies continue to progress rapidly, autonomous systems capable of performing tasks with limited or no human intervention increasingly rely on advanced environmental perception. Within this technological landscape, semi-autonomous vehicles have emerged as a transitional stage of automation, where the transfer of control between the driver and the system constitutes a central challenge for ensuring both safety and trust. In this context, a successful takeover depends not only on the technical functioning of the vehicle but also on the extent to which drivers' perceived trust is maintained at an appropriate level. Well-designed feedback mechanisms, therefore, play a vital role, as they keep drivers informed, aware, and psychologically prepared to re-engage with the driving task when required.

Existing research on user trust in semi-autonomous driving, particularly in takeover scenarios, has often approached the matter from a technical perspective, primarily focusing on specific design variables such as the timing of feedback or the modality of alerts. While these factors are undeniably significant and have provided valuable insights, they offer only a partial understanding of the complex dynamics underlying trust. Thus, it is crucial to examine their interrelations, since effects observed in isolation may not demonstrate the same effectiveness when experienced in combination. Addressing this gap, this thesis adopts a holistic approach to feedback design in semi-autonomous vehicles, particularly during critical takeover situations,

within the broader scope of automotive UI and UX. The research identifies the factors that influence perceived trust and safety, examining how different feedback design elements affect drivers' experiences, especially under critical conditions.

To achieve this, user-centered research was conducted through an itinerary using a think-aloud protocol, followed by semi-structured interviews to gain deeper insights, allowing for both observations of driver behavior and deeper reflections in terms of how drivers perceived and interpreted system feedback under different conditions. The findings were thematically coded and subsequently mapped against insights drawn from the literature, revealing relations between user insights and literature findings. Three overarching categories of trust-related factors (experience-related, interactional, and contextual) emerged from the thematic analysis, each associated with distinct yet interconnected elements influencing users' trust and adoption. The findings provide empirical evidence that trust is multi-layered and context-dependent, influenced by both system attributes (e.g., feedback mechanisms, transparency, adaptability) and user-related conditions (e.g., mental models, situational awareness, level of knowledge).

Specifically, the results demonstrate that feedback design should extend beyond the mere provision of information. It must ensure alignment between system confidence levels and user expectations, support situational awareness, and communicate transparently about both system strengths and limitations. Such alignment enables users to calibrate their trust appropriately, avoiding misuse while maintaining confidence in the system's capabilities. This approach highlights the design elements most effective in fostering appropriate levels of perceived trust and facilitating the adoption of semi-autonomous systems.

The findings emphasize that prioritizing user needs over merely communicating vehicle actions is essential. In addition, the use of implicit and adaptive feedback strategies that are sensitive to user expectations and contextual conditions can elevate the interaction between driver and vehicle from a functional exchange to a more meaningful and confidence-enhancing experience. Accordingly, feedback

mechanisms act as a critical means of fostering appropriate trust, enabling safe, timely, and effective user interventions during critical takeovers.

This chapter revisits the research questions considering the findings from both the literature review and the user research, aiming to provide comprehensive answers to the questions. In addition, the chapter critically reflects on the limitations encountered during the study. Finally, based on the findings and identified gaps, the chapter proposes recommendations for future research on feedback design and its impact on perceived trust and safety in semi-autonomous vehicles.

5.1 Revisiting the Research Questions

This research was conducted within the framework of two questions. They will be answered, respectively.

5.1.1 What are the main dimensions that affect user trust in semi-autonomous vehicles during unintentional takeover scenarios?

Findings from the literature, complemented by insights from the user research, indicate that user trust in semi-autonomous vehicles during unintentional takeover scenarios is shaped by a set of interrelated dimensions and can be categorized into three interconnected groups: user-related factors (e.g., self-confidence, situational awareness, mental model, intention to use technology, level of knowledge), system-related factors (feedback, customization, transparency, automation capability, system confidence level, predictability, adaptive automation), and contextual factors (communication, brand identity, common goals) (See Table 2.3). Together, these dimensions influence how users perceive, interpret, and respond to system interventions, ultimately shaping both perceived trust and takeover performance.

According to SAE (2021), as automation levels increase, vehicles acquire more advanced capabilities and provide users with richer streams of information and alerts.

Particularly in levels 2, 3, and 4 vehicles, the way the system communicates with the user becomes critical. Without effective communication, successful takeover cannot be achieved, which in turn undermines perceived safety and reduces user trust. Therefore, it is essential that vehicles convey their capabilities and limitations transparently. Communication also extends beyond the vehicle itself: brand-user interaction plays a significant role in the formation of initial learned trust. Well-managed communication strategies, reinforced by brand reputation and identity, not only support the adoption of these systems but also shape users' responses to system feedback and interventions.

Effective communication helps calibrate trust, preventing both disuse and misuse, and enables users to benefit fully from automation without developing overreliance. At the core of this communication lie feedback mechanisms. Through multiple modalities and channels, feedback conveys system status, alerts, and decision rationales, which strongly affect users' confidence in the system. Transparent feedback that explains and justifies system actions fosters appropriate levels of trust, enabling users to predict vehicle behavior more accurately and align expectations with system capabilities. In addition, offering customization for non-safety critical features in how feedback is delivered, such as its modality or placement, not only enhances user autonomy but also supports technology adoption. Beyond feedback alone, adaptive automation that adjusts to environmental conditions and driving styles further strengthens user trust by making the system more responsive and context-aware. Users' level of knowledge and past experiences with automated systems also play a decisive role in shaping perceived trust and their willingness to rely on system feedback.

Complementing these, thematic analysis of the user research conducted for this thesis identified additional factors such as experience-related (e.g., technology readiness of AVs, error information, false positive), interaction (e.g., feature, feedback [holistic approach], AV–AV communication), and contextual factors (e.g., type of driving, cognitive load, intention to use, knowledge of brand, inappropriate action of AV, critical conditions) (See ChapterCHAPTER 4). In addition to the importance of how

the vehicle's decisions, reasoning, and capabilities are communicated to the user, it is also crucial that the vehicle provides information in situations where it fails or is insufficient. By explaining the reasons for such limitations and allowing adequate time for the user to takeover, providing error information enhances users' trust in the system. When users do not receive this information from the vehicle, they may assume that the system is still in control, which can leave them unprepared for a takeover, especially in moments of low situational awareness. Furthermore, in lack of feedback, users may develop the prejudice that the system is not aware of its own limitations, which in turn undermines their trust in its ability to make correct decisions when it is capable, leading to reduced perceived trust. Similarly, vehicle responses that do not always correspond to real situations, i.e., false positives, cause users to question whether the vehicle consistently takes appropriate actions. Therefore, feedback provided to users through different modalities should be considered in combination with the timing, placement, and modality, depending on the feature and the criticality of the information.

