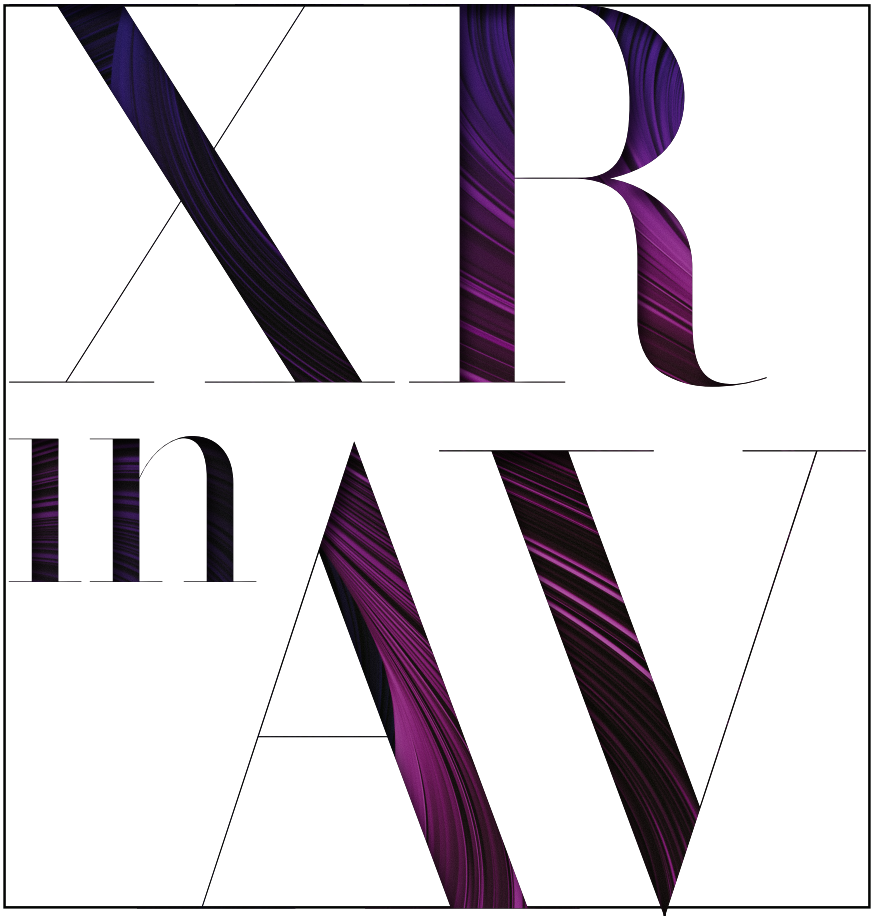


# ARCHITECHTURING THE JOURNEY

SPECULATING INTEGRATION OF
IMMERSIVE TECHNOLOGIES IN
AUTONOMOUS DRIVING

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MSc Integrated Product Design
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**ARchitecturing the journey:** speculating integration of immersive technologies in autonomous driving

**Masters degree thesis**
Integrated Product Design
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*“ I love combining mind and action for creating beautiful experiences for heart!”*

# Executive summary

Immersive technologies are redefining user interactions in the evolving digital landscape, promising deeper and almost physical digital experiences (Alpers et al., 2020). Concurrently, the mobility world is undergoing a paradigm shift, with an emphasis on advanced autonomous solutions. Such autonomy enables users to reclaim and repurpose their commuting time, fundamentally altering how people interact with their vehicles and ushering in an era of enhanced on-road experiences.

Mercedes-Benz hopes to be at the epicentre of these tectonic shifts by incorporating immersive technologies into their upcoming fleet. Their goal is to fundamentally transform user experiences, not just technological ones. Realising this ambitious vision, however, necessitates an in-depth exploration of this domain to ensure that the proposed innovations provide tangible value to end-users. This thesis delves into the complexities of such plausible futures, focusing on users' perceptions and expectations of these technological interventions.

This thesis combines speculative design and context mapping methodologies in a synergistic manner. The former allows users to empathise with potential realities by facilitating the creation and exploration of future scenarios. Context mapping, on the other hand, deepens our understanding of user needs, concerns, and aspirations, resulting in more nuanced and resonant solutions.

The thesis begins this investigation by delving into the theoretical underpinnings of XR in AVs, focusing on the intersections of autonomy and immersion levels. Following trend and stakeholder analysis, the existing tensions in this space were revealed. Five meticulously crafted future scenarios sparked conversations with selected participants during context mapping sessions. Thematic analysis revealed shifting vehicle perceptions, the changing nature of space within autonomous vehicles, and the criteria for successful XR integration in AVs. This process also shed light on the specific dynamics and implications of the tensions highlighted in the scenarios. As a result, some tensions were validated, new values emerged, and inherent biases towards certain values became evident.

Unsurprisingly, safety emerged as the top priority, with tensions especially high during control negotiations between systems and users, i.e. in Takeover (TO) scenarios. To address this criticality, the research focused on creating an ideal TO journey, with the goal of seamlessly transitioning a user from an immersive state to assuming vehicle control, all while minimising safety-related concerns. This design process, which was subjected to expert scrutiny, resulted in a comprehensive experience map and a detailed video elucidating the TO experience, capturing the intricate dynamics of user-system interactions.

The feedback from these expert consultations not only validated but also enriched the research, pointing out areas for further investigation and refinement. The resulting experience video was useful in focus group sessions, allowing the research team to identify elements that resonated and those that needed to be reconsidered.

Finally, the thesis emphasises the importance of collaborative problem-solving by highlighting key tensions, most notably the delicate balance between immersion and safety. Furthermore, it lays out a strategy for future research in this area, emphasising the robust potential of speculative design as an invaluable research tool, particularly in corporate settings. This study provides a blueprint for how companies like Mercedes-Benz can navigate the convergence of immersive technologies and autonomous vehicles, ensuring a future in which technology enhances, rather than dictates, the human experience.

# Reading Experience

This report has been meticulously structured to cater to diverse reading needs. Recognizing that our **span of audience from those newly acquainted with the subject matter to seasoned experts**, we've introduced a unique feature to enhance the reading experience.

**Introducing the 'Jump To' Feature:**
Understanding that time is of essence and clarity is paramount, especially for our expert readers and busy stakeholders from teams like Mercedes Benz, we've embedded 'Jump To' buttons throughout the report. These buttons are designed to allow readers to swiftly navigate between sections, enabling them to skip parts they're already familiar with and directly access the parts they're most interested in. This ensures a seamless reading journey while preserving the overarching narrative.

1. **Novice readers** will benefit from the detailed insights provided, granting them a holistic understanding of the emerging space.
2. **Internal teams from Mercedes Benz**, will find this report as a foundational and inspirational tool for design methodology and embedded design research. It not only serves as a knowledge base but also as a collaboration touchpoint for various teams, ensuring they are well-prepared for the presented future. For those keen on the intricacies of design choices and methodological nuances, some chpaters go in detail to recreate the methods and final design.
3. **Experts and supervisors** have the flexibility to use the 'Jump To' buttons, allowing them to bypass known information and delve straight into the heart of the matter, ensuring a focused and efficient read.

RX

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## List of Abbreviations

**SD:** Speculative Design
**AV:** Autonomoys Vehicles
**LOA:** Levels of Autonomy
**TO:** Take Over
**TOR:** Take Over Request
**ODD:** Operational Design Domain
**SAE:** Society of Automotive Engineers
**XRinAV:** Extended reality in Autonomous Vehicles
**XR:** Extended Reality
**AR:** Augmented Reality
**MR**: Mixed Reality
**VE:** Virtual Experience
**LOI:** Levels of Immersion
**MB.OS:** Mercedes-Benz Operating System
**HMI:** Human Machine Interactions
**HCI:** Human Computer Interactions
**HAI:** Human Automation Interaction

# 1 PROJECT INTRODUCTION

*This chapter presents the starting assignment for this graduate project, as well as an explanation of the project approach. The background and explanation of the problem are discussed, emphasising the significance and relevance of the research. This thesis's beginning point is specified, followed by a clear definition of the project's scope and purpose. The major project stakeholders are also introduced. This chapter provides a visual overview of the project's activities, as well as the project and report structure, thus laying the groundwork for the rest of the thesis.*



## 1.0 INITIAL ASSIGNMENT

### Context and Problem definition

The automotive industry is currently undergoing a significant transformation, primarily influenced by advances in computing and artificial intelligence (AI). The ongoing transformation process represents a shift from viewing vehicles solely as modes of transportation to viewing them as intricate and interactive environments capable of providing enhanced passenger experiences (Alpers et al., 2020).

The rise of self-driving cars (AVs) has resulted in an intriguing phenomenon: the reclaiming of passenger time. The concept of 'gained time' presents automakers with both a challenge and an opportunity. The primary challenge is transforming traditional transportation spaces into environments that encourage meaningful interaction. The potential, on the other hand, lies in utilising the time saved by these transformations to provide comprehensive experiences that go beyond the mere act of commuting (Kim et al., 2015).

Mercedes-Benz, a company well-known in the automotive industry for its innovative approach, is strategically positioned at this juncture. The company's recent collaborative efforts, particularly the development of MB.OS in collaboration with Nvidia-Omniverse and Google, demonstrate a strong commitment to creating exceptional passenger experiences and capitalisation on the integrated digital ecosystems. Mercedes-Benz, as one of the forerunners in the implementation of level 3 autonomy, is not solely focused on advancing autonomous capabilities. Instead, the company is integrating immersive technologies with great ambition, effectively combining physical and virtual elements.

Nonetheless, incorporating artificial intelligence (AI) and extended reality (XR) in future Autonomous Vehicles (AVs) poses a slew of complex challenges. The incorporation of XR in AV raises significant concerns about safety, regulation, and the ability to respond in real-time. Furthermore, when it comes to ethics, it is critical to thoroughly investigate the consequences of integrating immersive experiences with AI-powered vehicles. There is a need to thoroughly analyse the potential effects on society, specifically the wider implications on user confidence, personal information security, and the overall cultural implications of these advancements (Alpers et al., 2020).

Contemporary interventions in augmented reality (AR) and extended reality (XR), primarily driven by technological push, appear to overlook thorough evaluations that prioritise user needs and experiences. As the complexity of vehicular systems increases, as does the integration of intricate extended reality (XR) interfaces, it becomes increasingly important to fully grasp and comprehend this intricacy. One might wonder how users navigate through this amalgamation. To what extent does the experiential reality correspond to the technological assurances made available to individuals?

The project is positioned at a critical juncture. The purpose of this research is to critically analyse and elucidate the strategic aspects of XR interventions in the AV environment, with the goal of comprehensively evaluating and mapping the intricate nature of these complexities. The primary goal is not solely to innovate, but to provide stakeholders with a comprehensive understanding of the field. As Mercedes-Benz investigates this new field, the goal of this research is to gain a solid understanding, allowing for well-informed and strategic progress in the coming years. In order to shift from a primarily technocentric to a more user-centric approach, an important question arises:

***How might we design safe & meaningful XR interventions for users (in in-journey experiences) with different levels of immersion and autonomy?***

# Scope and Focus

## Objective

In the changing automotive and technological landscape, the thesis project seeks to understand the nature and perception of Extended Reality (XR) interventions in autonomous vehicles. This in-depth investigation looks at technology, interventions, and the effects they have on changing user roles and relationships.

Understanding user perceptions is critical to this study. Surfacing individual and societal interpretations of the values, meanings, and concerns of A(X)R interventions is a primary goal. Such foresight is critical for understanding technology adoption and roadblocks.

The safety of the user is critical as well. As a result, this study emphasizes the importance of designing interactions that seamlessly transition between autonomy and immersion. When transferring control from the autonomous vehicle to the human user, such interactions are critical. We attempt to surface and address the potential value dichotomies that might emerge as a result of this brave new world of immersive commuting.

In the thesis, speculative design is used to visualize and assess the benefits and drawbacks of combining immersive technologies with autonomous vehicles. This speculative approach to HCI and automotive research is more than just theoretical. To encourage critical thinking, it poses future scenarios, makes design recommendations, and illuminates ethical issues. This study also aims to demonstrate the significance of speculative design in HCI (in the automotive industry). We intend to shape the conversation about how technological advances, such as A(X)R interventions, can reimagine commuting and make the future thoughtful and innovative.

## Scope

The focus of this research project is on in-car (in-journey) experiences at the intersection of Autonomous Vehicles (AVs) and Extended Reality (XR), specifically Augmented/Mixed Reality (A/MR). While quantitative research has traditionally dominated the mobility sector (Nastjuk et al., 2020; Penmetsa et al., 2019), this project focuses on understanding user perceptions through a strictly qualitative approach. It positions itself as a middleman, translating user feedback to development teams. The scope, however, will not extend to quantitative analysis, exhaustive socio-economic implications, real-life user testing, or comprehensive implementation strategies, as these lie outside the study's parameters.

The scope of this thesis project revolves around conducting a qualitative research study on in-car experiences at the convergence of Autonomous Vehicles (AVs) and Extended Reality (XR), specifically Augmented/Mixed Reality (A/MR). Utilising speculative design and context mapping sessions, the project delves into the creation and exploration of potential future narratives. In doing so, it facilitates an in-depth examination of user perceptions, beliefs, and concerns linked to these immersive commuting experiences.

People haven't experienced autonomous vehicles (at various levels of autonomy) and immersive technologies in combination. This impacts the capacity of forecasting and user insight studies to account for people's future needs (Lindgren, T, et al, 2021). Developing insights and foresights into the contextual and evolving aspects of how AD and Immersive technology integrates in everyday life is essential, which demands for novel methodologies that allow for confrontation and generation during investigation.

The project employs speculative design methodologies to investigate potential interactions and interventions between the vehicle and its occupants. Though it doesn't aim to evaluate the feasibility of these interventions in terms of implementation, it seeks to ground its findings in plausible future scenarios, providing valuable insights to inform design decisions.

In essence, the scope of this thesis project is geared towards providing a comprehensive qualitative understanding of user experiences, perceptions, and concerns within the context of AVs and immersive technologies, while also informing design decisions.

***Future customer softwares innovation team (R&D)***

This team is the main project collaborator. The situated in R&D team researches future research directions and device strategies. The research focuses on creating seamless and unique consumer experiences through technological innovations. They also collaborate with other departments to inform the company's overall strategy.

The supervisory team and I were both heavily involved. Future customer softwares innovation team is the project's owner. The project also integrates several researchers and experts from fields like Human- Automation collaboration, human factors, regulations etc. to build real understanding of the emerging space.

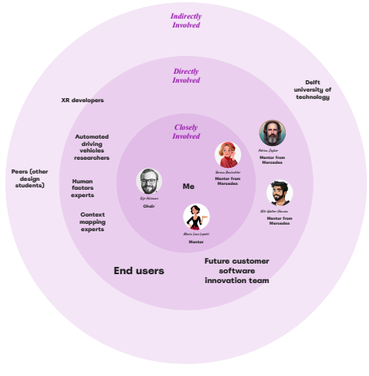



*Fig. 1.1. A high-level overview of the stakeholders in this graduation project.*

# 1.1 PROJECT APPROACH

### Phase 1: Understanding

During this foundational phase, extensive research was conducted to delineate the broad spheres encompassing XR (Extended Reality) and AVs (Autonomous Vehicles). This entailed a thorough examination of the theoretical frameworks of LOAs (Levels of Automation) and LOIs (Levels of Immersion). The primary domains shaping the technological landscape, as well as the dominant narratives emerging within it, were identified and mapped. Concurrently, stakeholders with distinct goals were identified. Understanding user interests and the implications was given special attention in stakeholders analysis. This mapping revealed the intersection of XR within AVs (XRinAVs), which subsequently directed the subsequent 'speculating' phase. This stage also solidified understanding of the chosen methodology, reinforcing the importance and urgency of the thesis.

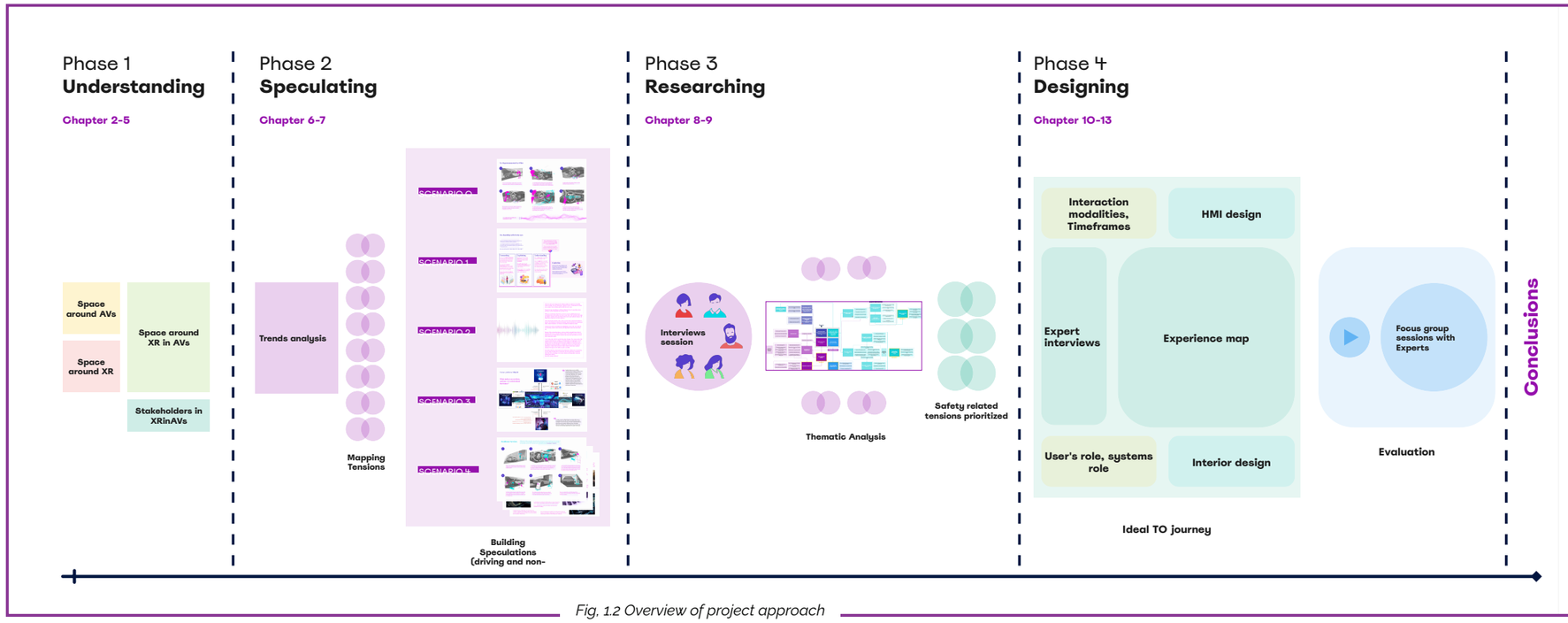



*Fig. 1.2 Overview of project approach*

### Phase 2: Speculating

In this section, we set out on a methodical journey to speculate the potential evolution of the XRinAV space, guided by the underlying dynamics of AV and XR trajectories. A thorough trend analysis, in conjunction with stakeholder insights, highlighted driving forces and inherent tensions (like immersion vs. safety, immersion vs. privacy, and integration vs. distraction) in the emerging space. These tensions are implicitly and explicitly used to craft the speculations. The emerging speculations are firmly anchored in this analysis, ensuring their plausibility and relevance to the key stakeholders. This phase resulted in the creation of five thought-provoking scenarios that captured the interventions with XR in both driving and non-driving contexts.

### Phase 3: Researching

Having crystallised speculations, the focus shifted to employing them as conversational tools in context-mapping sessions with the end-users. An exhaustive thematic analysis, after intensive user interviews, enabled the charting of tension dynamics and perceptions surrounding AVs and XRinAVs. From this emerged foresight regarding user desires, anticipations, and reservations. We also pinpointed the conditions essential for the mainstream acceptance and adoption of AVs and XRinAVs in both driving and non-driving situations. This research phase unearthed user perceptions of XR interventions in commuting. This understanding subsequently dictated which tensions and pivotal HMI (Human-Machine Interaction) facets were to be spotlighted in the designing phase. Given the paramountcy of safety, it was chosen as a central theme, especially after consultations with industry experts and clients.