Moreover, the type of driving has also been found to affect perceived trust regarding the features and feedback offered by the system. There are certain features that are preferred only in specific types of journeys (short vs. distance driving), dependent on the user's trust in the automobile for its capacity to respond to environmental conditions such as road quality and surrounding drivers. For instance, features such as LKA and drowsiness warning are more frequently relied upon during long-distance driving. In contrast, during short-distance driving, users tend to distrust the vehicle's behavior when it takes control and occasionally performs actions that may put them at risk, leading them to deactivate the features. Users also prefer high responsiveness in provision of feedback (e.g., context-dependent notifications) in terms of trust, as it allows them to access necessary information directly without experiencing cognitive overload. Moreover, providing warnings that vary according to the severity of the situation helps users achieve successful takeovers, particularly under critical conditions.

Past experiences and the level of knowledge also emerged as prominent dimensions in the analysis. When users' initial learned trust is properly established, their present experiences are positively influenced, which increases their motivation and willingness to use these systems in the future. Additionally, brand reputation and identity significantly affect users' perceived trust toward the vehicle and its features. For example, perceived safety is particularly high among users of Volvo vehicles, which consequently enhances their trust while driving them. Likewise, Tesla's pioneering role in autonomous vehicles and the perceived advancement of its systems elevate users' confidence in the vehicle's decisions.

These findings highlight that perceived trust of users in semi-autonomous vehicles is a multi-dimensional, context-dependent construct, shaped by the interplay between user characteristics, system capability, and situational factors, emphasizing the critical role of transparent, adaptive, and multimodal feedback in supporting safe and effective takeover performance.

5.1.2 What are the design considerations for effective feedback mechanisms to increase perceived trust, enhance users' ability to regain control, and make informed decisions in critical, unintentional takeover situations in autonomous vehicles to foster positive user experiences?

The findings of this study indicate that feedback mechanisms in semi-autonomous vehicles should be designed as multimodal, adaptive, and transparent systems that simultaneously enhance user trust, situational awareness, and takeover performance. Single-channel alerts often fail to capture drivers' attention in critical situations; therefore, combinations of visual, auditory, and haptic cues should be employed to enhance their effectiveness. These cues need to be concise, cognitively manageable, and presented through realistic yet simplified representations (e.g., traffic signs, nearby vehicles, pedestrians) that clearly illustrate the system's perception of the environment. Short and explainable notifications combined with symbolic

visualizations allow drivers to quickly understand the rationale behind system actions without being cognitively overloaded, thereby supporting calibrated trust.

The timing and spatial distribution of feedback also play a crucial role in the design of such mechanisms. Alerts must allow sufficient response time without being delivered too early or too late, and their placement within the vehicle should be intuitive and context-related (e.g., blind-spot alerts appearing near the side mirrors). Feedback intensity and frequency should adapt to urgency, reducing unnecessary alerts while ensuring critical warnings stand out.

Another key dimension is adaptability to user state and driving style. By increasing user awareness, vehicles can distinguish between unintentional and deliberate actions. For instance, when a driver makes a sudden maneuver to avoid an obstacle, the system should recognize the intentionality rather than interpret it as lane departure. Similarly, during short-distance drives with frequent sudden maneuvers, the system may temporarily bypass certain non-critical interventions while reminding the driver when takeover is necessary. Adaptive automation can further allow users to select the level of system intervention in non-safety-critical functions, such as choosing whether traffic sign recognition only provides warnings or actively adjusts vehicle speed.

Feedback should also reflect advanced environmental awareness. Systems capable of detecting upcoming risks (e.g., accidents, traffic congestion, complex uncontrolled intersections) should communicate them in advance, enabling users to prepare for potential takeovers rather than reacting in panic. Expanding awareness through vehicle-to-vehicle communication can further strengthen predictive capabilities, as AVs share real-time situational data. A 360-degree recognition and representation of the environment, presented through intuitive visualizations such as HUDs, can help users perceive not only what the vehicle senses but also how it intends to respond, thereby fostering trust in its situational competence.

Transparency remains a central element of trust. Feedback should include justifications when automation is unable to perform a function (e.g., poor road

quality preventing lane keeping) so that users understand the reason for the takeover request. This prevents misinterpretation, supports calibrated trust, and encourages users' intention to use these technologies. Moreover, communication should not be limited to in-vehicle interactions; extending AV–user communication beyond driving (e.g., through mobile applications that provide system status updates or safety notifications) can strengthen users' sense of relatedness and increase intention to use.

Finally, customization and contextual adaptation are essential for positive user experiences. Feedback should dynamically adjust to the driver's attentional state and the surrounding environment. For example, in quiet settings, an auditory cue may suffice, whereas in noisy conditions it should be reinforced with visual signals. Visualizations should follow a consistent, common knowledge–based design language, ensuring that users can quickly interpret their meaning without confusion. Real-time, dynamic illustrations of the vehicle's perception and planned actions not only increase situational awareness but also reinforce the user's trust in the system.

Taking together, these insights suggest that effective feedback in semi-autonomous vehicles should be multimodal, adaptive to both user and environmental conditions, transparent in communicating rationale, and proactive in anticipating risks. Such intuitive and implicit designs ensure that drivers remain situationally aware, able to make informed decisions, and confident in regaining control during unintentional takeovers, thereby strengthening both perceived trust and overall user experience.

5.2 Limitations of The Study

Although the study focused on feedback designs of autonomous features, since vehicles with level 3 and above autonomy levels according to SAE have not yet become widespread in the market and due to the difficulty of finding participants, level 2 vehicles were targeted (SAE International, 2021). Because of the difficulty of finding vehicles that include all autonomous features of levels 3 and 4 vehicles,

the research was conducted by choosing vehicle models that meet the most features based on certain features. (See Table 2.1) Working with more autonomously equipped vehicles in future studies may provide deeper insights. In addition, although the intention was to focus on feedback designs in critical conditions and users' perceived trust, since the protocol that includes active driving experience was conducted, creating these conditions was deemed risky in terms of participants, researchers, vehicles, and surroundings safety; thus, participants' past experiences were utilized. Nevertheless, the itinerary designed by the researcher specifically targeted areas where potential critical situations were more likely to occur, and in cases where such conditions could not be directly experienced during driving, participants were encouraged to recall related past experiences, which provided valuable insights. Fully equipped with autonomous features, simulation studies can be conducted, more simultaneous experiences can be experienced, and emotions and thoughts in the moment can be obtained specifically for critical conditions. Since participants are generally working people and the research period is short, the driving time and length were kept short, and data were collected mostly through examples and questions. Although the itinerary and duration of driving were kept short, retrospective questions asked in the protocol and semi-structured interviews provided more and richer data than the participant could experience at that moment. In future studies, long-term driving, different seasonal conditions, and driving experiences that include different challenges on the route can enrich the data obtained from the study.

5.3 Future Studies

Building upon the current study’s limitations, several directions for future research can be suggested. As autonomous driving technologies advance and Level 3 and higher vehicles become more accessible, conducting studies with these vehicles will enable a more comprehensive evaluation of feedback design and its impact on trust. Additionally, using fully equipped vehicles that include a wider range of autonomous

features will provide opportunities to examine feedback mechanisms across more diverse functions.