### Phase 4: Designing

A key finding was that safety tensions rise during control negotiations between the system and its users, which is especially noticeable in Takeover (TO) scenarios. This phase's design approach was centred on creating an ideal TO journey. The goal was to transition a first-time user from an immersive state to vehicle control while removing safety-related tensions. Expert interviews were facilitated to endorse the design direction and enumerate the primary challenges inherent in the design space, ensuring the design's robustness and depth. This feedback enriched our exploration, resulting in a detailed experience map. The creation of a detailed video capturing the intricate experience and interaction dynamics during TO was the pinnacle of this endeavour. The user's role, the system's contribution, and the communication imperatives across phases were all rigorously examined. Furthermore, interaction modes and phase timeframes were carefully evaluated in order to boost the TO's credibility. This video served as a lynchpin in focus group sessions, allowing for the identification of what resonated and what did not. These assessments paved the way for tangible insights and charted the course for future research endeavours.

Finally, our findings and their inherent limitations are discussed, serving as a springboard for future research.

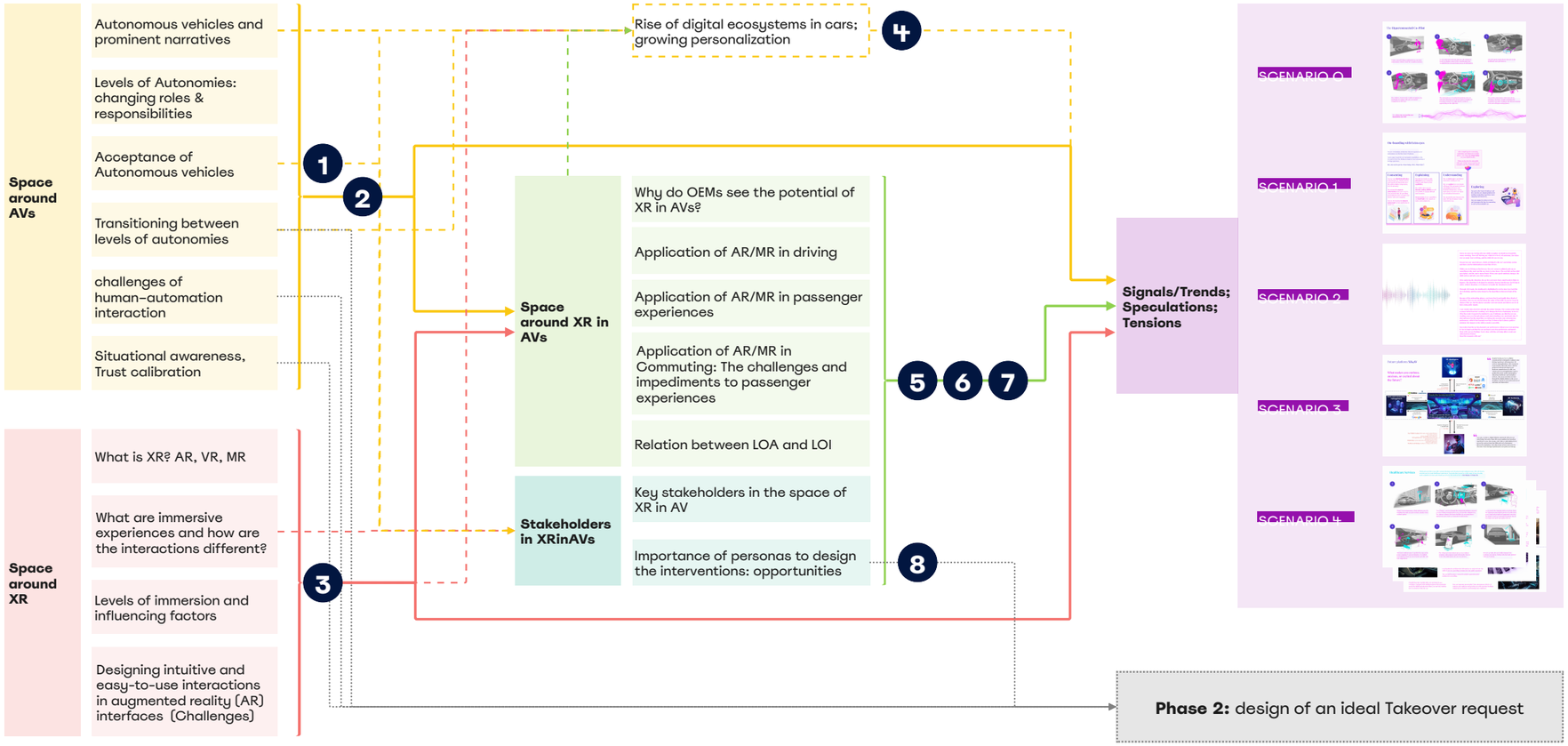
UNDERSTANDING

## Motivation

The goal of the literature review on Autonomous Vehicles (AVs) and Extended Reality (XR) was to gain a thorough understanding of their respective landscapes and forecast their collective potential. The review aimed to map out the dominant area for trends analysis, identify key stakeholders, and anticipate strategic speculation to understand the unique dynamics of the emerging XRinAV space. The review considered both systemic and personal (for users) implications, keeping the user and the technological interface at its core, with a distinct focus on user experiences within private AV markets. The literature review was extensive to understand the deep drivers of the space and how certain futures will turn plausible. Research for understanding key drivers and trends, literature from journal articles, company reports, statistical reports, academic reviews, theses, news and government publications was used. Whereas to understand the theoretical dynamics of AV and XR space empirical or practice-based Literature was used.

## Overview

comprehensive analysis of both the AV and XR spaces was performed, followed by their subsequent integration. The research procedure includes the depiction of the flowchart shown in figure below. The key insights, which are also visually represented, inform the project's subsequent stages. The primary findings are found near the end of the literature review.



# SPACE AROUND AUTONOMOUS VEHICLES

*In this chapter, we lay the groundwork for understanding Autonomous Vehicles. We begin by delving into the dominant narratives surrounding self-driving cars in society and industry. Following that, we investigate the acceptance of autonomous vehicles using technology acceptance models, which reassures the need for thesis. We also talk about the various levels of autonomy and the taxonomies that go with them. Finally, we emphasize the importance of trust in autonomous driving.*

## 2.0 AUTONOMOUS VEHICLES

The rise of self-driving cars (AVs) is a major turning point in the history of transportation. As the result of improvements in many different areas of technology, AVs promise to change the way cities look, change the way people move around, and usher in a new era of transportation solutions. Their rise isn't just a technological revolution; it's also a cultural and social change that requires a deep understanding of how they work, how their infrastructure works, and the many different fields that support them.

# What are autonomous vehicles?

Autonomous vehicles, commonly referred to as self-driving cars, are specifically engineered to autonomously navigate and function within various environments, without the need for direct human intervention. They combine complex hardware systems with advanced software to perceive their environment, make decisions based on data, and carry them out immediately. Autonomous vehicles (AVs) function by engaging in a perpetual cycle of sensing, processing, decision-making, and actuation.

## Technological Domains Underpinning AVs

Autonomous vehicles (AVs) represent the convergence of cutting-edge technologies (Biswas & Wang, 2023). Their systems' core components include LiDAR technology for precise three-dimensional mapping, radar and cameras for environmental interpretation, and ultrasonic sensors for in-depth analysis of nearby objects (Wood and Mohammadi, 2015; Campbell et al., 2018). These vehicles, which are equipped with Vehicle-to-Everything (V2X) connectivity, can interact with external entities ranging from other vehicles to infrastructure. Individual decisions are supported by adaptive machine learning algorithms that are designed to improve their learning and predictive capabilities (Kim and Shrestha, 2020). Blockchain technology improves the integrity and transparency of their data systems, while AI-powered tools, such as image generation for simulated training and intention detection, allow them to navigate real-world uncertainties with unparalleled accuracy.

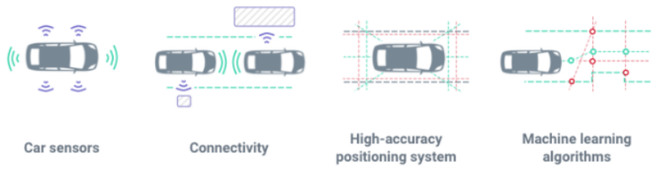



*Fig 2.1 Prominent technolgies in autonomous cars (Odukha, 2023)*





## Infrastructure is the key of putting everything together

The widespread adoption of self-driving cars (AVs) necessitates the presence of a robust and well-developed infrastructure. Although the vehicles themselves are impressive technological advances (Bagloee et al., 2016), they rely on external assistance in the form of intelligent road infrastructure outfitted with sensors to obtain up-to-date traffic information and other relevant environmental inputs. Traffic management systems evolve as well in order to adapt to and facilitate efficient navigation for autonomous vehicles (AVs). This infrastructure's essential components include charging infrastructures designed for electric autonomous vehicles, high-definition mapping systems, and data centres responsible for processing massive amounts of vehicular data. The most important aspect of ensuring interoperability is the seamless integration and enhancement of existing urban setups (Barabás et al, 2017), allowing new-age infrastructure to coexist peacefully with conventional vehicles.

# Prominent narratives in AVs

*The following text is a culmination of insight gathered through the sensing phase explained in chapter 6. Several resources were considered to create the text, some of the notable signals are mentioned here, however, for understanding the sources see Appendix D that presents the signals library.*

## Utopian visions in AV futures

Increased safety has the potential to reduce human-caused traffic accidents. AVs also have the potential to improve accessibility, ushering in a new era of mobility for the elderly, disabled, and non-drivers. Autonomous vehicles (AVs) can improve traffic flow, reduce congestion, and reduce traffic jams by streamlining vehicle-to-vehicle communication and optimising routing. Autonomous vehicles (AVs) powered by electric motors may also reduce pollution and emissions, thereby improving urban air quality. This paradigm shift suggests a new urban planning framework in which green spaces replace parking lots and streets are intentionally revitalised. New industries such as specialised maintenance and in-car entertainment have the potential to boost economic growth and employment. Integrating public transportation and personal mobility devices can benefit the ecosystem and make user journeys easier. Finally, lower transportation costs may render automobile ownership obsolete (growing trend of MaaS). This promising scenario, however, faces numerous significant challenges that must be overcome.

## Prominent Concerns

Concerns about autonomous vehicle deployment include high maintenance costs, road user fees, and software and hardware components, a potential increase in fuel consumption and carbon dioxide emissions, legal and ethical issues concerning user and pedestrian protection, privacy concerns and the potential for malicious hacking, safety concerns in mixed traffic situations, and job loss for al-

ternative transportation providers (Casley et al., 2013; Fishman and Davies, 2016; Varghese and Boone, 2015; Taeihagh and Lim, 2019; Jafary et al., 2018). According to some, the largest hurdle to broad acceptance of autonomous driving is psychological rather than technological in nature (Shariff et al., 2017; Xu et al., 2018; Panagiotopoulos and Dimitrakopoulos, 2018).

## The tales about AVs

Space around AVs is inherently dynamic (Kyriakidis et al., 2015) because it involves social changes, technological advancement, and ethical concerns. Several narratives surface on the web covering urban transformation, digital environments, ethical quandaries, and economic upheavals. They provide a comprehensive view of the effects of autonomous vehicles, which help in understanding the future projections.

### *Stories in Social front:*

The introduction of self-driving cars (AVs) will alter social norms and behaviours. Beyond transportation mechanics, AVs could alter daily routines, interpersonal relationships, and mobility. As shared AV solutions replace personal vehicle ownership, commuting options may change, becoming more accessible to all. Productivity, relaxation, and entertainment is taking precedence over driving, unlocking end-to-end business cases and integrated in-vehicular digital ecosystems. Cities may be renovated. Because AVs reduce the need for large parking lots (considering on demand mobility options and other urbanisation trends), urban areas could be used for recreation, such as larger pedestrian zones or entertainment venues. Quieter streets, cleaner air, and an urban renaissance that uses autonomous and electric functions for innovative city experiences may result if AVs and electric vehicles coexist (McKinsey Center for Future Mobility analysis. 2023).

### *Stories on Economic fronts:*

The economic consequences of AV dominance are extensive and complex. There is enthusiasm for the new economic opportunities that AVs may bring, ranging from innovative service models to one-of-a-kind tourism experiences, but disruptions loom large. Drivers such as truckers, cabbies, and others face uncertain futures. However, disruptions frequently generate new opportunities. AVs have the potential to accelerate growth in vehicle maintenance, software development, and autonomous travel experiences.

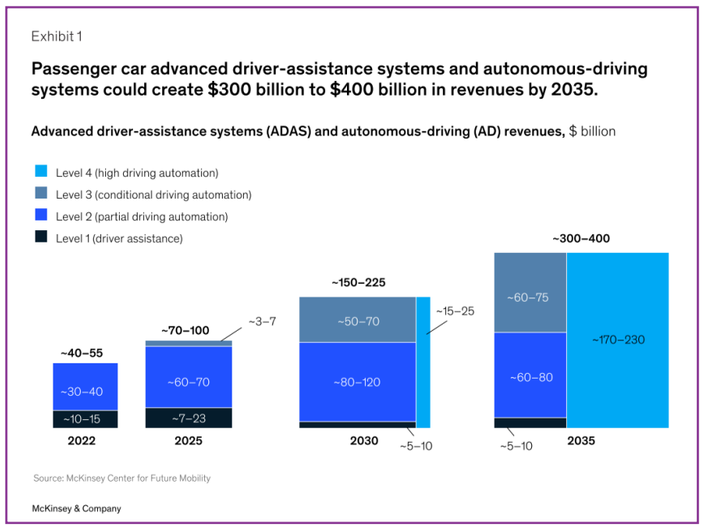



*Fig 2.1 Economic projections exihibited by McKinsey (McKinsey, 2023)*

### *Stories on Technological front:*

To redefine transportation, AVs combine multiple technologies. The benefits of integrating them with smart homes and personalised digital assistants will be maximised. As vehicles become extensions of users' digital spaces, personalization of travel will become more important. Users can expect personalised in-car entertainment and route recommendations. The convenience of AVs may also change culture in order to repurpose driving time. Rising digital ecosystems may provide numerous opportunities to use this "gained time" for work, relaxation, or entertainment.

### *Stories on Ecological fronts:*

AVs are surrounded by a complex ecological discourse. Cleaner cities with lower emissions are promised by AVs, especially if they use electric architectures. Concerns have been raised about their larger environmental footprint (Brown et al., 2014; Anderson et al., 2016; Marletto, 2019). Among these are the resource-intensive manufacturing processes, the fate of older vehicles that may become obsolete, and the environmental effects of AVs' increased travel frequency as a result of their convenience.

### *Stories on Systemic Narratives:*

AVs have a significant domino effect on systemic structures. A new era of AV dominance necessitates fundamental changes in established industries. Models of insurance may shift from fault determination to software reliability or manufacturer liabilities. Laws would also be altered to accommodate self-driving vehicles. It may be possible to reshape cities to accommodate AVs while prioritising pedestrian experiences or innovative transportation hubs.

### *Stories on Ethical fronts:*

The introduction of AVs raises serious ethical concerns. Beyond the impressive facade of automation, there are concerns about technological dependability, data security, and the long-term viability of cutting-edge technology (Taeihagh and Lim, 2020; Nastjuk, 2020; Riener, 2022). Concerns about technological failures arise when vehicles make decisions without human intervention. Another priority is to protect AV systems from malicious hacks or system errors. Philosophical debates over programming decisions in unavoidable accidents are heating up (Luzuriaga et al, 2020; Ju et al, 2019). In such situations, the ethics of prioritising passengers, pedestrians, or property highlight the moral implications of autonomous technology and the importance of transparent decision-making (Tabone et al., 2023).

### *Political Stories:*

Autonomous vehicles are a technological milestone with political implications. They improve urban management, which may lead to better traffic control, congestion, and mobility. Governments around the world are struggling to regulate this new technology. It is critical to strike a balance between innovation and safety. Creating coherent legislation that does not stifle innovation, navigating international tech competitions, and comprehending the geopolitical implications of AV tech leadership (or lag) are all priorities.

## To sum up

There is a lot of potential and a lot of uncertainty in the field of Autonomous Driving (AD) technologies, which is still growing. Even though AD promises to improve safety, make life easier for consumers, and change the way businesses work, its fast growth makes it hard to know what will happen next. Everyone with a stake in the situation, from automakers to tech experts, must use clear, flexible strategies that take into account both what consumers want and what the market will do. But operational strategies aren't the most important thing. The most important thing is to understand the changing paradigm of commuting from the users' point of view. As AD technology changes, its success depends not only on how well it works, but also on how well it fits with users' experiences and ideas. This shows how important academic research is in this process of change.

# 2.1 ACCEPTANCE OF AUTOMATED VEHICLES

The acceptance and spread of any new technologies by users is critical. This also extends to AVs. Although autonomous driving has numerous advantages, many people are wary of entrusting their vehicles to computer algorithms (American Automobile Association (AAA), 2019; Lienert, 2018). Acceptance and perception are distinct concepts, although they share common elements, as they both pertain to the user's behavioural inclination towards utilising technology.

Acceptance is defined broadly as "*general agreement that something is satisfactory or right, or that someone should be included in a group*". This term is more nuanced in the context of driving. Technology acceptance in driving, according to Adell (2010), is "*the degree to which an individual intends to use a system and, when available, incorporates the system in his/her commuting/driving*" (p. 477).

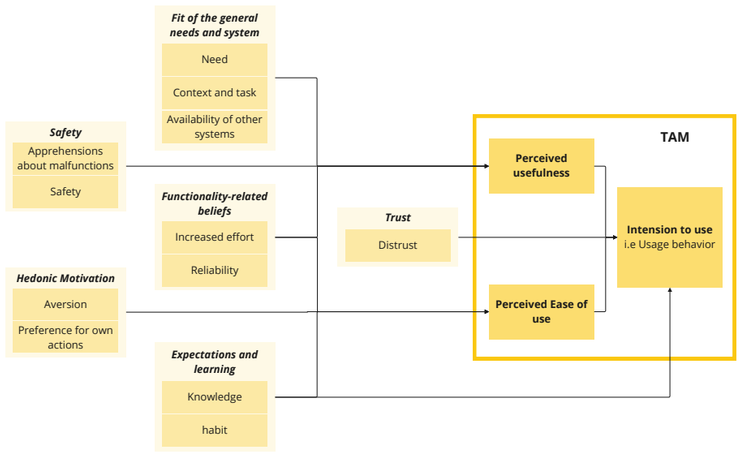



*Fig 2.2 an 'integrated TAM' Stiegemeier et al. (2022) (interpreted version).*





Technology Acceptance Models (TAMs) are used for studying acceptance. TAMs can assist in explaining how users accept new technologies, by examining factors that influence the acceptance. They also necessitate bridging the gaps in technology development and user's values. These models have been evolving over the years — from TAM1 to TAM3 (Venkatesh and Bala, 2008). Some researchers also have attempted making them specific to automotive contexts — such as CTAM, AVAM, MAVA — which are widely used in several studies so far. According to them, factors related to system performance, safety, and trust grow in importance (Benleulmi and Blecker, 2017; Kaur, and Rampersad, 2018) and consequently play a greater role in the acceptance models developed specifically for the vehicle sector.

Here, an integrated TAM developed by Stiegemeier et al. (2022) is used, as it offers a holistic view on factors influencing use of technology i.e acceptance. In fig 2.2 an '*integrated TAM*' is presented. (interpreted version).

### 1. Perceived Usefulness (PU):

**Definition:** Perceived usefulness refers to a user's belief that a given system will enhance their driving performance (Venkatesh et al., 2003; Davis, 1985).
**Implication:** The alignment of a system's features with a user's needs determines its perceived usefulness. A system is more likely to be accepted when it assists users in specific tasks or goals and is relevant to commonly encountered driving situations. However, drivers' perceptions of safety can vary depending on the type of system in question (Vaezipour et al., 2017; Oviedo-Trespalacios et al., 2020).