While the present study avoided creating risky conditions during active driving, future studies may employ high-fidelity driving simulators to safely reproduce critical scenarios such as sudden pedestrian interventions, adverse weather, or collision risks. Simulation-based experiments will allow researchers to capture participants' real-time emotions, behaviors, and trust dynamics in conditions that are difficult or unsafe to create.

Expanding the temporal and situational scope of driving studies can enrich insights. Longer driving sessions, conducted across different seasons and road conditions, can provide valuable data on how trust and perceived safety evolve over extended and varied experiences. Furthermore, longitudinal studies may reveal how drivers' learned trust develops over time compared to their initial impressions.

Diversifying participant profiles and exploring adaptive or personalized feedback designs tailored to driver characteristics (e.g., experience level, confidence, or cultural background) would enhance the practical relevance of future work. Such studies could also address how contextual factors such as brand reputation, communication strategies, or transparency in system behavior contribute to trust formation.

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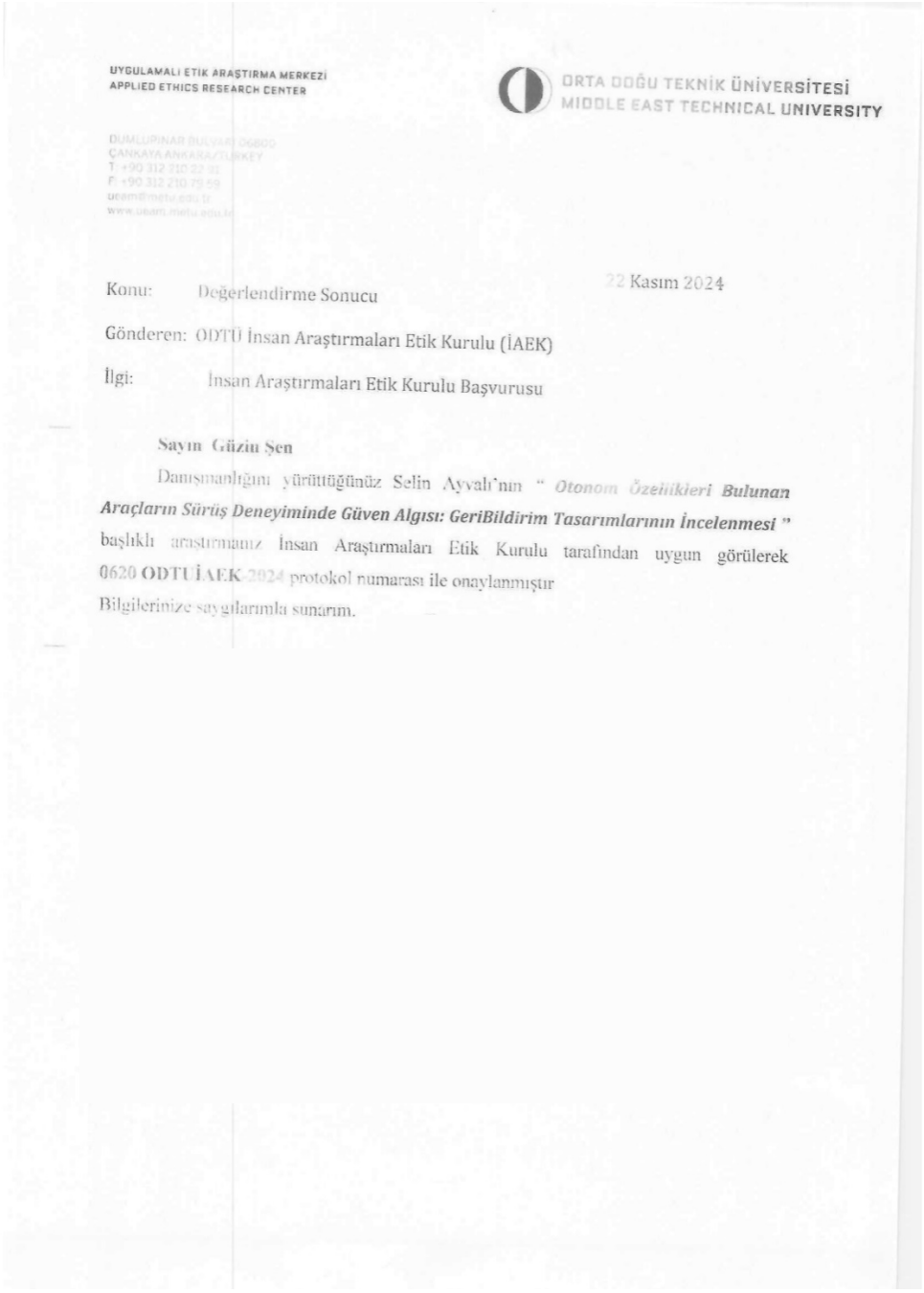
APPENDICES

A. Ethical Approval



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Konu: Değerlendirme Sonucu

22 Kasım 2024

Gönderen: ODTÜ İnsan Araştırmaları Etik Kurulu (İAEK)

İlgi: İnsan Araştırmaları Etik Kurulu Başvurusu

Sayın Güzin Şen

Danışmanlığını yürüttüğünüz Selin Ayvalı'nın " ***Otonom Özellikleri Bulunan Araçların Sürüş Deneyiminde Güven Algısı: GeriBildirim Tasarımlarının İncelenmesi*** " başlıklı araştırmanız İnsan Araştırmaları Etik Kurulu tarafından uygun görülerek 0620 **ODTÜİAEK** 2024 protokol numarası ile onaylanmıştır

Bilgilerinize saygılarımla sunarım.

B. Consent Form

Araştırmaya Gönüllü Katılım Formu

Bu araştırma, ODTÜ Endüstriyel Tasarım Bölümü yüksek lisans öğrencisi Selin Ayvalı tarafından yürütülen bir çalışmadır. Bu form sizi araştırma koşulları hakkında bilgilendirmek için hazırlanmıştır.

Çalışmanın Amacı Nedir?

Tez konusu, yarı otonom araçlarda sürüş deneyimini etkileyen zorlayıcı durumlarla karşılaşıldığında aracın geri bildirimleri yoluyla kullanıcının algılanan güven hissini anlamak ve yarı otonom araç arayüzlerinin geribildirim tasarımı hakkında tasarımcılar için bir rehber oluşturmaktır.

Zorlayıcı durumlara örnek olarak gösterilebilecek bazı durumlar şunlardır: Yoğun trafik, olumsuz hava koşulları, yaya yoğunluğunun çok olduğu güzergahlar, kısıtlı zamanda hedefe ulaşma isteği, araç önüne ani yaya çıkışları ve bu gibi durumlardan kaynaklanabilecek olumsuz durumlar.