### 2. Perceived Ease of Use (PEoU):

**Definition:** PEoU is about how simple it is for users to interact with a system without undue effort.
**Implication:** Systems perceived as complex or requiring specialised knowledge may face resistance in acceptance. Factors influencing PEoU include computer self-efficacy, perceived external control, computer anxiety, playfulness, perceived enjoyment, and objective usability.

### 3. Perceived Safety:

**Definition:** Perceived safety reflects a user's assessment of potential risks, such as distractions, when using a system (Hewitt et al., 2019, Osswald et al., 2012, Xu et al., 2018).
**Implication:** Systems that are perceived to compromise safety or amplify distractions are less likely to be adopted. While certain features are linked with perceived safety in qualitative studies, deeper understanding is necessary to determine the nuances of these associations.

### 4. Trust in Technology:

**Definition:** Trust in automated systems pertains to the reliance on technology, especially in situations filled with risk and uncertainty (Lee & See, 2004, p. 51).
**Implication:** Trust can be swayed by various system attributes, like frequency of malfunctions or system transparency. Drivers' concerns about data privacy and potential system vulnerabilities also influence their trust (Kyriakidis, Happee, & Winter, 2015). Trust is pivotal in in-vehicle technology acceptance, with its significance underscored in studies like those by Buckley et al. (2018). The evolution of trust is shaped by system performance over time (Hoff and Bashir, 2014), and design flaws can undermine it (Kraus et al., 2019).

### 5. Anxiety & Apprehensions:

**Definition:** Particularly in the context of autonomous vehicles, anxiety is closely tied to trust. "Computer anxiety" captures the unease or trepidation one feels towards using computer systems.
**Implication:** The role of fear and anxiety in technological acceptance is not yet fully defined, warranting more research to understand their ramifications and the technological or psychological factors steering them (e.g., Kraus et al., 2019, Miller et al., 2021).

The aforementioned factors point to a significant opportunity. It is critical to effectively communicate the benefits of technology to users, in order to mitigate deficiencies in knowledge, trust, safety, and usage patterns. This can be accomplished by providing comprehensive training programs aimed at facilitating the acquisition of necessary skills.

## Complex challenges of higher automation in AV

The Technology Acceptance Model (TAM) and Unified Theory of Acceptance and Use of Technology (UTAUT) have been used to determine tech adoption behaviour. However, these models often fail to predict AV acceptance. Increased automation changes driving paradigms, making older models obsolete as user demands and perceptions change. Therefore, understanding the complex challenges of higher automation in AV interactions is crucial. This comprehensive categorization addresses acceptance's many challenges, from security to user experience (Detjen et al., 2021).

### Security and privacy:

Integration of Automated Vehicle (AV) technology promises increased convenience, but it also exposes users to potential risks and vulnerabilities. Users have expressed concerns about the loss of control and the vulnerability of these systems to hacking (Smith et al., 2016). The paradox here is that as technology strives to secure vehicles, it frequently requires increased user input and vigilance, such as the implementation of fingerprint and facial recognition systems, which can be perceived as burdensome (Fischer et al., 2016). As a result, the challenge is to develop interaction methods that ensure security while minimising user effort.

### Transparency and trustworthiness:

Trust is the foundation of user acceptance and interaction with AV systems. According to Hoff and Bashir (2015), trust evolves dynamically through various means. It can be dispositional, situational, or learned, manifesting differently depending on individual predispositions or situational factors. The interaction between interpersonal and human-automation trust is also critical. Ineffective human-machine interactions may result in a loss of trust. Unlike interpersonal trust, which is frequently based on emotions, human-automation trust is based on the system's functionality and performance (Endsley, 2017). Mismatched trust levels with automation, on the other hand, pose a risk. Overconfidence can leave drivers in the dark about potential hazards (Merat et al., 2019). Under-trust, on the other hand, acts as a barrier to higher levels of automation adoption. Solutions may lie in striking a balance between humanising cars for trust formation and maintaining competence-based communication, particularly during critical moments (Häuslschmid et al., 2017). This is supported by research indicating that future vehicle interactions could be mediated by conversational interfaces and visual AI agents (Large et al., 2019; Okamoto & Sano, 2017). Furthermore, for long-term trust, the system must consistently communicate its capabilities. Colour hues (Kunze et al., 2018a), LED stripes (Faltaous et al., 2018), vibrotactile feedback (Kunze et al., 2018c), and even smell signals (Wintersberger et al., 2019) can help to portray system reliability.

### Safety and performance:

Transitioning control between the driver and automation can be a difficult task. Rapid and safe transfers are critical, often requiring completion within 15 seconds depending on the situation (Damböck & Bengler, 2012). Situational awareness, a three-step process defined by Endsley and Garland (2000), has a significant impact on takeover efficacy. Movement patterns to signal vehicle operations, auditory messages, and shape-changing steering wheels are some strategies for improving situational awareness (Kerschbaum et al., 2015). Long gaps in driver activity can result in skill atrophy and a loss of necessary vigilance (Trösterer et al., 2017b).

### Competence and control:

The extent to which drivers want to intervene in future AVs is unknown. Schmidt and Herrmann (2017) proposed "Intervention User Interfaces" that allow for different levels of control. Manoeuvre-based interventions (MBIs) provide an avenue for control in higher automation (Detjen, Schneegass et al., 2019), whereas cooperative control strategies, such as shared haptic feedback, enable harmonious interaction between man and machine (Lv et al., 2020). According to Walch et al. (2017), cooperative driving necessitates mutual predictability, directability, shared situation representation, and calibrated trust.

### Positive experiences:

Finally, while higher levels of automation may increase safety and efficiency, they may also lead to user ennui (Van Huysduynen et al., 2018). Ambient intelligence, augmented reality, and virtual reality have the potential to improve user experiences. Improving the hedonic quality of AV systems necessitates holistic design strategies that include multiple stakeholders such as employees, businesses, and mobility specialists.

## Key conclusions

When it comes to technological adoption, the intersection of people, technology, and circumstance is critical. The adoption of self-driving cars is a notable example of this. While existing research frequently relies on the Technology Acceptance Model (TAM) and the Unified Theory of Acceptance and Use of Technology (UTAUT), applying these models to this domain presents some inherent challenges.

For starters, these models frequently show limited or ambiguous efficacy in predicting an individual's intention to use, or 'accept,' a specific vehicle system. When considering the plethora of subjective factors influencing potential users, their predictive power becomes especially murky. Cultural background, knowledge, personal pride, and perceived autonomy can all have a significant impact on an individual's attitude toward technology. Because of its dynamic nature, iterative and periodically ongoing research is required.

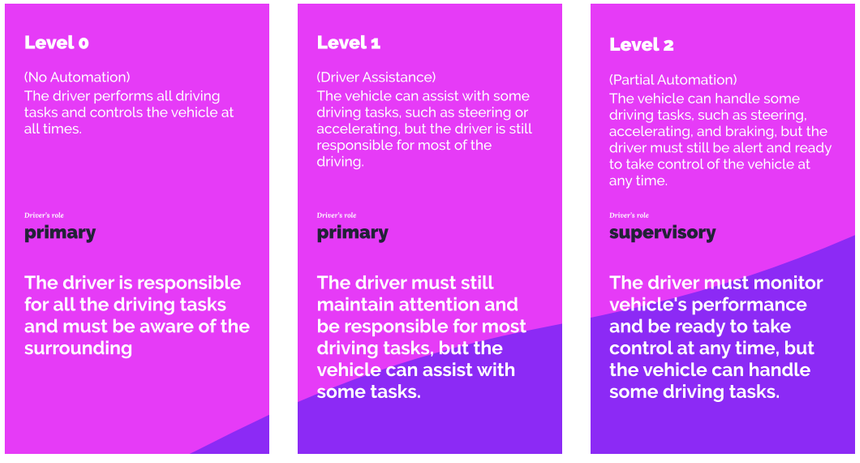
Furthermore, surveys are the primary data collection method for these models. While surface-level sentiments are important for capturing, they may not delve deeply into users' underlying needs, expectations, and reservations (Yan, 2023). To compensate for this shortcoming, the approach proposed in this thesis employs "speculated futures" as conversational tools, allowing researchers to probe deeper layers of user sentiment and build empathy.

The way we perceive and use automobiles will inevitably change as we move toward greater automation and assume less responsibility for driving. For example, the incorporation of Extended Reality (XR) into Autonomous Vehicles (AVs) represents a significant shift in the automotive usability paradigm. While these new technological integrations are promising, they also complicate acceptance dynamics. Moreover, there is a gap in current research methodologies. Many studies concentrate on vehicles with a single level of autonomy. In contrast, this thesis broadens the scope to include vehicles with varying levels of autonomy, recognizing the sector's technological progression.

To close the gap between AV technology and user acceptance, designers must prioritise trust, safety, security, control, comfort, fun, social connectivity, and well-being. Furthermore, clear communication of system benefits (utility) and user-friendly feature implementations (perceived ease of use) will be beneficial. Addressing these will be critical in removing biases and misconceptions, allowing for the seamless integration of AVs into the fabric of everyday life.

# 2.2 LEVELS OF AUTONOMY

Automated driving, potentially, could make roads safer, reduce traffic and pollution, improve car comfort, and make the economy more competitive and enhance mobility as the population changes. These benefits are often cited in a technology-centred view of vehicle automation. It is important to note that Human-machine issues are crucial for vehicle automation to succeed. This humanises automation. Human-machine interaction research has found "ironies of automation" (Bainbridge, L., 1983) that create a doubt around the benefits of automation. Mode awareness and transitions from manual to automated control, monotonous supervising tasks in partially automated driving, changes in attention allocation and engagement in non-driving tasks, and out-of-the-loop unfamiliarity, which decreases trust and situation awareness, are the main issues (Baumann, M. et al, 2022). Feedback on automation's states and actions can reduce its negative effects and make humans and machines work better together. In order to gain understanding of driver's role changes in automation, it is essential to understand what are Levels of Autonomy.





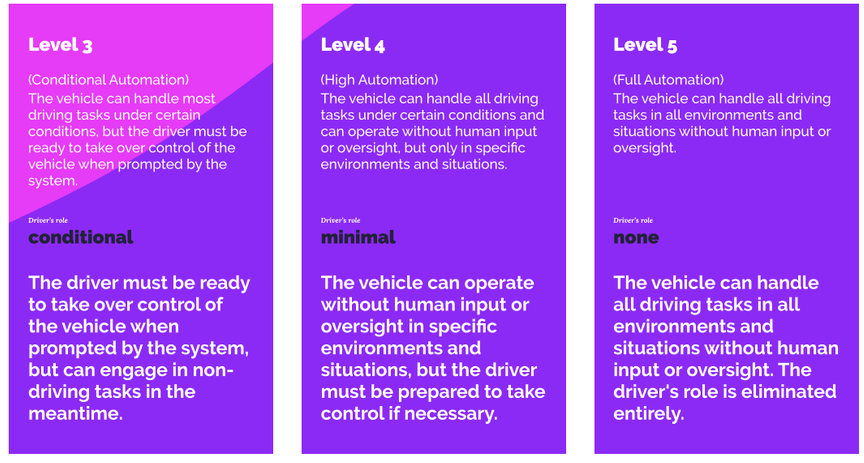



## Levels of autonomy

Automation is the process of replacing humans with machines to complete previously human-only tasks (Parasuraman et al., 2000). The concept of automation is not black-and-white, but rather a spectrum encompassing a wide range of computer and human operator involvement (Sheridan, 1997). Initially, BASt defined five tiers of automation in the driving context: driver-only, assisted, partial, high, and full (Gasser et al, 2012). The National Highway Traffic Safety Administration (NHTSA, 2013) and SAE International (SAE, 2018, 2021) have both developed taxonomies to standardise these levels globally. In this project we refer to the levels of automation defined by SAE (2021).

### Changes in the driver's roles and responsibilities

The driver is in charge of every aspect of the vehicle and the road at Level 0 (SAE, 2021). Level 1 automation, also known as driver assistance, delegated some driving responsibilities to the car (i.e system or algorithm). This means the driver only needs to focus on steering and accelerating or braking while the system handles the other aspects of the vehicle's operation. The system controls the speed and direction of the vehicle while it is in motion (level 2 partial driving automation). A system may, for instance, supply adaptive cruise control and lane-centering capabilities. The driver's responsibilities include system monitoring, environment response, object management, and event handling.
The automation really starts at level 3 (SAE), Level 3 till 5, the system takes full control of the vehicle. Level 3 conditional automation removes the need for driver involvement altogether once the automation system has assumed command. However, when the system reaches its limits and requests human intervention, the driver must be prepared to take control. How the driver reacts is of utmost importance. Within an operational design domain (ODD), a system with a high driving automation level (Level 4) can drive autonomously and manage system boundaries. The driver must pay attention to the system's requests for assistance and intervene as necessary. If the driver doesn't react or the system doesn't ask for help, the car should be put into a safe mode automatically. Finally, Level 5 refers to fully automated driving, in which the system can drive reliably and without fail at any time.



## Taxonomy of Levels of Automation in Autonomous Driving

The Society of Automotive Engineers (SAE) provides one of the most thorough models describing these levels in the J3016 standard. Let's examine some foundational concepts to better grasp the breadth and nuance of these tiers.

**Operational Design Domain (ODD)**
The term "Operational Design Domain" (ODD) refers to the specific conditions that an automated system or vehicle is designed to operate safely under. Think of it as the "comfort zone" of the automated system. It takes into account the following parameters: location, road type, weather conditions, speed range, and other environmental and operational parameters. For example, a vehicle's ODD may be limited to highways in clear weather and within a certain speed range. Extending beyond these limits may necessitate human intervention or jeopardise the vehicle's performance and safety.

**Dynamic Driving Task (DDT)**
Driving is, in essence, a jumble of tasks and responsibilities. There are three major stakeholders in this domain: The operator (human or automated), the driving automation mechanism, the car and its integrated systems. The DDT concept revolves around the roles that these stakeholders play. Importantly, the term "role" in this context refers to a stakeholder's intended function in the driving system, rather than its actual actions. For example, even if a driver is using a Level 1 Adaptive Cruise Control (ACC) system and is distracted, they are still expected to be responsible.

**DDT Fallback**
DDT Fallback refers to the protocol or action plan that will be carried out if there is a hiccup—either due to system failures or when the defined ODD limits are exceeded. The core of DDT Fallback is to ensure safety, whether through user intervention or the automated system itself. It also includes safety features built into the vehicle to address situations that go beyond the ODD.

### To sum up

"The availability and who controls the Dynamic Driving Task (DDT), DDT Fallback, Object and Event Detection and Response (OEDR), and Operational Design Domain (ODD) determine SAE's automation levels. If the vehicle doesn't DDT or DDT fallback, it's level 0. Level 1 applies to vehicles that partially perform DDT, such as cruise control, but not OEDR. Level 2 vehicles can control longitudinal and lateral motion. Level 3 requires the full DDT. The vehicle enters level 3 if it completes the DDT but not DDT fallback, which is the DDT after a DDT performance-relevant system failure (e.g., blocked lanes). Level 4 occurs when the vehicle completes the DDT and DDT fallback within a limited ODD (e.g., expected and manageable situations). Level 5 unconditional automation performs complete DDT and DDT fallback without expectations".





## Transitioning between the levels

Gaining a comprehensive understanding of the implications associated with changing the level of autonomy is of top priority. Users have the ability to control and make decisions regarding the extent to which they wish to interact with automated systems as an assistive measure. By opting to interact with the automation, individuals relinquish control to the system. This practice is commonly referred to as 'handback' (SAE, 2021). Alternatively, the system may also provide users with the option to assume control or request their intervention. In empirical research, the process being referred to is commonly known as "handover" or "takeover (TO)" request. These situations can be characterised as transitional situations.

According to SAE, there are several reasons the system transfers the control to users. They are as follows

- **System malfunction:** Failure of the automated driving system to work as planned may necessitate the driver taking over control of the vehicle in order to avoid a collision or other safety concern.
- **Road circumstances that are unexpected**: Automatic driving systems might not be able to manage conditions like construction zones, a lot of rain or snow, or sudden impediments in the road. To properly manage these situations, the driver may need to assume control.
- **Regulations:** In some circumstances, regulations may stipulate that a human driver must always be in charge of the vehicle. For instance, certain US states mandate that a driver must always be able to take control of an autonomous vehicle.
- **Safety concerns**: The driver may decide to take over control of the vehicle if the automated driving system makes them feel uneasy or dangerous. This is done to protect their safety.
- **Personal preferenc**e: Even when the automated driving system is active, some drivers may just prefer to be in constant control of the car.

A TO taxonomy explained by Wintersberger et al, 2017) is as, "*Takeover includes the phases preparation, perception (of the takeover signal), suspension (of in-vehicle tasks) and the actual process of taking over, which can be subdivided into sufficient (to steer and control speed) and full (where situation awareness is complete) control. Furthermore, takeover can be imminent, scheduled, or user-initiated. For the takeover processes, the duration and change of the control transfer (as a function of time) needs to be precisely described/specified.*"

The recent issues of Society of Automotive Engineers (SAE) has broken down the Takeover tasks into several distinct phases. See Fig 2.3.

**Preparation:** During the perception phase of an automated vehicle takeover, the driver must detect the initiation of the control transfer sequence. According to Lu et al. (2016), vehicle automation frequently has an impact on this perception. It is critical to consider whether the transition from automated to manual control is gradual or abrupt.
**Suspension:** The suspension phase encompasses the physical and cognitive changes that a driver goes through during a takeover. These modifications are personal and are based on the Non-Driving-Related (NDR) activity they engaged in prior to the takeover. The physical aspect could include adjusting one's seat or reacting to changes in the vehicle's interior. Automatic seat position adjustments could aid drivers in making this transition more comfortable.
**Handover:** In the final handover, the driver takes control. The transition is divided into two stages. *Sufficient handover* occurs when the driver has just enough control to drive safely. According to research, this phase ends with the driver's response time and begins the "transfer" phase of SAE 314. At *Full Handover*, the driver is fully aware of his or her surroundings and is ready to drive. It corresponds to the "receipt & recovery" stage of SAE J3114. Only when the driver reaches this phase does the automated system handover to the human driver complete.

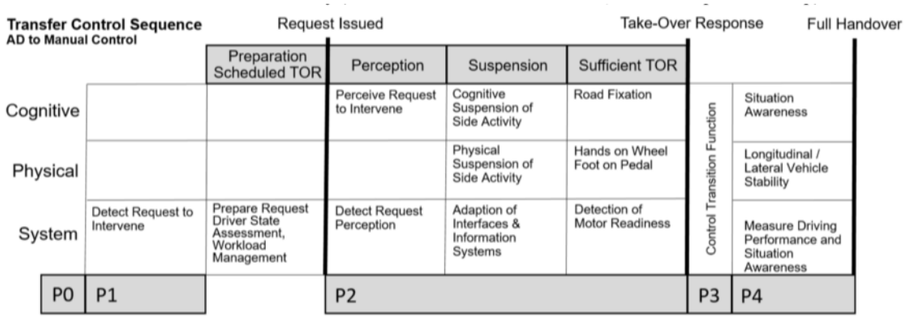



*Fig 2.3 Handover taxonomy (SAE 3114) phases*

**Importance of HMI in TOs**

A single journey may involve multiple instances of transferring control, as depicted in Figure 2.4. This implies that there are numerous instances in which control is subject to negotiation. This leads us to the recognition of the significance of Human-Machine Interaction (HMI) in transitions, as effective communication between the system and users is crucial for ensuring a secure transfer.

**Conceptual framework of TOR for HMI**

Conceptual framework of TOR defines the way information flows through the system and users. A TOR system sends information to the driver through an HMI depending on whether the ODD limits have been reached or an emergency situation has been detected. TOR starts when either the driver or the system (based on ODD) makes the first contact. A TOR can be thought of as a control switch between two systems that sets the security level based on how the systems are built and what parts they have.

The work in mulder et al.,( 2008) suggests a TOR system that works as a shared control model that constantly checks the driver's awareness of the situation before giving the driver full control. In order to do this, a DMS looks at the driver's physical responses and how they perceive their surroundings.