Araştırmanın amacı, yarı otonom araçların kullanıcı deneyimini ve geri bildirim mekanizmalarını daha iyi anlamak ve iyileştirme önerileri oluşturarak gelecekteki tasarımlara katkıda bulunmaktır.
Araştırmaya katılmayı kabul ederseniz, sizden beklenen 3 aşamadan oluşan çalışmayı tamamlamanızdır.

Bize Nasıl Yardımcı Olmanızı İsteyeceğiz?

İlk aşamada doldurmanız beklenen ve yaklaşık 10-15 dakika sürmesi öngörülen online ankette kendi aracınızın özellikleri ve yarı otonom araçlara karşı yaklaşımınızı anlamak hedeflenmektedir.

Sesli protokol aşamasında kendi aracınızla önceden belirlenmiş bir rota boyunca bir sürüş deneyimi gerçekleştirilecektir ve bu deneyim esnasında düşünce ve hislerinizi sesli olarak paylaşmanız beklenmektedir. Sürüş mesafesi 5 km olup trafik koşullarına bağlı olarak 10-20 dakika arası sürebilir. Deneyim öncesinde aracınızın bazı noktalarına -araca zarar vermeyecek şekilde- ses ve görüntü kayıt cihazları yerleştirilecektir. Yerleşim ile ilgili hazırlıklar sürüş deneyimi öncesinde tamamlanacaktır.

Mülakat aşamasında ise sürüşten hemen sonra ikram eşliğinde deneyiminize dair sorulacak sorular yardımıyla düşüncelerinizi paylaşmanız beklenmektedir. Bu şekilde sürüş sırasında detaylı bir şekilde paylaşmanızın mümkün olmadığı görüşleriniz hakkında da daha derinlemesine bilgi paylaşımı mümkün olacaktır.

Sizden Topladığımız Bilgileri Nasıl Kullanacağız?

Araştırmaya katılımınız tamamen gönüllülük temelinde olmalıdır. Cevaplarınız bütün araştırma aşamaları dahil olmak üzere anonim tutulacak olup, bütün katılımcıların cevapları ile birlikte değerlendirilerek raporlanacak ve herhangi bir yayında cevaplarınız isminizle eşleştirilmeyecektir. Alınan ses/görüntü kayıtları rızanız dahilinde toplanacak olup sadece araştırmaya yardımcı olması amacıyla kullanılacak ve herhangi bir şekilde yayınlanmayacaktır. Araştırma süreci bittikten sonra imha edilecektir. Sağladığınız veriler gönüllü katılım formlarında toplanan kimlik bilgileri ile eşleştirilmeyecektir.

Katılımınızla ilgili bilmeniz gerekenler:

Çalışmanızın günlük hayatta karşılaşılması muhtemel olağan risklerin ötesinde bir risk içermemektedir. Katılım sırasında sorulardan ya da herhangi başka bir nedenden ötürü kendinizi rahatsız hissederseniz cevaplama işini yarıda bırakıp çıkmakta serbestsiniz. Böyle bir durumda çalışmayı uygulayan kişiye, çalışmadan çıkmak istediğinizi söylemek yeterli olacaktır. Çalışma sonunda, bu araştırmayla ilgili sorularınız cevaplanacaktır.

Çalışmaya katılımınız, şu anda var olan sistemlerin ve gelecekte tasarlanacak olan yeni sistemlerin geliştirilmesinde bu araştırma sonucunda katkı sağlanabilmesi için önemlidir.

Araştırmayla ilgili daha fazla bilgi almak isterseniz:

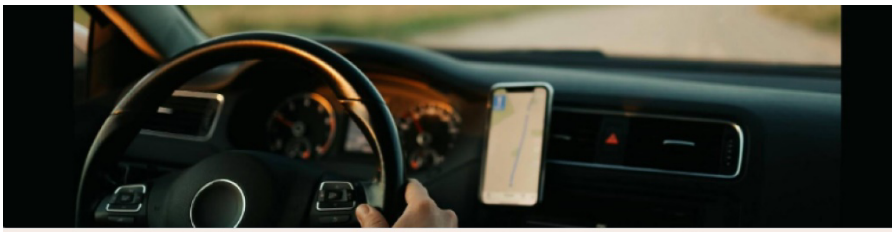
Bu çalışmaya katıldığınız için şimdiden teşekkür ederiz. Araştırma hakkında daha fazla bilgi almak için ODTÜ Endüstriyel Tasarım Bölümü yüksek lisans öğrencilerinden Selin Ayvalı ile aşağıdaki bilgiler yoluyla iletişim kurabilirsiniz.

Selin Ayvalı Danışman: Dr. Öğr. Üyesi Güzin Şen

Yukarıdaki bilgileri okudum ve bu çalışmaya tamamen gönüllü olarak katılıyorum.

İsim- Soy İsim Tarih ___/___/___ İmza

C. Questionnaire



Otonom Özellikleri Bulunan Araçların Sürüş Deneyiminde Güven Algısı: Geri Bildirim Tasarımlarının İncelenmesi

Merhabalar,

Adım Selin Ayvalı ve ODTÜ Endüstriyel Tasarım bölümü mezunu ve yüksek lisans öğrencisiyim. Yarı otonom özelliklere sahip araçlar ve kullanıcı deneyimi üzerine araştırma yaptığım tezim için **otonom özelliklere sahip araçları olan ve en az 2 yıldır aktif olarak araç kullanan** katılımcılar arıyorum.

Yarı otonom özelliklerden bazılarını aşağıda bulabilirsiniz.

- Adaptif hız sabitleme (Adaptive Cruise Control)
- Şerit takip / şerit ortalama (Lane keeping / Lane centering)
- Sürücü izleme kamerası (Driver Monitoring System)
- Seyir Kamerası (ADAS)
- Kör nokta tespiti (Blind Spot Monitoring)
- Çarpışma uyarısı (Collision Warning)
- Park asistanı (Parking Assistant)

Bütün özelliklere aynı anda sahip olunması zorunlu değildir.

Çalışma belirli bir rotada kendi aracınızla kısa süreli bir sürüş deneyimi sırasında gerçekleştirilecek bir sesli düşünme protokolü ve ardından kısa bir mülakat içerecektir.

Eğer sizde kriterlere uyduğunuzu düşünüyorsanız keyifli bir sürece katılarak araştırmama destek olmak ister misiniz?

Katılımınız ve desteğiniz benim için çok kıymetli. Değerli vaktiniz için şimdiden teşekkür ederim. Geri dönüşünüzü dört gözle bekliyorum.