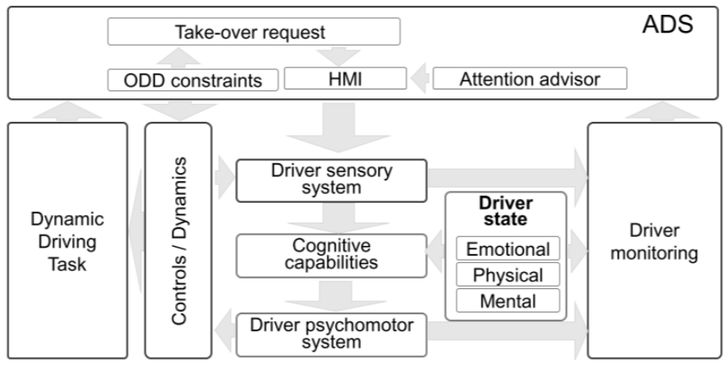



*Fig 2.4 Conceptual framework of TOR (Morales-Alvarez et al., 2020)*





# Challenges in HAI

When it works properly, automation is undeniably beneficial to human performance. The fact that automated systems introduce an automated technical agent into the human-machine system, who acts independently to varying degrees, creates several challenges.

**Different Perception of the Environment:** Sensors assist cars in planning and acting. When using radar, lidar, or ultrasonic sensors, an automated driving function may assess, plan, and act differently than a human driver. Even if the automated agent perceives the environment similarly to a human, its assessment, derived actions, and execution may differ. As the researcher put it, this results in "gut misalignment."

- Automated systems perceive their surroundings differently than human operators.
- Disagreements in situation assessment and action plans are possible.
- Inconsistency between automation and human expectations.

**Lack of Transparency:** Because of the previous tension, human-machine interaction design must make the behavior of automation transparent. If automation is opaque and unpredictable, especially when it fails, human trust and acceptance will suffer. Automation will be used inefficiently or abandoned, resulting in a waste of its potential.

- For human users, automation behaviour must be transparent.
- Automation that is opaque and unpredictable can lead to a loss of trust and acceptance.
- Automation inefficiency or abandonment may occur, resulting in lost potential.

**Overconfidence and complacency:** Another issue is that humans adapt to automation in two ways: they get used to it and integrate it into their tasks, and they rely on it if it meets their needs. Complacency and overreliance may result. Human adaptation research is growing because humans must intervene and resume manual control in automation limits (SAE Level 2 and 3 automation, when the automation requests driver intervention) and automation failures or malfunctions (all automation levels). Automated driving (SAE Level 3–5) requires drivers to completely disconnect. The more automation takes over human control processes and tasks, the harder it will be for human operators to stay or come back "into the loop". Parasuraman et al. (2000)

- Humans adapt to and integrate automation into their task performance.
- Overuse of automation can lead to complacency and decreased task engagement.
- The difficulty of retaining human operators' involvement and resuming manual control. (Endsley and Kaber, 1999)

**Changing the Nature of the Task:** Using technology to automate highway tasks like lane keeping or brake assist while leaving complex tasks like exiting the highway to humans can have unanticipated consequences for human performance. These are the result of cognitive changes in human operators that were not anticipated during the development of the new human-automation system (Parasuraman et al., 2000).

- The automation of certain tasks alters the overall task for human operators.
- Automation is assigned to routine and structured tasks, while humans are assigned to complex tasks.
- Changes in human cognitive processes have unanticipated consequences.

To overcome these challenges, researchers propose studying the evolution of human-machine interfaces in aviation. Human-factor automation improves the safety, efficiency, and comfort of human-machine interactions. Humans or drivers should be prioritized by developers of automated driving functions. This necessitates understanding of human psychology as well as automated system interactions. Only a few key points need to be addressed. Workload, trust mechanics, situational awareness (SA), and calibration are all factors to consider. Appendix E contains details on the SA cognitive model and trust model. We only present the most important concepts for comprehension.

# Situational awareness

Situational awareness is an operator's ability to understand a dynamic situation while interacting with more automated systems. "*Knowing what is going on around you*" is widely accepted as a prerequisite for successful interaction with automated systems in dynamic environments (Durso et al, 2008, p. 5), but there is a debate about the status, definition, and measurement of situational awareness (Dekker & Hollnagel, 2004; Durso et al, 2007).

## Situational Awareness in Autonomous Mobility

Endsley's s Situational awareness model has been applied to autonomous driving which has three levels of tasks: strategic, tactical, and operational (Michon, J.A., 1985). Perception, comprehension, and projection are Endsley's three situation awareness levels. The operator's goals and tasks determine these levels' importance. Strategic decisions like route planning require extensive future projections. At the tactical level, perception and comprehension of the current situation are prioritised over projection to choose appropriate manoeuvres (Matthews et al, 2001).

Situational awareness definitions depend on context and use. Designing human-machine interaction strategies takes the product perspective, which views situational awareness as knowledge. This makes it crucial to understand what support operators need to know during task execution. The process perspective emphasises product-process interaction and aligns with engineering psychology research on the cognitive basis of situational awareness. It's sound to avoid prematurely landing on the one view for designing HMI, due to the linked nature of product-process views.

To help drivers build a better understanding of the situation and to make it possible for driving automation systems to build a shared picture of the situation with the human driver or passenger, we need a better understanding of how these processes (SA building and maintaining) work. Therefore, it is essential to understand situation awareness as a comprehension process.

## Automation adversely affects Situational Awareness

**Cognitive Workload and Situation Understanding**

According to Endsley (1995) and Wickens (2001), the role of working memory in understanding a driving situation is critical. Working memory is the mental workspace that allows us to juggle multiple pieces of transient information while performing tasks, essentially serving as "RAM" for the cognitive process. When automation is introduced, the working memory load decreases noticeably. Automation can help to alleviate the burden of repetitive tasks, but it can also have a negative impact known as "out-of-the-loop performance."

**The Dual-Edge of Automation**

Automation in driving has the potential to both improve and impair situational awareness. According to a 2005 study by Ma and Kaber, the implementation of Adaptive Cruise Control (ACC) can assist drivers by automating specific driving tasks, thereby relieving cognitive demands. Nonetheless, the benefits of automation are not distributed evenly across all levels. Individuals tend to shift their focus away from the driving task when it is heavily automated, relegating themselves to a state of disengagement from the driving process, according to research (Endsley et al., 1995; Hancock, P.A., 2019).

Automation fundamentally alters the task-goal structure. This necessitates a HMI design opportunity. However, the disruption of control processes must be considered as well; automation may filter out critical real-time information, impairing the driver's ability to regain manual control (Engstrom & Hollnagel, 2007).





**Out-of-the-Loop Performance: The Nemesis of Automation**

One of the major challenges in the domain of automation, particularly in autonomous driving, is "out-of-the-loop" (OOTL) performance. The OOTL problem arises when human operators, separated from active control, struggle to identify and correct system failures or anomalies (Endsley et al, 1995; Hancock, P.A., 2019; Molloy et al, 1996; Skitka et al, 2000).

Several factors contribute to this difficulty. For starters, as human operators shift from active manipulation to simply observing how automation works, they may lose situational awareness (Sheridan, T.B., 1997). Second, maintaining vigilance becomes difficult, particularly when monitoring tasks become monotonous or uninteresting (Mackworth, N.H., 1948). Finally, when automation systems prove reliable over long periods of time, human operators have a tendency to over trust them, resulting in decreased alertness and potential negligence (Lee & See, 2004).

One significant implication of the OOTL problem emerges during control transitions, particularly at higher levels of automation. For example, in Level 3 and Level 4 automation, human drivers must reclaim control due to system limitations or unforeseen conditions (SAE International, 2018). To ensure smooth and safe transitions, drivers must maintain a strong understanding of the current situation, regardless of their recent detachment from active control (McCall et al, 2019; Walch et al, 2017).

**Motivational and Cognitive Barriers**

Endsley (1996) emphasises the importance of vigilance and motivation. Automation can lead to complacency, which can lead to a loss of situational awareness. However, this is a motivational issue as well as a cognitive one. This is complicated by the lack of empirical evidence linking trust and complacency (Moray et al, 2000).

# Conclusion: The Challenge & Opportunity to Design

While automation clearly provides a powerful means of reducing cognitive workload, it also presents unique challenges in maintaining an operator's situational awareness and ability to intervene effectively in emergent situations. The interaction of automation, mental workload, and situational awareness is not linear, but rather a dynamic relationship characterised by feedback loops and conditional dependencies (Endsley, 1995; DeWinter et al., 2015).

To create systems that are not only efficient but also cognitively ergonomic, designers and engineers must approach this complex ecosystem with a nuanced understanding of human cognition and behaviour. This entails planning for transitions, providing appropriate feedback, and understanding the limitations of both human cognition and automated systems. We are not simply designing an automated driving system; we are designing a complex, socio-technical system in which the 'human in the loop' is as important as the algorithms that drive the automation. It's an intriguing but daunting challenge, supported by a wealth of research that can guide our approch.

# 2.3 TRUST IN AUTONOMOUS DRIVING

In automation, "*trust is built on being able to see how the system works (performance), know what it's supposed to do (purpose), and know how it makes decisions (process).*" Mayer's definition from human-human trust still holds true here: When a driver uses automated systems, they open themselves up to some risk. The driver is then obligated to have expectations about contextualised vehicle performance. The driver must finally come to terms with the fact that they are unable to control or monitor the automation.

As seen in chapter 2.1, integrated TAM involves Trust in automation, but a separate category of models focuses just on trust. So this subsection primarily addresses the relationships between trust influencing and influenced variables. Two models that have made great impact are in focus— Lee and See's Model and Hoff and Bashir's model.

The trust model developed by Lee and See (shown in Figure 2.5) delves into the complexities of trust in the context of automation. Context, which includes both social relationships and physical environments, has a significant impact on how people process information and form beliefs. This fundamental belief system determines one's trust in automation, which influences one's intention to use and actual reliance on automated systems. The model emphasises the dynamic nature of trust, emphasising how it evolves via feedback loops. Users' interactions with automation shape and refine their trust levels, which in turn influence their future interactions and reliance on the system.

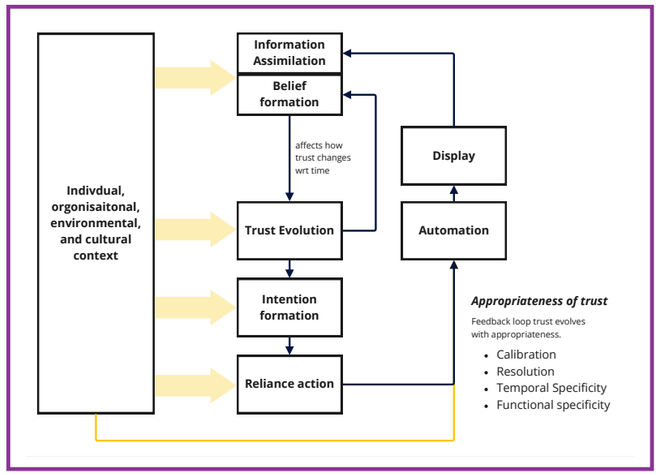



*Fig 2.5 The Lee and See (Bellet et al, 2007's version) trust in the automation model*





## Trust calibration

The one aspect of the Lee and See's model has been extensively studied i.e Trust appropriateness, which impacts intention formation, automation, display, and evolution. Simply put, trust calibration is the process of matching the capabilities of a system with how much you trust it (Lee & See, 200). Over-trust leads to misuse and distrust leads to disuse, which minimises automation's benefits. In Hoff and Bashir's model of trust in automation, "trust calibration" describes how a person's trust in an automated system changes during an interaction based on the system's performance.

Automated decision aids and simulated supervisory control tasks have been used to characterise trust in automation (Endsley, 2017). In contrast, trust in automated driving research has focused on calibrating trust to system performance.

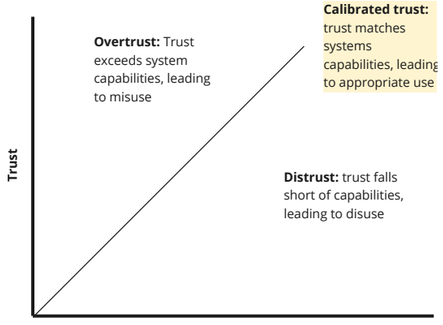



*Fig 2.6 Trust calibration*

## Aids for Trust calibration

In the context of making it easier for drivers to understand how automated vehicles work, Trust calibration tools/strategies can contribute significantly. Several ways have been tried to do this in the world of augmented reality displays:

- **Uncertainty Indication:** Automation can show where there is uncertainty, letting the driver know about the system's limits (Marr,1982).
- **Safe Transition Highlighting:** During takeover transitions, when the driver takes control of the car again from the automation, the system can show the driver where it is safe to drive (Lee & See, 2004).
- **Augmented Roadway Traffic:** The system can show the driver how far away the traffic ahead is from his or her car. This shows what the automation can see in the environment (Mackworth, 1948).
- **Personalised driving displays:** Driving profiles are used to figure out what information should be shown to different types of drivers. In a defensive driving profile, for example, cars and other objects on the road are highlighted to show that the car can see them (Ma & Kaber 2005).
- **Use of voice agents:** researchers have looked into how using voice agents in automated vehicles might affect trust in automation. To help people feel comfortable with automation, guidelines have been made for adding voice agents to cars (McCall et al, 2019; MacCarley et al, 2002; Michon, 1985).

## Characterization of Trust Dynamics

Trust dynamics characterization in automated driving is the study of how trust in automation develops and shifts over time without the use of external manipulations like displays.

**Key points:**

- Automated cars increase trust. This means under-trusted people gain trust and over-trusted people lose trust. (Klein et al, 2004).
- Trust affects how people feel about automated cars. More trust leads to a more positive view of technology, while less trust to more caution.
- User information can affect their trust in automated vehicles and how they interact with them. Drivers who trust automation are safer. (Engstorm & Hollnagel, 2007).
- A simulated highly automated vehicle taking over may increase trust. But, some aspects of trust decreased, such as— Safety gain and driver disengagement decreased after a takeover (Gold et al, 2016).

# SPACE AROUND EXTENDED REALITY

*This chapter debunks the concept of extended reality (XR). We begin by defining XR and the technologies that it encompasses. Our journey continues with an examination of XR experiences, culminating in a discussion of immersion and its various levels.*

## 3.0 EXTENDED REALITY (XR)

XR is an umbrella term encapsulating Augmented Reality (AR), Virtual Reality (VR), Mixed Reality (MR), and everything in between. It revolutionises human-computer interaction. VR immerses users entirely in digital worlds using headsets, while AR enhances reality by superimposing digital content through tools like AR glasses. MR combines VR and AR elements, offering spatial awareness and interaction via headgear like Microsoft's HoloLens (Obeidallah et al, 2023).

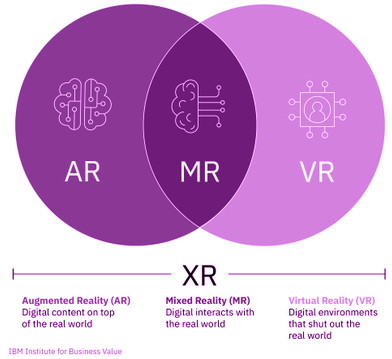



*Fig 3.1 The set of technologies constituting extended reality (XR).*

# What is AR, VR, MR?

Digital materials and the physical world are combined with augmented reality (AR). A user's perspective of the real world is overlaid with computer-generated images, text, or 3D objects in augmented reality (AR). By adding contextual information or interactive features that are frequently accessible through smartphones, tablets, or specialised AR glasses, this integration improves the real world. Examples include navigation apps that provide real-time information to workers or industrial apps that provide directions on actual streets as seen through a smartphone camera (Rauschnabel et al., 2022).

Digital environments are completely immersed when using virtual reality (VR). When using a VR headset, users replace their actual surroundings with computer-generated ones that frequently involve more than one sense, such as sight and sound. Users can explore and interact with virtual environments in very fascinating ways using this technology, which is popular in gaming, simulation training, and immersive storytelling.

The coexistence and interaction of the physical and digital worlds are made possible by mixed reality (MR), which combines aspects of AR and VR. Users of MR headsets, like those included with Microsoft's HoloLens, may view and interact with digital items that are seamlessly incorporated into their surrounding actual space. These systems can interact with real things and surfaces because they have spatial awareness. Architectural visualisation, remote collaboration, and advanced training simulations are just a few of the applications where MR is employed to give users a versatile mix of technological and physical interactions. numerals placed side by side.

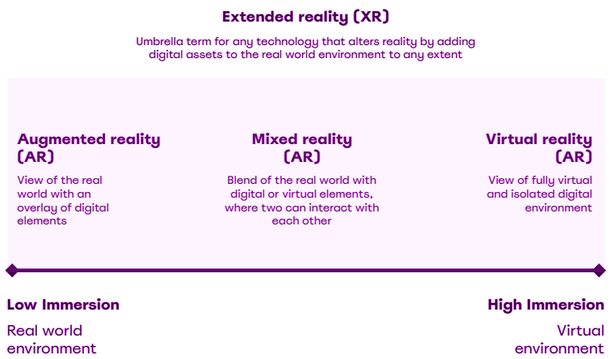



*Fig 3.2 Immersion spectrum representation of current XR technologies.*





## How do these technologies differ from each other in terms of user experiences?

Due to how they differ in fusing the digital and physical worlds, augmented reality (AR), virtual reality (VR), and mixed reality (MR) all offer distinctive user experiences.

By superimposing digital features, augmented reality (AR) improves the user's actual surroundings. Users' continued connection to their actual surroundings is both a benefit and a drawback. This experience is less immersive than VR or MR, making it appropriate for jobs like remote support or navigation that demand ongoing awareness of the outside world. AR can improve everyday experiences by giving context-specific information and allowing users to visually try on clothing or visualise where furniture is in a real environment.

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In short,  MR merges digital material with the physical world, whereas VR immerses viewers in a wholly virtual environment. AR enriches the real world with a digital overlay. Depending on the desired user experience, different technologies are used: MR for integrating the two, VR for complete immersion, and AR for contextual improvement (Beyond AR Vs. VR: What Is the Difference Between AR Vs. MR Vs. VR Vs. XR?, 2023).

# 3.1 EXPERIENCES IN XR

## General use cases of AR/MR for immersive experiences

Spatial experiences are three-dimensional immersive encounters that frequently involve the sense of presence and depth perception in a physical or virtual setting. AR/MR avail these experiences (Scholz & Smith, 2016). The integration of Augmented Reality (AR) and Mixed Reality (MR) into various sectors is reshaping our interactions with the digital and physical world. In design, architects use AR to overlay blueprints onto real construction sites, optimising design decisions. Education has been enriched with immersive MR simulators, allowing medical students to practise surgeries or history enthusiasts to delve into past events interactively (Kawulich & D'Alba, 2019).

The entertainment landscape has evolved with spatially aware games like Pokemon Go, powered by platforms such as Microsoft's HoloLens (Jung et al, 2016). Remote collaboration has transformed, with MR creating virtually shared spaces that foster realistic teamwork (Schröeter & Steinberger, 2016). Industrial sectors leverage AR glasses to overlay repair instructions, streamlining maintenance (Kim & Gabbard, 2019). In healthcare, surgeons employ AR for enhanced accuracy during operations, while retailers offer customers AR-based product previews (Agarwal, R., 2019; Baric et al, 2020). Recent research in human-machine interfaces highlights the expanded capabilities of AR, with potential applications in automated vehicles (Steinberger et al., 2016). The Virtuality Continuum positions MR as a blend of real and virtual elements, with AR evolving towards more active displays in automobiles.

## XR is rapidly evolving

*(The following text is a culmination of insight gathered through the sensing phase explained in chapter 6. Several resources were considered to create the text, some of the notable signals are mentioned here)*

The fields of MR and AR are developing quickly. With the development of more reasonably priced MR headsets and AR-capable smartphones, they are becoming more widely available. The precision and realism of these encounters are being improved by developments in computer vision, machine learning, and geographical mapping. Real-time data streaming and improved team collaboration capabilities in AR and MR are made possible by the inclusion of 5G connectivity. The potential for immersive spatial experiences is also being expanded by developers' exploration of applications in fields like telemedicine, IoT integration, and spatial computing. As these technologies develop, we may anticipate the emergence of even more creative use cases that will revolutionise a number of industries and the way we connect with the outside world.

Extended Reality (XR) technologies, which were previously limited to gaming and entertainment, have broadened their applications. XR is now being used in a variety of industries, for everything from immersive music experiences (Young and Smotic, 2022) to virtual property tours. This widespread acceptance highlights XR's growing versatility and market reach.

The democratisation of XR development is a significant trend in its evolution. Platforms such as Unity and Unreal Engine, in conjunction with cloud solutions (Aloqaily at al., 2022), have streamlined and made XR content creation more accessible (Nebeling, 2022). This shift portends an increase in diverse and rich XR content.

Early XR technologies faced difficulties in terms of user comfort and experience. Modern advances, on the other hand, have resulted in ergonomic headset designs and lower latency, enhancing controlled immersion and user retention.

Personalization is being revolutionised by the combination of AI and XR. AI-powered adaptive content responds in real-time to user behaviours and preferences, resulting in more engaging XR interactions (Flemisch et al., 2020; Ratican et al., 2023). Furthermore, AI's ability to automate the creation of intricate 3D content promises richer XR experiences with less development effort (Unity Technologies- Unity Releases Unity Industry, An Optimised Offering For Enterprises Building Real-Time 3D Experiences, 2023).

## How are immersive experiences different from 2D experiences?

Users can fully immerse themselves in three-dimensional environments through spatial engagement in immersive experiences such as VR and MR. This allows for unrestricted exploration, interaction, and navigation. 2D experiences on flat screens, on the other hand, are limited to clicks, taps, and scrolls, and lack the immersive spatial qualities. Immersive experiences strive to create a strong sense of presence in virtual environments, making users feel truly present. They enable users to interact with characters and objects in a more natural and engaging manner. Interaction in 2D experiences is limited to buttons, links, and menus, which are less immersive. Immersive experiences involve multiple senses, including haptic feedback and spatial audio for increased realism. This is in contrast to 2D experiences, which rely primarily on visual and auditory stimuli and lack sensory depth. Through depth and perspective, immersive environments effectively convey size and realism, facilitating the perception of spatial relationships. 2D experiences on flat screens, on the other hand, struggle to convey depth convincingly.

Furthermore, AR and MR seamlessly blend digital content with the physical world, enabling useful applications such as navigation and remote support. In contrast, 2D experiences on screens remain disconnected from reality and are primarily used for instructional or entertainment purposes.

# 3.2 IMMERSION

Immersion in the academic realm is multifaceted, particularly in virtual reality, narrative, and digital games. From a technical standpoint, Slater and Wilbur (1997) define it as a computer system's ability to generate a vivid virtual experience. Witmer and Singer (1998), on the other hand, define it as a psychological state of being deeply involved in an environment that consistently offers stimuli. Brooks (2003) broadened the term to include narratives, emphasising both the sensory and storytelling aspects of immersion. He, like Ermi and Mäyrä (2005), emphasised the importance of sensory components, particularly sights and sounds. Furthermore, Brown and Cairns (2004) emphasised the atmosphere of the game, including graphics and sound, as key immersion drivers. Ermi and Mäyrä (2005) developed the concept of challenge-based immersion based on gameplay mechanics. Finally, in VR studies, Diemer et al. (2015) emphasised the importance of system technology and content in determining immersion, which leads to the user's sense of presence. Note that immersion and presence are technically different terms, and there are several debates around the exact definitions (Slater, 2003).

"Immersion is a fundamental concept that defines the depth of engagement and absorption individuals experience within a given context or environment. It characterises the extent to which an individual becomes fully absorbed in an experience, to the point where they may lose awareness of their immediate surroundings."

Immersion can manifest in various contexts, from reading gripping novels or watching enthralling movies to engaging with cutting-edge technologies like virtual reality (VR) and augmented reality (AR). Key to immersion is sensory engagement. The more sensory modalities an experience stimulates, the more immersive it tends to be. Immersive storytelling, for example, harnesses visuals, sounds, and even tactile sensations through haptic feedback, creating a rich and captivating environment. This sensory diversity envelops individuals in the experience, rendering it more convincing. Furthermore, immersion requires a deep level of focus and concentration. When fully immersed, individuals become less aware of external distractions, wholly absorbed in the narrative or environment. This state of absorption, known as being "in the zone" or "in the flow," heightens enjoyment and engagement (Nah et al., 2014).

Emotional engagement is another integral component of immersion. Immersive experiences have the power to evoke strong emotional responses, such as fear, excitement, empathy, or joy. This emotional connection deepens the bond between participants and the content or environment, enhancing the experience's meaning and memorability.

In the realm of technology, spatial presence becomes significant, referring to the sensation of being physically present within a virtual environment (Berkman and Akan, 2019). VR, with its ability to create highly convincing and interactive virtual worlds, often excels in delivering spatial presence. Users feel as though they have entered a new reality, contributing significantly to the overall immersive experience. Temporal distortion, where individuals lose track of time or perceive it differently, is another hallmark of immersion. Deeply engrossed in an immersive experience, people may find that hours pass like minutes, underscoring immersion's profound impact on time perception.





## Factors influencing immersion

Immersion comprises sensory engagement, focus and concentration, emotional connection, spatial presence, and temporal distortion. It plays a pivotal role in various contexts, influencing how individuals interact with and respond to the world. Whether achieved through traditional media or cutting-edge technologies, the pursuit of immersion aims to create captivating, enjoyable, and impactful experiences. There are several factors that influence the state of immersion (Slator, 2018; Mütterlein and Hess, 2017)

### *Primary influencing factors*

- **Sensory stimuli**: The level of immersion can be determined by the quality and quantity of sensory stimuli that are presented to the user, such as visual, auditory, and haptic feedback.
- **Interactivity**: The level of immersion can be influenced by the level of interactivity and the degree of control that the user has over their virtual environment.
- **Narrative**: The level of immersion can be impacted by the narrative or story that is presented within the application. The more engaging and compelling the story, the more likely the user is to feel immersed.

### *Secondary influencing factors*

- **Comfort**: The level of immersion can be impacted by the comfort of the hardware used to deliver the experience. Discomfort or fatigue can detract from the overall sense of immersion.
- **Realism**: The level of immersion can be influenced by the degree of realism in the graphics, sounds, and other sensory stimuli presented within the application.
- **Agency**: The level of immersion can be influenced by the degree of agency that the user has within the virtual environment. The more agency the user has, the more likely they are to feel immersed.
- **Social factors**: The level of immersion can be influenced by social factors, such as the presence of other users or the ability to communicate with other users within the virtual environment.

## Levels of immersion in virtual environments

There are several key differentiating factors to define levels of immersion in VEs. Stater and Wilbur (1997) identify 5 key determinants —The first factor, "Inclusive," assesses how well the VE conceals actual evidence. The VE is less immersive and inclusive if you can feel the joystick or hear outside noises. In the second factor, "Extensive," the VE employs a variety of senses. Is it only visual, or does it include sound, touch, and smell as well? The third factor is "Surrounding," which refers to how the VE is visually presented. Virtual reality goggles, multiple screens, or a single computer monitor can all be used. As the VE fills your field of vision and blocks out the outside world, it becomes more immersive.

Using these 5 factors, authors __ classify levels as low, moderate and high immersion. However, their measurement construct doesn't account for the user's perceptual experience. Moreover, there is a lack of consensus on how levels are defined in various contexts (Wallace et al., 2010) . Therefore, in the development industry, the following levels are commonly used depending on experience's level of stimuli. (In light of this, BMW's 'vision dee' concept also uses these levels of immersion).

- **Non-immersive**: Non-immersive applications are those that do not fully engage the user's senses. They may use 2D interfaces or simple graphics that do not provide a fully immersive experience.
- **Semi-immersive**: Semi-immersive applications are those that partially engage the user's senses. They may use 3D graphics or other technologies to create a more immersive experience, but the user is still aware of their surroundings.
- **Fully-immersive**: Fully-immersive applications are those that completely engage the user's senses. They may use VR headsets, haptic feedback, and other technologies to create a fully immersive experience that feels like a separate reality.
- **Hyper-immersive**: Hyper-immersive applications are those that go beyond fully immersive experiences and provide a level of immersion that is almost indistinguishable from reality. They may use advanced technologies such as brain-computer interfaces or full-body haptic suits to create a fully sensory experience that blurs the line between reality and virtual reality.

## Key conclusions

The use of physical devices such as glasses or heads-up displays is required for the implementation of augmented reality (AR) and mixed reality (MR), albeit with certain limitations, influencing the level of immersion that users can experience. As a result, it can be argued that Augmented Reality (AR) and Mixed Reality (MR) are important in the automotive industry because they help to develop semi-immersive and fully immersive environments. This claim is supported further by the inclusion of client consultation in the confirmation of this relevance. The previously mentioned factor has significant implications for its application in the automotive industry because it has the potential to influence perceptions of safety and attentiveness. The ability of Augmented Reality (AR) and Mixed Reality (MR) to display additional and relevant information in their appropriate context, specifically in the form of visualising points of interest.

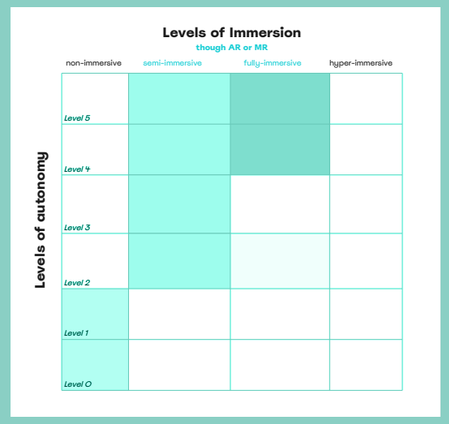



*Fig 3.3 Mapping XR technologies on LOA vs LOI matrix*

XR technologies are ushering in innovative, immersive experiences. Their widespread application signifies a vast potential for personalised immersive experiences across domains. It shows promise to change lifestyle at personal levels, which could translate to autonomous mobility with gained time. However, different mental models and interaction familiarity required for spatial experiences mediated through XR.

# SPACE OF XR IN AVS

*This chapter focuses on empirical and interpretative research on the integration of augmented reality (AR) and mixed reality (MR) technologies into autonomous vehicles. First, we examine the applications in driving and non-driving, the emerging challenges as a result of technological embodiment, the parallels between LOA and LOI, and finally, the stakeholders in the emerging space.*



## 4.0 APPLICATION OF AR/MR IN COMMUTING

The rise of self-driving cars (AVs) is a major turning point in the history of transportation. As the result of improvements in many different areas of technology, AVs promise to change the way cities look, change the way people move around, and usher in a new era of transportation solutions. Their rise isn't just a technological revolution; it's also a cultural and social change that requires a deep understanding of how they work, how their infrastructure works, and the many different fields that support them.

### AR/MR in driving situations

#### Automotive AR Windshield Displays Concepts

Augmented reality (AR) arguably plays a pivotal role in making driving safer and more enjoyable. The technology employs a wide range of display concepts, the most notable of which are windscreen displays (WSDs) and head-up displays (HUDs), each with their own set of distinguishing characteristics:

- **World-fixed HUDs and WSDs**: These displays anchor digital information in the real world, making a dynamic addition that interacts with the environment. Langlois and Soualmi (2016) found that AR-HUDs that are built into the windshield made it easier for users to stop and change lanes. This is because they help drivers quickly see what's going on again. In the future, large-scale world-fixed 3DWSDs could be used for immersive AR in cars.

- **ARHUDs or 3D HUDs** are displays that are fixed in the real world and have more than one depth plane, making AR experiences even more real.
- **Head-mounted AR glasses**: Devices like Microsoft's Hololens5 or MagicLeap's One6 (like in Audi Sky sphere concept) could be used in cars as an alternative to AR displays on the windshield.

AR technologies in self-driving cars can help with issues like distraction, user experience, trust, intention, and awareness of the situation. They can also be used to reduce distractions when driving manually (lower levels of automation, SAE 1,2,3). AR has many uses in the car industry, such as:

- *Communicating traffic light info*: AR cues can help make driving safer in bad weather when it comes to traffic light information.
- *Reduce inattentional blindness*, over-reliance, and risk compensation: AR-HUDs can be used to study how drivers see the road and what distracts them when they are driving manually (Ng-Thow-Hing et al, 2013; Tran et al, 2013).
- *Aids for navigation*: AR-map images on the windshield have been shown to reduce navigation errors by a large amount, especially for older drivers (Kim & Dey, 2009).
- *Declutter Information that isn't central*: It has been found that showing things like the weather or social media posts that have nothing to do with driving doesn't have a big effect on driving performance (Hauslschmid et al, 2015).
- *Influencing driving behaviour through gaming*: Ideas like "traffic light angry birds" and "zombie cars in poisonous clouds" have been suggested to get people to drive better (Steinberger et al, 2015).

## AR for elevating in-vehicle user experiences

User Experience (UX) research has shown that augmented reality (AR) can make it easier for people to trust and use automated vehicles. For instance:

- **Communication of system decisions**: Wintersberger et al. (2019) found that using AR displays to communicate system decisions made it easier to predict how AVs would act.
- **Design of visual elements**: The way AR visual elements, like navigational elements, are designed can have a big impact on how well they are accepted by users and how well they do their jobs (Parsch et al, 2019). Soro et al. (2014) said that creative prototyping should be the first step in making better user interfaces.

## AR for Trust Calibration in Autonomous Driving

AR has the potential to make a significant contribution to one of the most important human factors in automated driving, which is the calibration of trust. The technology can help the driver gain a comprehensive understanding of the autonomous vehicle's functionalities/performance, which can help to foster trust. The following are some of the most important findings of related research:

- **Path visualisation**: Sawitzky et al. (2019) found that showing a preview of the planned move made people more confident in fully automated vehicles.
- **Highlighting latent information**: Making hidden information about driving that is important for driving visible has been shown to increase trust in automated driving systems (Wintersberger et al, 2017).
- **Potentially reducing visual workload**: Comparing the AR HUD condition to the HUD condition showed that the AR HUD condition had more trust and a lower subjective workload (Ferlie et al, 2019).

## AR to Support Take Over Requests (TORs)

Take Over Requests (TORs) are an important part of automated driving that require drivers to respond quickly and accurately. AR has proven to be a dependable tool for managing TORs, a critical aspect of automated driving. Augmented reality can ensure a smooth and risk-free transition from automated to manual control by keeping drivers informed and vigilant:

- Gerber et al. (2020) discovered in their study on the use of heads-up displays (HUDs) for non-driving related tasks (NDRTs) that using HUDs to display NDRTs can help keep drivers' attention focused on the road, which leads to higher situation awareness during automated driving. However, when in the user journey it is most effective and is still open for investigation.
- Colour-coded road augmentation, such as that used by Lorenz et al. (2014), can visually guide the driver during the transition from automated to manual control. The use of a colour-coded corridor augmentation demonstrated this.
- An augmented reality head-up display (AR-HUD) can help drivers keep their eyes on the road by reducing the need to check the dashboard, thus improving road safety (Schroeter & Steinberger, 2016).
- Combining entertainment and information, as suggested by Schroeter et al. (2016), can aid in maintaining high levels of situation awareness even while performing tasks unrelated to driving.

With this, there are some key challenges that need to be considered while designing User experiences that involve such AR interfaces. Some of the challenges are varying level trust in the automated system, varying level of in-situ and pre-known knowledge and familiarity (mainly due to lower exposure), varying attention spans (subjective causes of distraction) and interpretation biases (multimodal displays could be interpreted differently).





# AR/MR in passenger experiences

Future transportation innovations will make passengers more important than drivers. Due to rising self-driving cars and Mobility as Services adoption. This makes it crucial to help passengers maximise their extra travel time regardless of mode of transportation. Modern passengers alternate between reading or watching videos and looking ahead or out the window. Same thing happens when a car drives itself. Higher levels of autonomy may allow for more use of surplus time. The chapter discusses how extended reality can improve passenger experiences.

In-vehicle displays, such as smartphones and dashboard screens, have gained popularity due to the convenience they provide travellers. Window displays or any flat surface inside a vehicle can now function as displays thanks to modern technological advancements. However, there are a number of issues with these displays. Their small size frequently limits the immersion experience (Cummings et al., 2015). Another issue is a lack of privacy, and the presence of multiple screens can create a distracting environment for passengers. External lighting conditions can also have an impact on these displays, causing glare and reflections that reduce visibility (Frangakis et al., 2014). Long-term use may cause physical discomfort, with issues such as neck pain becoming a concern (Farias Zuniga A & Cote, 2017). Furthermore, passengers may experience motion sickness if the display limits their perception of the vehicle's motion. Despite advancements in display technology, passengers continue to feel confined inside a vehicle (Groening, 2016)

## The novel XR displays:

Mixed reality displays can potentially alienate the drawbacks of the current in-vehicle displays. MR headsets address issues by displaying 2D and 3D virtual content with depth all around the person sitting in a chair (Mcgill et al., 2020)

It's a challenging space

Based on current technological architecture, content remains private and personal, unless shared with software. Novel headsets offer better graphics and consume relatively lower power. Occlusion issues can be solved by displaying any view in the headset and making interactions move with the user's movements. MR headsets enable new forms of communication, such as telepresence (McGill et al., 2016; Orts-Escolano et al., 2016). They can also be used to interact in a variety of ways, including gaze ( Lucero & Vetek, 2014) and direct (virtual) touch (Chan et al., 2010). MR headsets control how people perceive motion, preventing motion sickness by matching what they see to what they feel. They aid in the prevention of MS by tracking head movement and altering visual cues and appearance in the digital space (McGill et al., 2017). Virtual environments that transport users to another world enhance the "place illusion" and the sense of being there i.e presence (Cummings et al., 2015; Slater,M., 2009). MR headsets have been shown in studies to help with things like showing people how to properly put on a life vest (Chittaro et al., 2018). and blocking out noise in the cabin (Gulliver., 2017). They have been used by passengers on flights.

*Primary Applications*: Getting Things Done, Having Fun, and Being immersed

- **Productivity**: Because MR headsets can create a large virtual workspace, users can begin working immediately while on the train or bus ((Mcgill et al., 2020; McGill et al., 2015).
- **Entertainment**: They can display real-world landmarks, create games, and create experiences based on the landscape and location (Wienrich & Schindler, 2019).
- **Isolation**: MR headsets can block out real-world distractions, resulting in a private, relaxing virtual environment that can even resemble the user's home (Lewis et al., 2016).

## Effects on Passengers' Emotions

MR technology has the potential to alter people's perceptions of themselves and their surroundings. It can create more private and personal spaces while also blocking out outside noise. The technology could be used to completely or partially divert people's attention away from things that make them uncomfortable. It was most effective in situations with limited space (Lewis et al., 2016) MR headsets have been used to test various vehicles, including planes (Gulliver, 2017 ; Holly, R., 2017 ; Kuchera, B., 2015) and self-driving cars from Renault (Dent,S., 2017) and Apple (Rober, M., 2018). It is expected that passengers will be able to access their private virtual workspace, making their journey more enjoyable.

## Challenges and impediments

Several challenges must be overcome before the potential of Mixed Reality (MR) headsets in transit can be realised. VR headsets have limitations in terms of field of view (typically 90˚-130˚) and comfort, particularly in mobile versions. The Microsoft Hololens 2, an AR headset, has a 70˚ field of view. However, given technological advancements, its anticipated that the high-quality, lightweight headsets will become mainstream in the near future, as evidenced by the progression of Oculus Rift DK1 (2013) and Oculus Quest 2 (2019).

It is critical to remove roadblocks to their use in transit. The VR Hyperspace project (University of nottingham) identified barriers such as cost, scepticism about VR immersion, a lack of standardisation, and security concerns. McGill et al. (2019) classified these difficulties as follows:

- **Functional impediments:** Issues such as maintaining a sense of direction in moving environments, ensuring physical safety, and avoiding motion sickness are examples of functional impediments.
- **Impediments to acceptance/adoption:** While technical capacity may exist, obstacles such as social acceptability and limited interactive features may prevent adoption.

Addressing these issues will pave the way for improving and popularising MR experiences in public transportation. Here, tables 4.1 present an overview of functional impediments (challenges or problems related to use of headsets in commuting) and impediments to Acceptance and Adoption, with their resolution strategies.