Bilgilendirme
Formu: https://drive.google.com/drive/folders/1XT7xytBVxNW7FoU9MUoGcTBIys-cPokO

İletişim:

Selin Ayvalı

Çalışmaya gönüllü katılmayı kabul ediyorum. *

◯ Evet

◯ Hayır

Aracınızın marka ve modeli hakkında bilgi verebilir misiniz? *

Yanıtınız

Aracınız aşağıdaki hangi otonom özellikleri sağlamaktadır? *

☐ Şerit takip (Lane keeping)

☐ Şerit ortalama (Lane centering)

☐ Adaptif hız sabitleme (Adaptive Cruise Control)

☐ Sürücü izleme kamerası (Driver Monitoring System)

☐ Seyir Kamerası (ADAS)

☐ Kör nokta tespiti (Blind Spot Monitoring)

☐ Çarpışma uyarısı (Collision Warning)

☐ Park asistanı (Parking Assistant)

☐ Otomatik Acil Durum Freni (Automatic Emergency Breaking)

☐ Diğer:

Bu özellikleri ne sıklıkla kullanıyorsunuz? *

	1	2	3	4	5	
Nadiren	◯	◯	◯	◯	◯	Her zaman

Bu özellikler size nasıl bir deneyim sunuyor? Size göre güçlü ve/veya zayıf yönleri nelerdir? *

Yanıtınız

Yarı otonom veya otonom sürüş teknolojileri hakkında genel düşünceleriniz nelerdir? *

Yanıtınız

Bu teknolojilere karşı nasıl hissediyorsunuz? *

	1	2	3	4	5	
Kendimi hiç güvende hissetmiyorum.	◯	◯	◯	◯	◯	Kendimi fazlasıyla güvende hissediyorum.

Çalışmanın ikinci aşamasında içinde bulunduğunuz durum ve kullanıcı deneyiminiz hakkında yorumlarınızı sesli olarak araştırmacıyla paylaştığınız bir çalışma yöntemi olan sesli protokol yöntemi uygulanacaktır. Önceden belirlenmiş 5km-10 dakikalık bir rotada araç ile sürüş deneyimi gerçekleştirilecektir. Sonrasında kısa bir görüşme yapılacaktır.

Katılım için iletişim bilgilerinizi ilgili alanlarda doldurmanız beklenmektedir.
Bilgileriniz kimseyle paylaşılmayacaktır, sadece sizinle iletişim kurmak için kullanılacaktır.

Çalışmanın devamına katılmak istiyorum. *

◯ Evet

◯ Hayır

Adınız ve Soyadınız *

Yanıtınız

Telefon numaranız *

Yanıtınız

Mail adresiniz *

Yanıtınız

D. Think Aloud Protocol

Sesli Düşünme Protokolü

Araştırmanın amacı: Yarı otonom araçların sürücüler üzerindeki etkisini anlamak ve geri bildirim tasarımını iyileştirmek.

Süreç: Belirlenmiş bir rotada yarı otonom modda araç kullanımı.

Beklenti: Sürücünün düşüncelerini, hissettiklerini ve araçla olan etkileşimlerini sesli olarak paylaşması.

Bilgilendirme

Sizinle bir sesli düşünme protokolü uygulayacağız. Bu aşamadaki beklenti sizinle paylaşacağım rota boyunca yapacağımız sürüş esnasında düşüncelerinizi ve hissettiklerinizi sesli olarak paylaşmanız olacak. Bu süreçte, yaptığınız her aksiyonu ve aracın tepkilerini açıklamanızı rica edeceğim. Ara ara deneyiminizi daha iyi anlamak için ben de size bazı sorular sorabilirim.

Lütfen, yaptığınız her eylemi, aracın size verdiği geri bildirimi ve bu durumların size hissettirdiklerini detaylı bir şekilde aktarın. Örneğin, araçtaki şerit takip sistemi aktifken şeritte kalmanızı nasıl sağlıyor, şeritten çıkmaya yakın olduğunuzda veya şeridinizden çıktığınızda araç size nasıl tepki veriyor, bu gibi durumları deneyimlediğinizde hissettiklerinizi ve düşüncelerinizi paylaşın.

Tekrar belirtmek isterim, cevaplarınız anonim tutulacak olup, bütün katılımcıların cevapları ile birlikte değerlendirilerek raporlanacak ve herhangi bir yayında cevaplarınız isminizle eşleştirilmeyecektir.

Başlamadan önce son olarak rota ile ilgili ufak bir bilgilendirme yapacağım. Yolumuzda karışık bir kavşaktan geçiş, yola bağlanma sonrası hızlı sağa dönüş, yaya yoğunluğu olan okul bölgesi, trafik ışıkları, büyük kasisler gibi etkenler bulunabilir. Lütfen kendinizi, aracınızı ve çevreyi riske atacak manevralardan kaçının ve dikkatinizin öncelikli olarak yolda olduğundan emin olun.

Anlaşılmayan, daha detaylı açıklanmasını istediğiniz bir yer var mı?

Önce kısa bir soruyla başlayalım. Aracınızın arayüzünü biraz anlatabilir misiniz? Otonom özellikleri kullanırken araç size nasıl ve nereden bilgi veriyor? Hangi ekranda hangi uyarı ve/veya bilgiyi görüntülüyorsunuz?

Açıklamanız için teşekkürler. Hazırsanız şimdi yolculuğumuza başlayabiliriz.

Rota Linki: https://maps.app.goo.gl/REUJjQpVtSjjNpHw5

Katılımcıya sorulabilecek sorular:

Araç Kullanımı:

- Yarı otonom modda araç kullanırken düşündüklerinizi ve hissettiklerinizi açıklayın.
- Otomasyonun sürüş deneyiminizdeki rolünü nasıl anlatırsınız?
- Bu araçtan başka yarı otonom bir araç kullanım deneyiminiz var mıdır?
    - (Evetse) Otonom özellikler ve geri bildirim çeşitlerini düşünerek, bahsedilen aracın / araçların şu an sürmekte olduğunuz araca göre nasıl farklılıkları bulunmaktadır?

Geri Bildirim ve Etkileri:

- Araçtan gelen geri bildirimin sürüş deneyiminizi nasıl etkilediğini anlatabilir misiniz?
    - Araçtan gelen geri bildirimin hangi yönlerinin sürüş deneyiminize yardımcı olduğunu ve/veya olmadığını düşünüyorsunuz?

Karar Verme ve Güven:

- Belirli durumlarda aracın otomasyonuna güvenmek veya devre dışı bırakmak için nasıl karar veriyorsunuz?
- Araçtan gelen geri bildirimin sizi güvende hissettirdiği veya aracın yeteneklerine daha fazla güven duymanızı sağladığı bir anı anlatabilir misiniz?

Zorlayıcı Durumlar ve Başa Çıkma:

- Tam tersini düşünecek olursanız, aracın aldığı kararların veya araçtan gelen geri bildirimin kafa karıştırıcı/belirsiz olduğu bir durumu yaşadınız mı? Olduysa ne hissettiğinizi ve bu durumla nasıl başa çıktığınızı paylaşabilir misiniz?