Functional Impediments

| Challenge | Description | Resolution strategy |
|---|---|---|
| **Maintaining a Forward Bearing** | The gyroscopes and accelerometers in MR headsets are not intended to account for vehicular motions in transit (LaValle et al., 2014). As the headset's bearings shift, the presentation becomes disoriented. | One solution could be to create new tracking technology that is adaptable to transit motions. Another option is to use data from the vehicle's accelerometer and gyroscope to calibrate the headset in real time. |
| **Physical Crash Safety** | MR headsets increase the mass of the head by about 10% (The 360 Guy., 2019 ; Gekhman, D., 2006) which may affect the force exerted on the neck during a collision. Furthermore, airbags may collide with the headset, causing it to break and release dangerous debris. | Future MR headset designs must consider crashworthiness. Regulatory agencies should also impose safety standards for the use of MR headsets in public transportation. When a crash is imminent, advanced warning systems could be integrated to prompt headset removal. |
| **Motion sickness** | The visual presentation in MR headsets can cause a sensory mismatch with the actual motions of the vehicle, resulting in motion sickness (Mcgill et al., 2016 ; Carter et al., 2018 ; Stevens & Butkiewicz., 2019). | Sensory mismatch can be reduced by synchronising the visual cues in the headset with the actual motion of the vehicle in real time. Furthermore, vestibular counter stimulation techniques such as Galvanic Vestibular Stimulation (Sra et al., 2019) could be used. To reduce motion sickness, a comprehensive framework that takes into account both the physiological state of the passenger and the state of the vehicle could be developed (Iskander et al., 2019). |

Impediments to acceptance and adoption

| Challenge | Description | Resolution strategy |
|---|---|---|
| **Interface Design** | Making the MR experience seamless and simple to use, even in confined or moving environments such as vehicles (Arshad et al., 2015 ; Ahmad et al., 2015). | Creating specialised interfaces that work well in constrained environments and can adjust based on the spatial constraints of the user (Burnett et al., 2013 ; Ng & Brewster., 2016). |
| **Sensory Mismatch and Motion Sickness** | Motion sickness can be caused by the disconnect between what the user sees in MR and what they feel in real life (Ng et al., 2017). | The incorporation of vehicle motion data into the mixed reality (MR) experience aims to achieve synchronisation between visual and kinesthetic cues. This sync reduces sensory mismatch and the occurrence of motion sickness (Frisson et al., 2017). |
| **Privacy Concerns** | Information transmitted through MR headsets could potentially be overheard by other passengers on public transportation. | Using filters or screens within the MR experience to hide sensitive data from anyone who isn't supposed to see it (Lucero & vetek, 2014), supporting isolation for productive tasks. . |
| **Social Acceptability** | Using MR headsets in public places may cause social stigma or discomfort. | Sociological and psychological studies are being done to learn more about how people think about MR devices, and work is being done to improve their design and look to make them more socially acceptable (Chan e al., 2010). |
| **Supporting Shared Experiences** | Supporting long-distance communication with real-world depth and scale, particularly suited to private transportation modes such as self-driving cars (McGill et al., 2016 ; Orts-Escolano et al., 2016 ; Fanello et al., 2016). | Capturing passengers with integrated depth camera technology for more embodied telepresence; determining how to render others at a distance, particularly in confined spaces such as cars or planes (Hoffman,M., 2016 ; Pots, J., 2016). |
| **Exploiting Vehicle Motion for Immersion** | Using the vehicle's motion and context to create more novel, engaging, and immersive experiences (Marshall et al., 2019 ; Kodama et al., 2017 ; Simeone et al., 2015) could be overwhelming. | Allowing users to have control ranging from active to passive in the movement calibration (Goedicke et al., 2018). Prior knowledge of the route and actions could build anticipation of felt experience and awareness of context (Dent. S., 2017 : Baldwin et al., 2017). Differentiation of Motion Profiles, Motion Conveyanceand Magnitude of Motion Modifications (Wilson et al., 2018). |

*Table 4.1 Impediments to embodiment and acceptance*

# 4.1 PARALLELS BETWEEN LOA AND LOI

There is a significant gap in empirical research concerning the interaction of Levels of Autonomy (LOA) and Levels of Immersion (LOI). Therefore, the following interpretation draws on previously synthesised findings to investigate the dynamics of LOA and LOI in the context of user experience. We can gain a better understanding of the relationship between varying degrees of autonomy and immersion by analysing how these two dimensions influence the user experience in autonomous vehicles, which ultimately helps to realise the problem statement.

## Relation between LOA and LOI

The following are the possible connections between different levels of autonomy and different levels of immersion:

**Driver disengagement allows deeper NDRT participation**: Increasing autonomous vehicle autonomy allows for greater immersion. As vehicle autonomy increases, passengers will be able to focus less on driving and more on other activities. This role and responsibility change allows for deeper immersion in augmented and mixed reality interfaces. This high level of immersion allows passengers to interact extensively with augmented and mixed reality interventions and create personalised experiences that meet their needs. Level 5 fully autonomous vehicles will let passengers immerse themselves in virtual worlds or interactive simulations while the vehicle drives.

Note that relation LOA and LOI is not direct, meaning level of immersion doesn't increase as level autonomy goes up. It is mediated by the user's choice. LOA defines the role of the user whereas LOI defines the level of stimuli the experience entails. The in-situ experience occupants choose is driven by their mental state and commuting motivations.





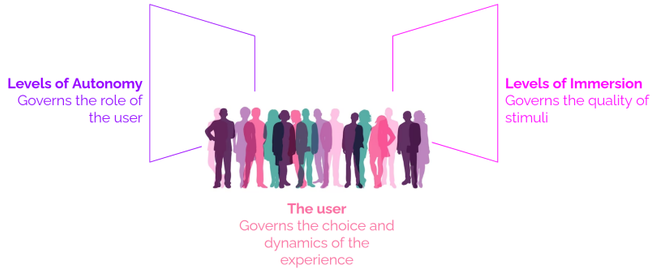



*Fig 4.1 Understanding relation between LOA and LOI*

Possibly,, LOA and LOI may affect passenger experiences in the following ways:

**Less autonomy and immersion**: Level 0 or Level 1 vehicles, where humans have significant control, may focus more on driving. Due to driving, passengers must limit immersion. Small displays and audio systems may be present.

**Higher Autonomy, Lower Immersion**: Level 2 and Level 3 autonomy allows passengers to do more than drive. Critical driving moments may limit immersion. Passengers could use larger displays or advanced infotainment.

**Higher autonomy and immersion**: Vehicles with Level 4 or Level 5 autonomy can operate without human intervention in most situations, giving passengers a more immersive experience. They work, play, or relax in cars. Advanced AR/VR, larger displays, and interactive interfaces could enhance passenger immersion.

**Autonomy fosters interaction, which enhances Immersion**: Passengers have more ways to interact with the vehicle and the world as autonomy increases. Augmented and mixed reality interventions can enhance immersion and interaction. Passengers can use augmented reality interfaces or voice commands to control and interact with vehicle features, access information, and manipulate virtual objects while the driver focuses on the road ahead.

**Immersion levels affect user commitment and autonomy confidence**: Immersion can affect a passenger's engagement with the vehicle and perception of its autonomy. Immersion can increase passengers' trust in the autonomous system and willingness to use it for various tasks. Immersive augmented and mixed reality interventions can boost passengers' confidence in autonomous vehicles and improve user experience.

**Creating immersive experiences for different autonomy levels**: Augmented and mixed reality interventions can be designed using the autonomy-immersion mapping. Designers can customise immersive experiences based on each level's autonomy. At lower autonomy levels, interventions can focus on providing informative and engaging content to improve passive observation. Interventions can immerse passengers in their chosen activities with interactive simulations, entertainment, or productivity tools at higher autonomy levels.

**Higher-level immersion challenges and ethics**: Immersion in autonomous vehicles can be difficult and ethically questionable. Higher immersion in autonomous vehicles is difficult and ethically questionable. As immersion increases, balancing virtual and physical realities becomes more important. This protects passengers and prevents distractions that could impair autonomous driving. When creating hyper-realistic experiences, ethical issues like data privacy, content moderation, and virtual environment addiction should be addressed.
Understanding these relationships between autonomy and immersion helps create meaningful, personalised augmented and mixed-reality interventions that improve the occupant experience in autonomous vehicles.

# 4.1

# STAKEHOLDERS IN SPACE OF XRinAV

Understanding the diverse stakeholder landscape is critical in the field of integrated Extended Reality (XR) and Autonomous Vehicles (AV). This landscape is created by dissecting the AV and XR arenas separately, then combining these analyses using logical and informed judgement. The stakeholders in XRinAV space are visualised in figure 4.2. This sub chapter describes the primary stakeholder groups, as well as their interests and goals in this innovative space.

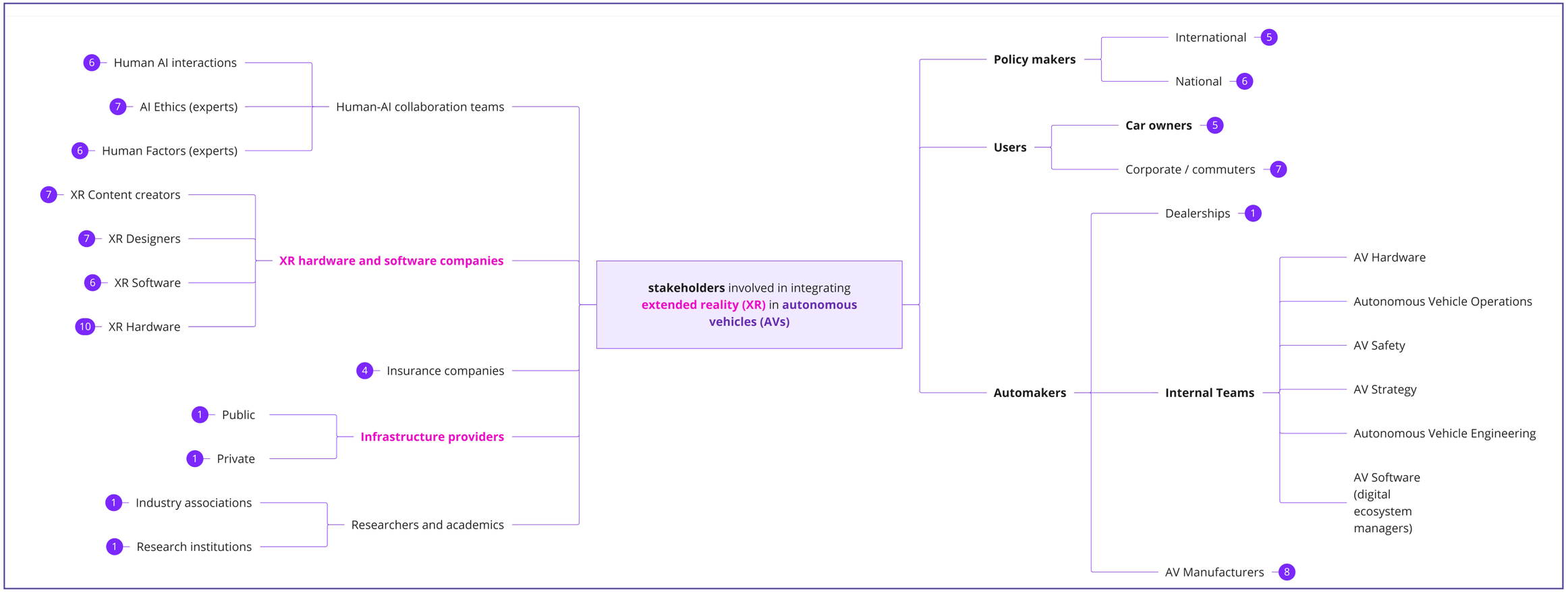



*Fig 4.2 Stakeholders in XRinAV*

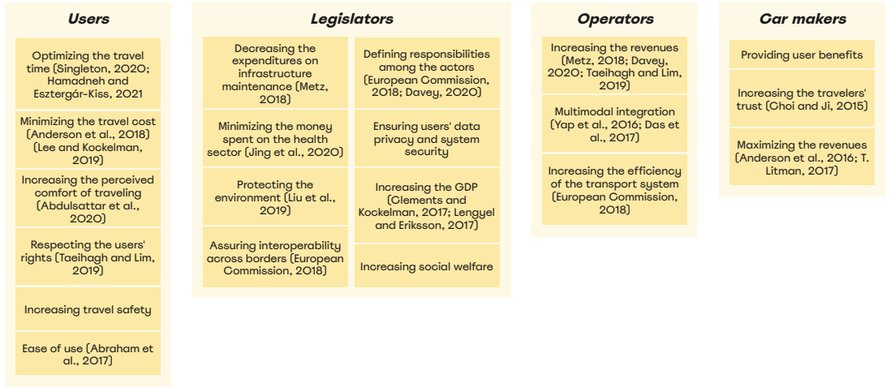



*Fig 4.2 Key Stakeholders in space of AV and thier objecives*

## Key Stakeholders in the space of AV

The users or travellers are at the forefront of this convergence. Users' motivations vary across a broad spectrum of mobility choices. Several factors influence their decisions. The allure of reduced travel times provided by AV route optimization promises shorter commutes (Elvarsson et al., 2020; Zhang and Guhathakurta, 2017). Furthermore, the elimination of manual driving relieves travellers of the frequently experienced stresses of traditional travel (Hao and Yamamoto, 2017; Kopelias et al., 2020). With AVs poised to revolutionise safety paradigms with their advanced features, safety, an ever-present concern, gains renewed importance (Taeihagh and Lim, 2019). Furthermore, the incorporation of XR technologies enhances the AV experience by providing rich avenues for onboard multitasking and entertainment (Singleton, 2019). Finally, aspirations for dependability, increased comfort, and cost-effective travel intersect in the AV domain (Abdulsattar et al., 2020; Malokin et al., 2019; Shet and Schewe, 2019; Bösch et al., 2018; T. Litman, 2020).

Legislators emerge as the defenders of technological evolution. Their primary goal is to create a strong and effective regulatory framework, which includes regulatory bodies, local and national governments, and road safety departments. This framework not only aims to ensure the smooth integration and operation of AVs, but it also prioritises public safety and anticipates potential legal issues.

On the operational front, both public and private operators navigate operational challenges. Their agenda is two-fold: they want to ensure seamless AV integration and operation while also ensuring customer satisfaction and profitability.





Car manufacturers and technology firms are the primary stakeholders in the tech dimension. This category includes everything from Original Equipment Manufacturers (OEMs) to technology providers, insurance companies, and tier suppliers. Their goals are multifaceted, with a focus on the development, production, and marketing of cutting-edge AV technologies. Furthermore, insurance stakeholders are developing specialised policies for AVs, while tier suppliers are embarking on specialised component manufacturing and delivery missions.

## Additional stakeholder when XR is integrated in AVs

The XR landscape introduces its own set of stakeholders in addition to the direct AV canvas. XR providers—companies at the cutting edge of AR, VR, or MR technologies—emerge as critical players. Their attention is focused on the ground-breaking incorporation of XR within AVs, which has the potential to usher in a transformative passenger experience. They are complemented by XR platform content creators, whose role becomes critical in curating engaging and immersive content for AV passengers.

# Introducing key user personas

Understanding user personas is critical in the rapidly evolving landscape of XR and AV integration. These detailed profiles not only reveal who is likely to engage with such emerging technologies, but they also influence stakeholder decisions ranging from policy formation to service implementation. Each persona, with its distinct blend of knowledge, curiosity, and emotional inclinations—be they optimistic or anxious—provides a lens through which engagement strategies can be tailored that ultimately, inform the plausibility of the interventions. While early adopters may be quick to embrace, sceptics may require solid proof of safety and functionality. Furthermore, personas provide invaluable insight into design preferences, such as a preference for control or a desire for immersive XR experiences during commutes. In essence, by delving into user personas, stakeholders can ensure that their efforts are aligned with real-world expectations, ensuring the technology's seamless adoption and societal resonance (Hassenzahl, 2013).

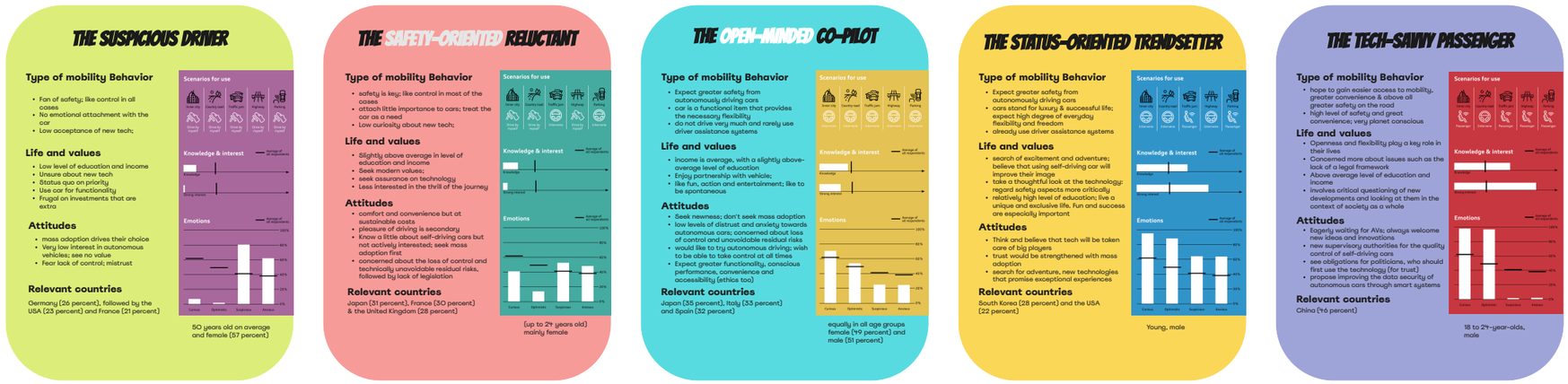



*Fig 4.3 User personas defined by Audi in the space of AV (2019)*

In light of the significance of user personas, it is critical to note that major automobile manufacturers have already recognized and acted on this understanding. Renowned brands such as Volvo, Bentley, and Audi have invested heavily in developing and deploying user personas in order to align their innovations with customer expectations. While there is a wealth of information from various automakers, Audi's EV personas from 2019 stood out in their depth and comprehensiveness, closely mirroring what might be expected from Mercedes — though direct access to Mercedes' internal personas was restricted due to corporate logistical reasons. This alignment between car manufacturers' personas and their innovations emphasises an important point: those who are inclined to invest in and use AVs are the same people who will embrace the transformative experience of XR in commuting. Understanding these personas and predicting XR engagement becomes an invaluable asset in shaping the future of autonomous mobility.

The overview of personas from Audi that entail pointers of lifestyles, values, mobility behaviours and preferences. Moreover, they show how subjective measures like knowledge, curiosity, optimism affect the choice of automation.

## Plotting persons on levels of autonomy

Personas show clear tendencies of which category of users will choose to go into higher levels of autonomy and opt into immersive space in AVs. As seen before, in higher levels users' role in driving is minimal, leaving occupants with a choice to engage in the NDRTs. Moreover, this choice is also driven by trust in the system (Frison et al., 2019; Miglani et al., 2016) . This suggests that in the higher levels interactions should be occupant centric and in lower levels they should be drive centric interactions. One of the key opportunities here is to design trust building/calibrating experiences with immersive technologies to address personas that have low tendency to choose higher levels of autonomy — The suspicious drivers and The safety oriented reluctants.

The comprehension of personas facilitated the identification of XR interventions that would yield the most significant outcomes for users across varying levels of autonomy. This factor also influenced the decision-making process regarding users' cognitive and affective states, as well as their anticipatory behaviours, during the design of the optimal TOR in phase 2.