Genel Değerlendirme ve Öneriler:

- Araçtan gelen geri bildirimin genel sürüş deneyiminizi nasıl etkilediğini düşünüyorsunuz? (Eğer yanıt alınamadıysa)
- Yarı otonom özellikleri kullanırken konfor ve güven düzeyinizi etkileyen faktörler nelerdir?
- Güvende hissetme ve sisteme karşı güven duygunuzu artırmak ve geri bildirim tasarımının tercihlerinize ve beklentilerinize daha iyi uyum sağlaması için hangi iyileştirmeleri önerirsiniz?

E. Semi-Structured Interviews

Sürüş Deneyimi:

- Sürüş sırasında araçtan gelen geri bildirimlerin sizi nasıl güvende hissettirip hissettirmediğini düşünerek bir örnek verebilir misiniz? Güven hissinizi artırıcı veya azaltıcı etkilerini fark ettiniz mi?
  Örnek durumlardan bahsedecek olursak
    - Yoğun trafikte veya karmaşık yollar üzerinde araç kullanırken nasıl bir geri bildirim tasarımı sizi daha rahat hissettirir?
    - Olumsuz hava koşullarında (şiddetli yağmur, sis, kar vb.) araç kullanırken hangi tür geri bildirimler sizi daha güvende hissettirir?
    - Kısıtlı zamanda bir yere ulaşmak istediğinizde aracın hangi tür geri bildirimleri size daha fazla güven verir?
    - Araç önüne aniden çıkan bir yayaya veya bir kaza durumuna nasıl tepki verdiğinizi ve aracın size nasıl geri bildirim sağladığını açıklar mısınız?
- Araçtan gelen geri bildirimlerin ne kadar hızlı ve doğru olduğunu düşünüyorsunuz? Örneğin, bir tehlike algılandığında araç nasıl tepki veriyor?
- Sizin bu geribildirimleri fark etmediğiniz / gözden kaçırdığınız oluyor mu? Sürekli dikkat etmenizi gerektiren bir durum var mı yoksa aracın sizi uyarış biçimi durumu fark etmeniz için yeterli mi?

Kullanıcı Deneyimi ve Konfor:

- Araçtan gelen geri bildirimlerin sürüş konforunuza etkisini nasıl değerlendirirsiniz? Bu konforu artırmak için ne tür geri bildirimlerin daha etkili olabileceğini düşünüyorsunuz?
- Uzun süreli sürüşlerde araçtan gelen geri bildirimlerin sizi nasıl etkilediğini ve konforunuzu nasıl artırabileceğini düşünüyorsunuz?

Tasarım Tercihleri ve İyileştirmeler:

- Geri bildirim tasarımında renklerin, simgelerin veya seslerin kullanımını ve bu bildirimlerin araç üzerinde verildiği konum, zamanlama ve bildirimin etki süresini nasıl değerlendirirsiniz?
    - Bu unsurların sürüş deneyimine etkisi hakkında ne düşünüyorsunuz?
- Geri bildirim tasarımının iyileştirilmesi gerektiğini düşündüğünüz alanlar var mıdır? Örneğin, geri bildirimde daha fazla bilgiye ihtiyaç duyduğunuz veya geç bildirim verildiğini düşündüğünüz durumlar var mı?

- Varsa bu durumlar nelerdir? Daha iyi bir deneyim yaratmak için bilgiyle, bilgiyi sunma şekliyle ilgili neyi değiştirirdiniz?
- Özellikle daha hızlı bildirim verilmesi gerektiğini düşündüğünüz durumlar var mıdır?
    - Neden böyle düşünüyorsunuz?

Teknolojiye Güven ve Kabul Edilebilirlik:

- Yarı otonom araçların geri bildirimlerine ve bu doğrultuda aldığı kararlara / aksiyonlara her zaman güveniyor musunuz? Neden?

Genel Değerlendirme ve Öneriler:

- Yarı otonom araçlardaki geri bildirim tasarımının gelecekte nasıl geliştirilebileceğini düşünüyorsunuz? Özellikle, yeni teknolojiler veya tasarım yaklaşımları hakkında ne düşünüyorsunuz?
- Eklemek istediğiniz başka bir şey var mı?

F. Original Quotations in Turkish

P0.1 *"Kendime daha çok güveniyorum diyebilirim. Bu sistemleri de yapanlar biz insanlar. Ne zaman düzgün çalışıp ne zaman hata verebileceğini biliyorum."*

P0.2 *"Sarıyla işaretlenmiş olan ani dönüş kısmı çok riskli bir yer…Etkili kör nokta uyarı sistemleriyle beraber bu kavşakta da daha fazla yararlı olabileceğini düşünüyorum."*

P0.3 *"Tabii burada patinajı önlemek amacıyla kendisi bir sistem devreye soktuğu için görsel ortaya çıkıyor. Bundan dolayı tabii ki de daha güvenli hissettiriyor."*

P0.4 *"Sarıda daha dikkatli bir şekilde yaklaşmam gerektiğini, kırmızıda ise hızlı bir şekilde yaklaştığımı ve çarpma riskinin oluşabileceğini anlamlandırıyorum ben."*

P0.5 *"Araçta kullanılan dil emir kipi ve kısa bir şekilde olması hem karmaşıklığı engelliyor hem de okunurluğu kolaylaştırılıyor. Bundan dolayı kısa, net, emir kipindeki bildirimlerin daha doğru olduğunu düşünüyorum."*

P0.6 *"Uzun yolda kullanmak konforumu arttırıyor bence."*

P0.7 *"Otonom araçlar ilk gördüğü etkiye karşı bir tepki verecektir. Sonuçlarını, daha sonrasını insana gibi değerlendirip, analiz ederek doğru kararı verebileceğini düşünmüyorum."*

P1.1 *"Daha teknolojik araçlar kesinlikle konforu ve güveni arttırıyor."*

P1.2 *"Çevresi hakkında bilgi verdiği için güvenim artıyor."*

P1.3 *"Araçtan gelen geri bildirimlerin çoğu gerçekten hem gerçekçi hem doğru hem de etkileyici bir şekilde sizin güvenliğinizi sağlıyor, öyle söyleyeyim yani.*

P2.1 *"Çok fazla yağışta zaten ADAS devreye girmiyor. Radarın önünde bir şey var diyerek devreye girmiyor."*

P2.2 *"Mesela ani fren yapması gerekince kırmızı yakıyor, onun sesi falan daha farklı daha yüksek."*

P2.3 *"Kullandıkça alışıyorsunuz neyi algılayıp neyi algılamayacağına."*

P3.1 *"Eskiden tamamen insan odaklıydı. Şimdi biraz daha makine ya da yapay zeka odaklı oluyor. Eskiden full-dikkat araba kullanmaya gerek yokken artık o kadar da dikkat etmeniz gerekmeyebiliyor. Sistemler sizi uyarıyor."*

P3.2 *"Önce güvenmeye çalışıyorum. Güvenmediğim ya da hoşuma gitmeyen noktalar varsa artık iptal ediyorum."*

P4.1 *"…bazen bir viraja geliyor ama virajın ortasında artık kendi başınasın dediği olabiliyor bazen. O an sürpriz yapıyor baya."*

P4.2 *"Ama Türkiye'de sağ olsun en ufak boşluğa sürücüler girdiği için, o çok fazla şey içinde iş yapmıyor… Uzun yolda ben daha çok kullanıyorum. İstanbul'a giderken direksiyonu bırakıyorum bazen Instagram'da reels izlediğim falan oluyor."*

P4.3 *"Verdiği bildirimleri ben anlıyorum ama mesela çok anlamayan biri için o kadar da açık anlaşılır olabilir mi? Bilemiyorum. Mühendis olduğumdan terimlere de daha çok aşinayım. Ne yapıyor ne ediyor. İşin artısını, teknolojiyi bildiğimden de ne tepki vereceğini az çok kestirebiliyorum."*

P5.1 *"Bu alet sağındaki arabadan kaçmayı bilmiyor. Henüz bilmiyor. Öğrendikten sonra belki çok daha iyi olduğunda o zaman mantıklı olabilir."*

P5.2 *"Şerit değiştirirken özellikle hızlı gittiğimiz yollarda kör nokta uyarı sistemi insanı çok kazadan kurtarabilir. Bu epey güven veren bir sistem benim için."*

P5.3 *"Görsel ve işitsel bildirimler direksiyonu kontrol etme ile birlikte çok başarılı. Şeritten taşarken, şerit ihlali yaparken tutuyor direksiyonu riski durumları önlemek için. Bu üç geribildirimin kombinasyonu gayet makul şeyler. Onun haricinde uyuyan bir sürücüyü uyandırmak emniyet kemeri sıkma ya da direksiyon titretmek de çok güzel geri bildirim oluyor."*

P5.4 *"Adaptif hız sabitleme veya lane keeping asistanı uzun yolda giderken çok daha kullanışlı oluyor. Arabadan indiğimde, varacağım yere vardığımda çok daha az yorgun oluyorum. Bu bir avantaj."*

P6.1 *"Infotainment ekranında üst tarafa uzun bir yazı geliyor ve bir tane kırmızı sembol çıkıyor. Yazıda 'Aracınızın hızı sınırlandırılmıştır, kaldırmak için buraya dokunun' yazıyor. Bu uzun bir uyarı. Ve bunu hızlı bir şekilde park etmeye çalışan biri okumaz. Ve ona bastığınız zaman araba normale dönüyor. Basmazsanız araba çok yavaşlıyor ve bu kullanılabilirlikten çıkıyor. Orada bence deneyimi olmayan veya orayı okumayan daha panik sürecek. Muhtemelen çok sıkıntı yaşayacak."*

P6.2 *"Yoğun trafikte genelde etrafımızdaki çok fazla noktaya dikkat ettiğimiz için cluster a gelen görsel bir uyarı yeterli olmayabilir."*

P6.3 *"Aracı ilk aldığımda bunları deneyimlerken, uzun yola çıkmıştım ve ışıklarda durup kalkarken bir anda fren yaptı. Bu kötü bir tecrübeydi. Hiç beklemediğim bir anda gereksiz bir yerde fren yaptı."*

P7.1 *"Çünkü yarı otonomu açınca genellikle telefon kullanımımızı arttırıyoruz. Bildirim gelince daha rahat bakıyoruz. Sisteme güvenmek istiyoruz içten içe. Hani gidiyor işte, yarı otonom. Ben şu mesajı bir okuyayım."*

P7.2 *"…Lazer işareti geldiğinde lane centering demek yani ben seni o lazer çizgisi üzerinde ilerletiyorum demek oluyor. Öndeki araba da çıkarsa o da senin Adaptive Cruise Control'ün devrede diyor. İkisini beraber kullandığında zaten yarı otonom sistemi devrede demek. Şu an kendisi gidiyor."*

P7.3 *"Burada otomotiv sektöründe yorgunluğu belirten tell-tale denilen bir şey var. Halbuki bence burada bir false positive var. Yorgunluk değil de sürücü dikkatsizlik uyarısı olmalıydı."*

P8.1 *"Konforumu kesin arttırıyor, su götürmez bu gerçek yani. Birçok şey artık düşünmekten uzaklaşıyorsun. Kendi kendine bazı şeyleri yapmış oluyor."*

P8.2 *"Çok iyi çalışan ama çok kötü arayüzü olan bir web sitesi gibi düşün. Araç da aynı şekilde. Çok iyi çalışabilir ama bunu sana kötü yansıtıyorsa ya da tam olarak neler başarabildiğini ifade edemiyorsa hiçbir anlamı yok yani... İyi de çalışsa, kötü de çalışsa bunu iyi bir şekilde ifade eden bir sistem çok daha iyi benimsenecektir. O yüzden de burada bu geribildirimler benimseme açısından güvenimin %70'ini falan olarak düşünüyorum yani."*

P8.3 *"Uzun süre hız sabitleyiciyle gidince tepkilerimin yavaşladığını düşünerek bir kahve ikonu gösteriyor ve mola veriniz yazıyor. Arabayı durdurup başlattığında bile geri geliyor. Arabanın kapalı geçen bir süresi olması gerekiyor. Mesela şoför değiştirmiş olabilirim bu durumda rahatsız edici oluyor. Şehir içi sürüşlerde de 5 dakikada bile sinyalsiz şerit değiştirmelerde yorgunluk uyarısı veriyor. Dikkatsiz dese anlayacağım ama yorgun demesi yanlış ve gelecekteki kararlarını sorgulamama sebep oluyor."*

P8.4 *"Açıkçası şöyle bir iyiliği var, sesi yaklaştığım yere göre veriyor. İşte mesela sol arkaya yanaşınca bu sefer de sol arkadan verecek sesi. Sesi dağıtması çok iyi bir yeri bildirim. Sese göre bir yerden vermesi."*

P8.5 *"Onda da mesela hız sabitleyiciyi açtım, şerit takibi de açtım…ileride bir yerde şerit bitiyor ya da şerit tanıyamayacak bir yer oluyor. Orada mesela şeridi bulamadığını ben araba şeritten çıkınca anlayabiliyorum."*

P8.6 *"Şeritler kaybolduğunda 'Aa ben bulamadım' diyor. Ondan önce vermesi lazım. En azından bir tepki süresi olacak kadar. Yoksa kaza yapabilirim."*

P8.7 *"Burada ayarlarda sesi istediğim gibi ayarlayabiliyorum. Ya da kişiselleştirebilirsin. Mesela bildirimleri hiç söyleme ya da şu durumda söyle diye seçebiliyorsun. Bir de hangi özelliklerin açık olacağını seçebiliyorum. Bana böyle bir iyiliği var."*

P8.8 *"Uzun yolda insan belli bir süre sonra sürüş körlüğü denilen bir hipnoz durumuna geçtiği durumlarda özellikle. Gerçekten çok işe yarıyor. Yani bir bakıyorsun şeritte aslında ben geziyormuşum ya da şeridin dışına çıkıyormuşum gibi durumlarda kontrolü ele alıyor."*