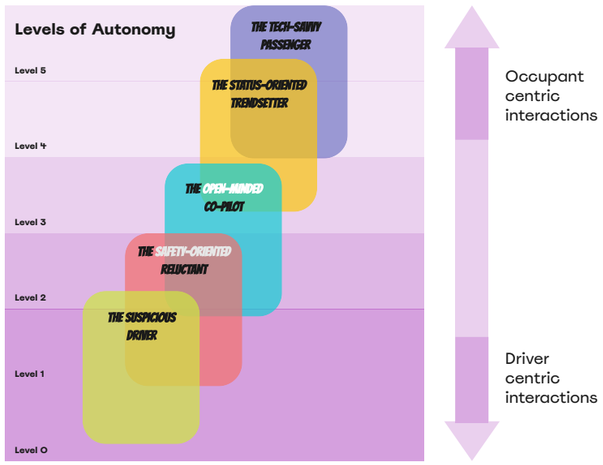



*Fig 4.4 User personas in relation with Levels of Autonomy*

# SUMMARY OF KEY FINDINGS FROM LITERATURE



The primary aim of the literature review was to understand the strategic opportunities for designing the speculated scenarios. The approach here was – the speculated XR interventions should tap the gaps (in unaddressed values, or challenges) that only XR interventions could fill. For example, XR adds the possibility of engaging in productive or entertainment related tasks in higher levels of autonomy, where the user's role is minimal. This approach creates a strong value proposition for proposed interventions, which eventually add to the validity of the results, relevancy to the stakeholders (especially the client) and finally, to the plausibility of the proposed future. Secondly, it was necessary to create an understanding of XRinAVs with respect to Levels of autonomies and immersion. As there is a lack of empirical evidence in this domain, primarily due to its novelty.

The following insights were drawn from the literature that informed the subsequent phases of the project—speculations and the groundwork for phase 2.

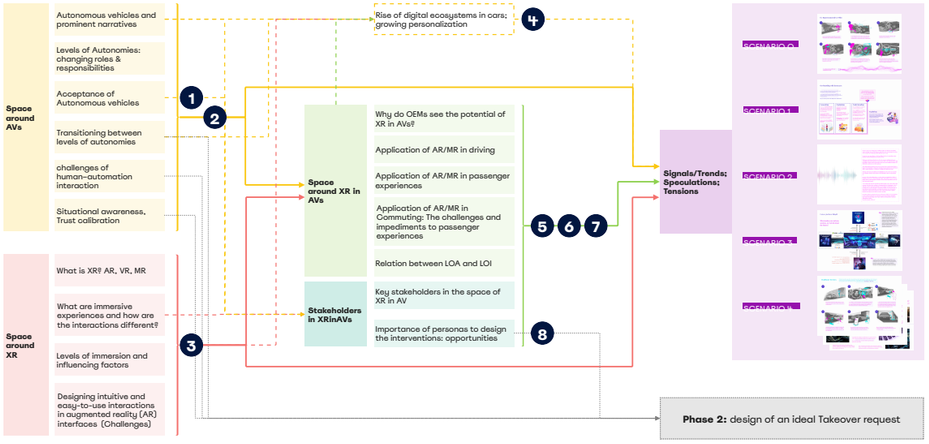



*Fig 4.5 Overview of literature review (numbered insights in black dots)*

**Insight 1**

Acceptance studies confirm the importance of developing a qualitative understanding of the deeper layers of perception of novel technological interventions. It also emphasises the importance of prioritising values such as trust, safety, and control when developing hypothetical interventions. This also implies that during research sessions, it is critical to begin with AV and XR and then move on to XRinAV for a better understanding of the future and to uncover the deeper needs, concerns, and expectations of technology.

**Insight 2**

Trust plays a pivotal role in the adoption and enhancement of user experience. It stems from perceived usability, safety, security, privacy, and reliability (Kaur & Rampersad, 2018). The literature emphasises the importance of appropriately calibrating trust for promoting acceptance and adoption (Jing et al., 2020). This trust is multifaceted, influenced by a myriad of subjective factors such as knowledge, curiosity, and optimism, as reflected in technology acceptance models and user personas (Nastjak, 2020; Stiegemeier, 2022). Intriguingly, personas illuminate the ways in which individual values and mobility behaviours influence these subjective factors, leading to differing levels of acceptance towards greater autonomy and immersive experiences in Autonomous Vehicles (AVs). It's crucial, therefore, to design trust-enhancing experiences using immersive technologies tailored for those personas less inclined to embrace higher autonomy, notably 'The suspicious drivers' and 'The safety oriented reluctants'.

**Insight 3**

Following an investigation of the XR space, it became clear what types of experiences can be obtained and through which media (hardware and software- which also require some kind of content platform for accessing those experiences). It also stated that AR/MR are the most relevant technologies from level 0 to level 4. And, VR is only relevant for levels 4-5, given that the challenges have been resolved. Furthermore, the most relevant levels of immersion for this study are semi-immersive and fully immersive.

**Insight 4**

Roles with higher levels of autonomy open up the possibility of repurposing users' time and engaging in non-driving activities. As a result, OEMs are integrating digital ecosystems and e-commerce capabilities into automobiles to enable a variety of productive and entertainment-related experiences. Following this path of development may lead to the integration of XR platforms (which provide immersive services) in automobiles. Collaborations with relevant stakeholders such as XR hardware manufacturers, XR software developers, and XR content creators may be required.

**Insight 5**

The combined understanding of the XR and AV spaces clarified the key challenges that AR/MR could solve in driving scenarios. AR interventions can effectively address challenges such as situational awareness and workload management during control transfer situations.

**Insight 6**

Despite positive inclinations from personas like trend-setters or the tech-savvy, there persists a significant scepticism regarding AVs. This scepticism arises from limited knowledge (owing to scarce exposure and evidence), safety concerns (stemming from perceived loss of control), and privacy apprehensions. This presents a unique opportunity: the creation of an immersive, experiential onboarding experience that caters to all user types. Such a platform would equip users with the essential knowledge about AVs, acting as an educational playground. It promises to foster familiarity with evolving roles and establish robust mental models for Human-Machine Interfaces (HMIs). A proposed structure for this immersive on-boarding experience could look like the following —.

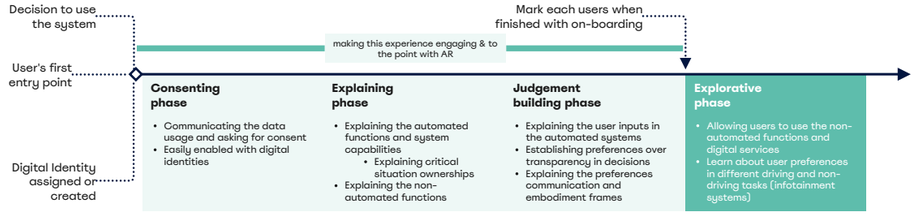



*Fig 4.6 Hypothised phses of on-boarding*

**Insight 7**

Understanding diverse stakeholder values/interests and dynamics of XRinAV space enables investigation of several tensions that show complexity of this space. These tensions are discussed later in chapter 6.

**Insight 8**

Understanding the personas created an understanding of which type of XR interventions will provoke what kind of users. For instance, if speculated intervention talks about an immersive gaming experience, then insights from personas like The-status oriented trend setters will be more favouring whereas, personas like suspicious drivers will be extensively critical. This informed the selection of personas for phase 2, it is explained later in the report where it's relevant.

# ABOUT THE METHODOLOGY

*This chapter describes the methodologies used in our study. We begin by understanding context mapping, followed by an introduction to speculative design, also known as "futuring." We conclude by discussing how strategic blend of these methodologies shape the overall approach of our project.*

## The blend of two methodlogies

This project uses speculative design to stimulate imagination, generate ideas, and foster debate about the challenges of integrating immersive technologies into autonomous vehicles. We create detailed scenarios that embody various speculative outcomes to help users better connect with what the future may hold. These scenarios are intended to prompt users to consider their future selves and express their thoughts, ideas, and concerns.

We use context-mapping techniques to delve deeper into the nuances of public needs, expectations, and concerns. These methodologies enable us to investigate deeper layers of human reaction to potential future technological interventions. Our research activities, which include developing thought-provoking questions, creating fictional scenarios (both with and without participant participation), and identifying key thematic connections, serve as a solid foundation for future research in this area.

The theoretical foundation for these research methodologies is provided in this chapter, which is followed by a demonstration of the practical application of this technique in the following chapter.

# 5.0 CONTEXT MAPPING

Context mapping is critical early in research projects, laying the groundwork before a clear problem statement emerges. This method is intended to draw on users' and stakeholders' rich reservoirs of knowledge, recognizing them as experts in their own lived experiences (Sleeswijk Visser et al., 2005; Sanders & Stappers, 2012). Context Mapping Study (CMS) distinguishes itself from traditional interview and observation techniques by delving into acceptance factors and perceptions. It evens the playing field, allowing designers to step away from their expert roles and embrace experimentation. Stakeholders can access tacit knowledge (understandings we can't easily articulate) and generate novel insights through dynamic discussions by facilitating collaborative and creative exercises.

Despite the inherent challenges and demands on the facilitator, qualitative research, particularly when motivated by genuine curiosity, can derive enormous value from context mapping (Esser, 2018). The primary goal is to elicit emotional responses from participants when they are presented with imagined future scenarios. This provides insight into consumers' perceptions of the risks and benefits of these hypothetical futures. The "*path of expression*" assists participants in correlating insights from current and historical commuting experiences, facilitating discussions about anticipated future interactions.

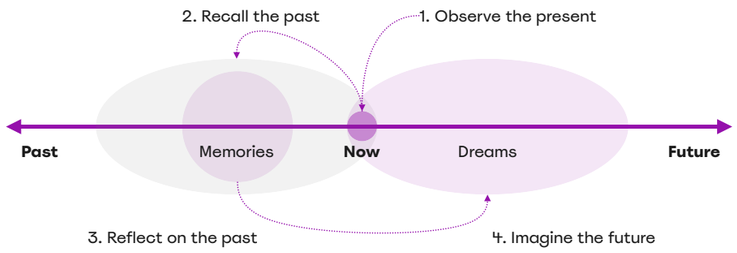



*Fig 5.1 The path of expression*





However, because needs, values, and future desires are intangible and unfamiliar to most people, discussing them can be difficult. Sanders and Stappers (2012) explain this using a layered model that distinguishes between latent knowledge (unexperienced thoughts and ideas) and tacit knowledge.

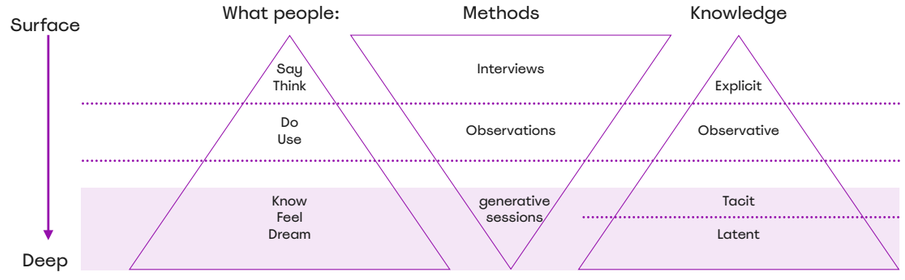



*Fig 5.2 Methods to assess different levels of knowlegde*

## A three-phased approach to context mapping

**Set-up**: In this stage, the researcher prepares for the session by carefully selecting and inviting participants. It is critical for the facilitator to define the scope of the study and the primary areas of focus.

**Sensitizing Activity**: Prior to the main session, participants may participate in a "sensitizing" activity. This exercise, which can last from a single day to a week, aims to awaken participants' dormant tacit knowledge. While it covers the broad scope of the research, the focus can be narrowed during the main session.

**Session**: This phase consists of a dynamic mix of creative activities in which 2-10 participants actively participate. Provocative scenarios and questions serve as catalysts, igniting expressive conversations and experience mapping.

**Analysis**: Following the session, the facilitator processes the information gathered. The acquired data (such as recordings) is analyzed with the necessary permissions. During the synthesis phase, techniques such as Statement Cards, Clustering, and Grounded Theory coding are essential for translating raw data into meaningful insights.

To summarize, context mapping is more than just a research methodology; it is a gateway to deeper, often intangible, user insights. It provides a nuanced understanding through its multifaceted approach, empowering designers to make informed decisions in their subsequent designs.

# 5.1 SPECULATIVE DESIGN

> *We want to investigate the perception of future. But, which future are we talking about? and, when we pose questions to end users, where would they are start answering the question. The scope of the future is so large that it is impossible to fully consider all of the potential outcomes. so how can we zoom in?*

At its core, speculative design employs imagination to address complex issues, creating spaces for debate and alternative ways of envisioning our world (Raby & Dunne, 2013). In contrast to traditional design, which provides tangible solutions, speculative design is provocative, abstract, and rooted in possible futures, prompting people to reflect on the present (Auger, 2013).

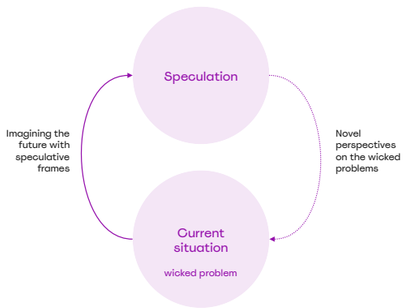



*Fig 5.3 Use of speculative design the given context*

Speculative design "*thrives on imagination and aims to open up new perspectives on what are sometimes called wicked problems, to create spaces for discussion and debate about alternative ways of being, and to inspire and encourage people's imaginations to flow freely*" (Raby & Dunne, 2013).

Critical design is the foundation of speculative design. Key figures in this space, Dunne and Raby, changed their terminology from "critical design" to "speculative design" in the early 2010s, reflecting the evolving nature of their practices (Dunne and Raby 2013). The practive of speculative design is also commonly known as futuring.

Though the definition of "speculative design" varies, it has been used in a variety of fields. It was used by Gaver and Martin (2000) to create design workbooks that present new design possibilities. Its influence can also be seen in urban planning and literary criticism, demonstrating its adaptability (DiSalvo et al. 2016; Bardzell and Bardzell 2013).





While traditional design emphasizes current solutions, speculative design emphasizes the act of speculation, emphasizing future narratives (Galloway and Caudwell, 2018). It does not always provide concrete solutions; instead, it encourages people to empathize with potential future scenarios, making its outcomes more intangible and its impact difficult to quantify. Design research is more concerned with what we can learn from the artefact/embodiment of a future narrative, whereas speculative design is more concerned with the speculation itself (Galloway and Caudwell, 2018). Speculative design in the world of HCI presents potential alternate futures that may not always align with conventional notions of practicality and profitability. This approach encourages us to question our preconceptions and imagine alternative sociotechnical worlds.

Speculative Design serves as a bridge in corporate settings, challenging conventional corporate thinking while introducing innovative future possibilities (Wyche, 2005). Because of this integration, speculative design has become an essential tool for imagining potential corporate futures.

## The methodical practice of 'futuring'

Speculative design is a systematic approach to developing informed hypotheses. Futuring is the cognitive process of perceiving and analyzing transformation patterns, and then generating hypothetical scenarios that depict potential future states (Smith, 2020; Inayatullah, 2013).

Futuring is a methodical approach. Future scenarios are based on meticulously researched components such as signals, trends, and drivers (Smith, 2020; Figure 12). **Signals** are thought to be the most fundamental units of building speculations. These are empirical observations, or real-world occurrences found in various sources. A **trend** is the accumulation of signals that show a consistent pattern over time and serves as a foundational element for subsequent analysis. Trends are recurring transformation patterns that occur over a long period of time. Patterns can follow a linear, exponential, or cyclical progression and have an ascending or descending trend. Examples include the decline of a once-powerful political movement, an increase in specific educational institutions, and the spread of technological use. The ultimate constituent: **drivers**, initiate trends. These long-lasting phenomena serve as the underlying causes for the occurrence of specific trends over time. Capitalism, climate change, and neocolonialism are some of the issues that can be discussed.

Figure 5.4 depicts the future in theory. This is due to the fact that signals, trends, and drivers will shape the future. Trends will form and disintegrate depending on the drivers, and events (signals) will occur. This is true both now and in the future. Note that it is impossible to predict the future and create such a clear "*image*" of it, due to uncertainity. However, because drivers are very long-term, they can be used to imagine and plan for likely future trends and events.

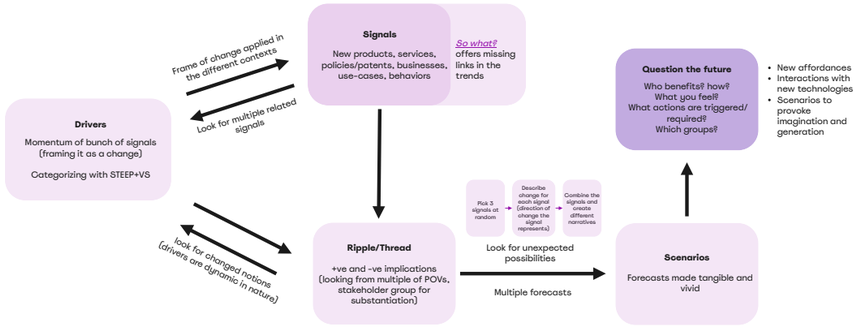



*Fig 5.4 Overveiw of futuring process to avail novel perspectives*

## Mapping for plausible futures

The future is uncertain. As a result, attempting to forecast it with any degree of accuracy is deemed irrational. Uncertainty is a natural and pervasive component of all future scenarios. Nonetheless, by determining the probability of various scenarios, it is possible to narrow the vast array of potential futures to a more limited set that is more relevant to the given project, issue, or situation.

Figure 5.5 depicts Voros's (2003) classification of futures into four distinct types. Potential future scenarios that are expected to occur based on extrapolation of existing trends are referred to as *probable* futures. This phenomenon is commonly known as a forecast, with the goal of predicting future events. Potential developments and patterns rooted in existing knowledge and comprehension are used to generate *plausible* future scenarios. This phenomenon can be defined as the cognitive ability to predict or anticipate future events or outcomes. *Possible* trends are used to generate potential futures.

The three aforementioned variants are '*neutral*' in the sense that they refer to potential outcomes rather than preferred outcomes. However, it is also possible to build a *desirable/preferred* future (Puglisi, 2001), which is normatively evaluated based on values.

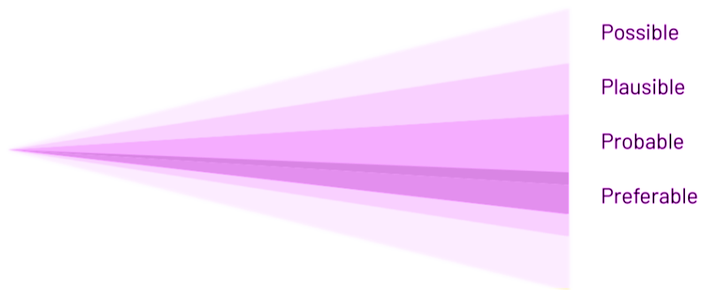



*Fig 5.5 Types of futures*





## Rationale for priorotising plausible futures

To meet both research objectives and stakeholder interests, it is critical to focus on plausible futures rather than just possible or probable ones. Layers of complexity are introduced by the rapidly evolving world of immersive technology, combined with the complexities of the mobility space. Furthermore, stakeholder objectives frequently diverge, making it difficult to forecast likely futures. Users may feel distant or disconnected from possible futures, especially given their unfamiliarity with emerging immersive technologies and their familiarity with mobility. Therefore, emphasizing plausible futures works best for this study. Lawson et al. (2015) argue in support of this approach, that speculating on and discussing such plausible yet hypothetical technologies can be especially effective in understanding and analyzing trends in contemporary technology design.

## Various forms of speculations

As deisgn fictions, various form such as scenarios, personas, sketches, storyboards, and videos can be conceptualized (Blythe, 2017). The use of a audio-visual format in presenting the scenario is widely recognized as the most effective method of eliciting a response from stakeholders. The manner in which text is presented is critical in a variety of situations. According to Smith (2020), starting frames with phrases like "*What if?*" or "*Imagine...*" can be a good way to get stakeholders talking.

## Evaluation criteria for experimental Futures

According to Baumer, Blythe, and Tanenbaum (2020), the evaluation criteria for experiential futures differ depending on the work's intended purpose. They've proposed several frameworks for evaluation, including critical design, narratology, entertainment, and user studies. User studies provide the most appropriate framework for evaluation in this study. The responses to the introduced design fiction in these studies provide valuable insights into people's perceptions and priorities regarding XR in AVs. Furthermore, it is worth noting that speculated futures should be generative in nature.

Several essential criteria for scenarios and future prototypes emerged during the "*concretization*" phase of Baumer, Blythe, and Tanenbaum's evaluation framework: Clarity: The scenarios must be easily understood; Plausibility and Relevance: They must be both likely and useful to the company's goals; Persuasiveness: The scenarios should encourage participants to propose conditions that would make the future scenario a reality. They should reveal their concerns and suggestions for the future.