P8.9 *"Mesela bir gün daldım. Müzik seçiyordum. Öndeki akan trafik durmuş. Ben görmedim durduğunu ve engel saptandı yazdı sağ ekranda büyükçe. Frene bastı, ben de kafamı kaldırdım bastım ama o basmasaydı ben büyük ihtimalle çarpardım. Bir şeye bakıyordum, dalmıştım."*

P8.10 *"Trafik işareti tanıma konusunda biraz fazla bağırıyor. Bir tabela denk geldiğinde ve ben hızı geçtiğimde göreceksin ısrarla bana bir sesli uyarı veriyor. O böyle biraz şey çok ergonomik olmadığını düşünüyorum. Bazen işaret doğru olmayabilir ya da o an o hızda sürmek için koşullar uygun olmayabilir."*

P9.1 *"Yani onu bana hissettirdi. Eğer ki benim kontrolümde olmayan bir şey olursa kendi durduruyor. O gün bunu daha net anladım. Kazadan korudu beni."*

P9.2 *"Her türlü uyarı, özellikle de gerektiğinde, bu tek ekranda zamanında beliriyor. Gereksiz uyarılar vermiyor... İçimi rahatlatıyor. Göremediğim arabaları bile algılayıp ekranda gösteriyor ve olası tehlikelere karşı beni uyarıyor."*

P9.3 *"Herhangi bir araç fren yaptığı zaman onu da algılıyor buradan. O güzel bir şey. Seni ona göre uyarıyor... Buradan kırmızı olup, bak şu arabalar mesela frene basmışlar görüyor musun? Gerçekten basmışlar. Kapısını açsa kapısının açıldığını görüyorsun buradan. Onu da algılıyor… Trafik ışığının yeşil olduğunu görüyor. Her şeyi görüyor buradan. İnsanların yürüdüğünü görüyor… Yani bu sistem çok güzel bence... Seni çoğu anlamda zaten birçok noktada koruyucu oluyor. Sen bir şeyi kaçırsan o kaçırmıyor yani."*

P9.4 *"Düzenli olarak yazılım güncellemesi alıyor Tesla. Bütün bu müşteri şikayetlerini, şu şöyle olsaydı dediğim çoğu şey aldığımdan beri sürekli güncellendi. Bu güncellemeleri otomatik olarak yapıyor ve kolay olmasında çok memnunum. Mesela buradaki araç görselleştirmesi büyük bir güncelleme geldikten sonra çok gelişti hatta manşetlere bile çıktı. Çok profesyonel."*

P9.5 *"Bazen farklı uyarılar veriyor ama yani önemsiz, her bildirime de bakmıyorum orada ya. Çok fazla çünkü. Güvenliğimi ilgilendiren bildirim olduğunda, bakıyorum. Nedir bu? İşte lastik basıncı düştü mü? Önemli. Araba çünkü lastikler üzerine gidiyor. Onun dışında da böyle kaza falan olursa bakarım. Onun dışındaki her bir yere de bakmıyorum yani. Çok o kadar zihnimi meşgul etmek de beni mutlu etmiyor yani."*

P9.6 *"Çocuğum var. O açıdan güvenlik benim için önemli. Ailemle seyahat ediyorum çoğu zaman… Hani adamlar ciddi anlamda güvenliğe önem veriyorlar. Yani kendimi güvende hissediyorum. Kendimi de ailemi de mümkün olduğunca güvende hissediyorum yani."*

P9.7 *"Medyadan takip ettiğim kadarıyla bir kazası var böyle saçmaladığı Tesla'nın. Video görüntülerini de izledim, araç beyin arızası yaşamış ve gelip sağı solu parçalayarak gitmiş. Bir tane. Şimdi milyon tane aracın içerisinde bir tane olabiliyor. Uçaklar da bakımları yapılmazsa, kötü kullanılırsa düşebiliyor. Yani milyonda bir olabilecek bir risk. O yüzden bunu kabul ediyorum."*

P10.1 *"Bir tık daha erken bildirim veya kademeli bildirim gelebilir. Direkt olay panik anında değil de daha önceden bir risk durumu sezilip daha erken uyarı sistemleri olursa tabii ki daha iyi olur diye düşünüyorum."*

P10.2 *"Mesela Sürücü Yorgunluk Algılama Sistemi DMS ile birlikte özellikle uzun yolda herhangi bir dalgınlık, yol hipnozu veya uyuma durumunda hem sesli hem de titreşimli uyarılar vererek bizim olaya farkındalığımızı arttırarak herhangi bir kaza durumunda bizi koruyor. Onun dışında akıllı şerit takip sistemleri yine bir dalgınlıkta şeritten çıktığımız zaman arabayı yolda tutuyor ve kazayı önlüyor."*

G. Feature Definitions

ACC	Adaptive Cruise Control	Automatically adjusts speed while maintaining a safe distance from the vehicle in front.
ADAS	Advanced Driver Assistance Systems	The general name for safety and comfort technologies that assist the driver.
AEB	Automatic Emergency Braking	Break the vehicle automatically when a collision risk is detected.
AP	Automatic Pilot	Allow the vehicle to drive autonomously in certain conditions.
DDAW	Driver Drowsiness and Attention Warning	Detects when the driver is drowsy or inattentive and issue a warning.
DMS	Driver Monitoring System	Monitors the driver's attention and behavior with cameras.
Infrared & Thermal Sensors	-	Detects pedestrians/objects at night or in poor visibility using heat and infrared sensors.
LDWS	Lane Departure Warning System	Warns the driver when the vehicle begins to drift out of its lane.
LIDAR	Light Detection and Ranging	Creates a three-dimensional map of the surroundings using laser beams. It is less affected by weather conditions than sensors.
LKA	Lane Keep Assist	If the vehicle drifts out of its lane, it makes small steering adjustments to help it stay in its lane.
LRR	Long-Range Radar	Detects vehicles and obstacles at a distance.
LVDA	Lead Vehicle Departure Alert	Warns the driver when the vehicle in front moves.
PA	Park Assist	Help the vehicle automatically execute parking maneuvers.
RCCA	Rear Cross-Traffic Collision Avoidance Assist	Detect vehicles approaching from the side during a reversing maneuver and apply the brakes if necessary.
RVC	Rear View Camera	Projects the rear-view image onto the screen.
Software Developments and Algorithms	-	Software and computing methods that enable autonomous systems to operate.
SRR	Short-Range Radar	Detects objects and vehicles at close range.
SVC	Surround View Camera	Projects a 360° view of the vehicle's surroundings onto the screen.
Stereo Camera	-	Measures distance using two cameras to provide depth perception.
TJA	Traffic Jam Assist	Provides automatic steering, braking, and acceleration support at low speeds in heavy traffic.
TSR	Traffic Sign Recognition	Detect traffic signs on the road and display them to the driver.