### The following criteria was deviced for refining the speculations.

**Clarity**: Is the situation presented easily understood?
**Plausibility**: How likely is the scenario presented? How useful is the scenario in terms of planning for the future? Are there any other potential scenarios or events that should be considered?
**Persuasiveness**: After experiencing the scenario, how do you feel about potential interventions? Can you recommend any strategies or policies to address the aforementioned events?
**Revealingness**: How helpful is the scenario in identifying future issues? What questions or thoughts does it elicit? How should the government respond? What goals should it pursue?

5.2

# STRATEGIC BLEND OF SD AND CONTEXT MAPPING

Understanding the future necessitates the use of novel methodologies that combine both current user perceptions and long-term vision. The strategic blending of speculative design and context mapping is one such method that has yielded promising results. Here's a more in-depth look at this integration:

Context mapping projects primarily investigate user perceptions for the near future. When combined with Context Mapping Sessions (CMS), speculative design adds a temporal dimension, emphasizing the uncertain, ever-changing nature of the future.

The power of speculative design extends beyond forecasting. It actively challenges the status quo, encouraging individuals and societies to do so. Speculative design investigates the future by forming a coherent vision, which sparks rich discussions and guides thought. Individual and societal resilience and adaptability are encouraged by this method. The use of speculative design in urban planning and design is critical. It alters our perception of cities by emphasizing the importance of a balanced approach that addresses immediate needs while also facilitating long-term change. Its emphasis on collaboration is notable. Rather than persuading stakeholders, it promotes cooperative and equitable growth. Finally, by focusing on resilience, speculative design encourages proactive and forward-thinking planning, making our future visions robust and flexible.

### The Integration Methodology:

This combination of speculative design and context mapping was thoughtful. Following extensive consultations with experts, a strategic approach was adopted. This unique blend was created with the help of design professors and practitioners, including those from Muzes studios.

During the sensitizing phase of the CMS research, speculated scenarios were incorporated. This served to stimulate generative thinking right before the interviews, ensuring that participants were thinking about the future. Furthermore, elements of speculation were introduced during sessions to simplify discussions about complex topics. Participants were not simply passive recipients when scenarios were narrated or displayed to them. Instead, these scenarios served as probes, prompting participants to articulate their reasoning and facilitating comprehension of their points of view.

The sensitizing phase was critical in this blend for several reasons. It prepared participants by prompting them to think ahead of time. It facilitated discussions on abstract concepts such as seamlessness, immersion, and ideal journeys. It laid the groundwork for scenarios that would encourage participants to consider potential use-cases and reflect on their emotions and perceptions.

Speculative design, interestingly, departs from traditional design methods by moving away from a solely user-centered view of the future. It acknowledges the importance of multiple stakeholders, resulting in a more comprehensive and informed approach to future scenarios. This complemets the context mapping frame of investigation.

Finally, the strategic combination of speculative design and context mapping provides a promising approach to understanding both current perceptions and future visions, bridging the gap between today's realities and tomorrow's possibilities.

SPEACULATING

# 6 BUILDING SPECULATIONS

*Speculative design provides a methodical approach to scenario planning, as we have seen in the chapter 5. Here, we see how the futuring was applied in the project to build plausible speculations. This chapter also presents the drivers of change and tensions that were identified through trends research.*



Tensions in the space of XRinAV (88)

Final forms of speculations (96)

# 6.0 SCENARIO BUILDING

## Signals mapping: Sensing

A signal is anything that can be used to gain insight into what might happen in the future, and according to the Smith and Ashby, everything can be considered a signal. No matter how small, every signal tells us something about what might happen in the future.

### Sensing deep and broad, from diverse sources

Learning about the present and how it differs from the past can help predict the future. Sensing is a process of mapping signals. Instead of relying solely on one source for information, it is advisable to utilize a diverse range of sources.

Over the course of two weeks, signals conducive to the assignment scope were mapped with keen attention. Based on the theorotical foundations (phase 1), project's objectives and needs, the major domains or sub-domains that are most important to the future were identified for being examined. The temporal scope was defined to be 3-5 years— the chosen duration allows for significant change and takes into account the topic's systemic nature.

Once the signal was traced, it was examined for frequency of occurrence, source strength, directionality, maturity, and spread/contagion. The following source categpries were used to map the signals.

1. a datapoint, such as a quantitative or qualitative indicator (eg survey data or economic data);
2. a piece of analysis (eg an expert opinion); Industry News and Magazines
3. a new product or service (eg a new piece of technology or an interesting business model);
4. sentiment (eg a public poll or an informed review);
5. a behaviour (eg a hack of an existing product or system or a shift in buying patterns);
6. an item of news (eg an announcement or update in ongoing news);
7. a message or communication (eg advertising, slang or a visual signal);
8. a scientific finding (eg a breakthrough in research or a new insight); Univeristy research labs
9. Technical Journals and Conferences, Industry Reports, XR and AV-centered Online Platforms

The exact sources could be seen the Notion database — Appendix D.

When using these sources to sense signals and map trends, a multi-modal approach was ensured. Meaning, leveraging both qualitative and quantitative data and gathering information from both technical and non-technical sources.

## Protocol to write signals

A signal library (database) — a central location — was created on Notion to capture and organise the signals in one place. The signal was assigned a title that was framed as a change in a succinct way — helps to interpret the trend. For example, a trend with the description — "*Based on McKinsey's sales scenarios, L3 and L4 systems for driving on highways will likely be more commonly available in the private-passenger-car segment by around 2025 in Europe and North America, even though the first applications are just now coming into market*" — was framed as "*L3 and L4 more commonly available by 2025*". The description and source (Autonomous driving's future: Convenient and connected, 2023) of the signal was also captured in separate columns

## Organizing the signals using STEEP framework

As the signals were being mapped, they were assigned category tags from the STEEP framework: *Social, Technological, Economic, Environmental, or Political*. This categorisation helps to understand the spread of signals and visualise the gaps to fill in. As I gathered signals from various sources, need for two more category tags emerged. Autonomous mobility presents a lot of systemic changes such as infrastructure, road safety policies, changes in supply chain, etc. Plus, commuting has been part of users for a long time, resulting in value associations. Autonomous mobility also presents ethical and ideological issues that might shift mobility space significantly. Therefore, *Values* and *Systemic* tags were added. One important thing to note here is, the code were categorised based intuition (informed by personal vision and judgement build from initial research) of the researcher.

The category tags are —

**Social:** Issues related to human culture, demography, communication, movement and migration, work and education.

**Technological:** Made culture, tools, devices, systems, infrastructure and networks.

**Economic:** matters of value, money, financial tools and systems, business and business models, exchanges and transactions.

**Environmental:** The natural world, living environment, sustainability, resources, climate and health.

Political: Legal issues, policy, governance, rules and regulations and organizational systems.

**Values:** trends or drivers that address issues such as ethics, spirituality, ideology or other forms of values that represent important shaping factors in a project's scope

**Systemic:** trends or changes that are originate/occur/drive/impact the development at systemic scale.

## Assigning Impact horizons

Gathering signals was a dynamic process. As the signals were being scanned, the database 'signals library' was being updated dynamically. After assigning category tags, the impact horizons were assigned. This involves the mapping of the likelihood and anticipated consequences of trends onto forthcoming timeframes. It could be thought of as a life of a trend. For this, three future horizons were considered.

After assigning a few horizons to trends, it was observed that some trends could have larger impact on one horizon and minor one on the other horizon(s). Therefore, 'secondary impact horizons' column was added. For example, the trend mentioned before— *L3 and L4 more commonly available by 2025* — will have primary economical and technological impact on the horizon 1 and it will have secondary impact on horizon 2. This could be translated as with widespread adoption of L3 and L4, people will start trusting the AVs more, and the increasing user buy-in will drive the economy. This is also in relation with other economical trends, such as *'New economical models on the rise ( in and around AV space)', 'Softwares in cars show great monitory prospect'* and, *'Companies are offering new services in Metaverse'*.





## Criteria for assigning horizons

A number of variables that might affect the creation and uptake of new trends are the basis for the criteria used to assign horizons to trends. The criteria considers the level of technical maturity and accessibility, as well as the trend's present stage of growth. Additional requirements are determined by outside variables including the political and regulatory framework, market demand, and the availability of resources. The time it takes for a new trend to catch on in society might also depend on infrastructural needs and other factors. Technological advancements, economic and geopolitical circumstances, and cultural and behavioral conventions may all significantly affect how quickly a trend is adopted. Lastly, while determining the time frame for adopting a new trend, the potential for disruption and the influence on various industries was taken into account. Overall, based on a variety of pertinent aspects that may influence a trend's development and adoption, the aforementioned criteria are intended to give a thorough and diverse approach to evaluate the trend's horizon.

Master table | by categories (STEEP+VS)

**Signals library**

| Aa Title | STEEP+V | Pri Horiz... | Sec imp... | Three Ps | Description of trend | Sources |
|---|---|---|---|---|---|---|
| Autonomous vehicles can communicate with the pedestrians directly | Social | Horizon 3 | Horizon 1<br>Horizon 2 | Plausible | Pedestrians are vulnerable in the autonomous mobility | Habibovic, A., Lundgren, V. M., Andersson, J., Klingegård, M., Lagström, T., Sirkka, A., ... & Larsson, P. (2018). Communicating intent of automated vehicles to pedestrians. *Frontiers in psychology*, *9*, 1336. |
| Systemic approach towards AV from governments | Political | Horizon 1 | Horizon 2<br>Horizon 1 | Plausible | Autonomous vehicles are part of the larger system, that monitors the overall movement and efficiency | Sarah Pink, Katalin Osz, Kaspar Raats, Thomas Lindgren, and Vaike Fors. 2020. Design anthropology for emerging technologies: Trust and sharing in autonomous driving futures. Design Studies 69 (2020), 100942. |
| Automating the AI generated content | Technological | Horizon 1 | Horizon 1<br>Horizon 2 | Probable | The release of GPT-4, the adoption of APIs, and LLM open-source solutions have added to the acceleration of (ai-generated content) | DelSignore, P. (2023, March 24). *AI and the Law: What You Need To Know*. Medium. https://medium.com/the-generator/ai-and-the-law-what-you-need-to-know-bfebb51b7d53 |
| AI-content creation has questionable IP | Political | Horizon 1 | Horizon 2<br>Horizon 1<br>Horizon 3 | Probable | AI-generated content is still a new technology and copyright laws are a mess | DelSignore, P. (2023, March 24). *AI and the Law: What You Need To Know*. Medium. https://medium.com/the-generator/ai-and-the-law-what-you-need-to-know-bfebb51b7d53 |
| AR in AVs has a growing market | Economical | Horizon 1 | none | Probable | According to Fortune Business Insights , the global AR in the automotive market size was 4,51 billion US dollars in 2021 but is expected to grow to 14,4 billion US dollars in 2028 | https://www.fortunebusinessinsights.com/augmented-reality-ar-in-automotive-market-105593 |
| Increased adoption of XR in social media platforms | Social | Horizon 1 | none | Probable | An example of an industry segment that has taken advantage of AR are social media platforms, such as Snapchat, TikTok and Instagram, with social media AR filters that are used in photos to engage their users and improve user experience. | Ohlson, S. (2022, November 2). *Use Cases of Augmented Reality in Vehicles | Basemark*. Basemark. https://www.basemark.com/news/use-cases-of-augmented-reality-in-vehicles/ |
| 2D to 3D visuals using HUDs | Technological | Horizon 1 | none | Probable | Most of the HUDs today are 2D, but in the future there will be 3D HUDs that allow to visualize depth information on the windshield. | Ohlson, S. (2022, November 2). *Use Cases of Augmented Reality in Vehicles | Basemark*. Basemark. https://www.basemark.com/news/use-cases-of-augmented-reality-in-vehicles/ |
| Video AR as way of visualising contextual information | Technological | Horizon 1 | none | Probable | Video AR is real-time camera footage from the front-facing camera that is used in heads-down displays (HDD), such as, the instrument cluster or on the central display system where enriched data is rendered on top of the camera input. | Ohlson, S. (2022, November 2). *Use Cases of Augmented Reality in Vehicles | Basemark*. Basemark. https://www.basemark.com/news/use-cases-of-augmented-reality-in-vehicles/ |
| AR enhances safety and navigation | Technological | Horizon 1 | Horizon 2 | Probable | AR enhanced navigation experiences are also applicable on HUDs, where the navigation will take place on the windshield – eliminating the need for the driver to move the head and sight away from the road. | Ohlson, S. (2022, November 2). *Use Cases of Augmented Reality in Vehicles | Basemark*. Basemark. https://www.basemark.com/news/use-cases-of-augmented-reality-in-vehicles/ |
| Higher levels of Autonomy require higher level of trust and transparency in decision making | Values | Horizon 1 | none | Probable | As we reach higher levels of autonomous driving, the need to understand how well the vehicle can identify and make decisions based on different driving scenarios is crucial. | Ohlson, S. (2022, November 2). *Use Cases of Augmented Reality in Vehicles | Basemark*. Basemark. https://www.basemark.com/news/use-cases-of-augmented-reality-in-vehicles/ |
| AR helps to communicate the decision made by ADAS | Technological | Horizon 1 | none | Probable | Using AR to visualize the ADAS detections allows the driver to understand the reasoning behind actions while adding an additional level of safety measures. | Ohlson, S. (2022, November 2). *Use Cases of Augmented Reality in Vehicles | Basemark*. Basemark. https://www.basemark.com/news/use-cases-of-augmented-reality-in-vehicles/ |
| 'Point of Interest' visualisation in AR will grow | Technological | Horizon 1 | none | Probable | Point of interest, also called location-based AR, combine GPS data with AR to generate relevant | Ohlson, S. (2022, November 2). *Use Cases of Augmented Reality in Vehicles | Basemark*. Basemark. |

*Fig 6.1 Signals library created on Notion for easier orgonisation (found in Appendix D*

| STEEP+VS | Criteria | 0-3 years | 4-7 years | 7-10 years |
|---|---|---|---|---|
| Technological | Available technology | High | Medium | Low |
| Technological | State of maturity | High | Medium | Low |
| Technological | Technological breakthroughs | Low | High | Medium |
| Political | Existing political or regulatory environment | High | Medium | Low |
| Economical | current Market demand | High | Medium | Low |
| Economical | Long-term investments | Low | Medium | High |
| Economical | Projected Economic or geopolitical factors (+gut) | Low | High | Medium |
| Social | Societal readiness | Medium | High | Low |
| Social | Behavior or cultural norms | Low | High | Medium |
| Systemic | Disruptive potential; predictions from experts; Influence on industries | Low | Medium | High |
| Systemic | Infrastructure requirements (not sufficient yet) | Medium | High | Low |
| Ecological, systemic, Technological | Resource availability | High | Medium | Low |

*Table 6.1 Criteria for assigning 3Hs*

**Note:** This criteria is not state of the art. It was made specifically to aid reader's comprehension of the followed process. While the 3Ps have soft edges, there may have been a few instances that didn't match this metric precisely. Depending on the context and particular circumstance being examined, the criterion (each variable) might change.

## Assigning 3Ps

For complementing the process of assigning impact horizons, 3Ps come handy. 3Ps— probable, plausible, possible— talk about the probability of likelihood. It is explains in simple terms below.

**Probable:** The continuance of existing patterns that are expected to occur, based on our collective understanding of the world at the time. *(based on current knowledge, it's fairly likely to happen)*
**Plausible:** Trends that are possible based on what we now know or understand. *(It might happen)*
**Possible:** Future developments that are not implausible based on our existing understanding. *(well, it's not impossible to happen)*

| *Criteria* | Probable | Plausible | Possible |
|---|---|---|---|
| existing evidence | High | Medium | Low |
| Data and statistics about present | High | Medium | Low |
| Consensus among experts | High | Medium | Low |
| Alignment on different fronts (steep+vs) | High | Medium | Low |
| Emerging technologies; evidence in reports | Low | High | Medium |
| Early indicators; partial evidence | Low | High | Medium |
| Consistent with societal values | Low | High | Medium |
| Economic or geopolitical factors | Low | High | Medium |
| Gradual shift in behavior or cultural norms | Low | High | Medium |
| Speculative or hypothetical scenarios | Low | Low | High |
| Dependent on multiple factors; complex to predict with gut | Low | Low | High |
| Unpredictable events | Low | Low | High |
| Niche groups or subcultures | Low | Low | High |
| Weak signal | Low | Low | High |

*Table 6.2. Criteria for assigning 3Ps*





## Peer review to mitigate the bias

Two peers investigated the category tags, impact horizon, and probability of likelihood to reduce potential interpretation bias. The review sparked a fruitful discussion, which resulted in an improved iteration. For example, the previously mentioned signal — *L3 and L4 more commonly available by 2025* — was discussed in terms of its classification as a technological or economic trend. Given that the origin of this signal was derived-from/ grounded-in economic forecasts, the decision was made to classify it within the economic domain. This way, as a result of the discussion surrounding the topic, the interrelationships between the signals and their impacts were discovered.

## Data visualisation for tapping the underrepresented areas

In futuring, it is recommended that the signals should be well distributed in all categories. Getting a broad sense of distribution and realise the blind spots or under-researched areas is important to create a more detailed sketch of the futures. For visualising, the data was refined manually, and converted into a csv file. It was then visualised using *Tableau*. On the vertical axis 3Ps were plotted and on horizontal axis primary impact was plotted. Fig 6.3.

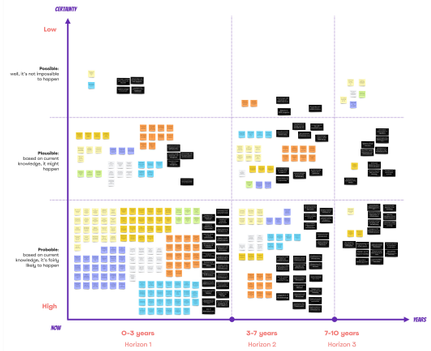



*Fig 6.2 Ideated trends to map impact trends (in black)*

After understanding the gaps, ideation was done by keeping technologies central (as acceptance and perception technology and availed experiences was in focus). The ideated (in black) trends were then added to the library.. See Fig 6.2.

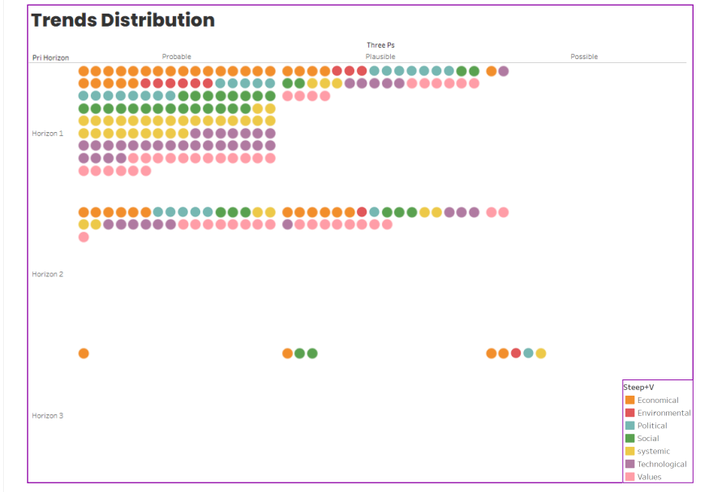



*Fig 6.3 Visualising the data points (using Tableau's co-occurrence matrix)*

# 6.1 IDENTIFYING DRIVERS AND TENSIONS

## Mapping Drivers of change

A key part of Futuring is recognizing what are called "drivers of change." Drivers show the momentum of clusters of signals. They are the driving force behind the change. It is important to strike a balance between research, expert perspectives, and the active participation of stakeholders when trying to identify change drivers. Having a solid grasp on these foundational elements allows us to foresee potential future scenarios and create novel *threads* that not only meet upcoming challenges but also spark new ideas/debates.

All of the aforementioned factors — such as judgement build from environmental scanning, trends identification, stakeholder dynamics— play pivotal roles in determining drivers or influencing the nature of future outcomes. The following drivers were found — fig 6.4.

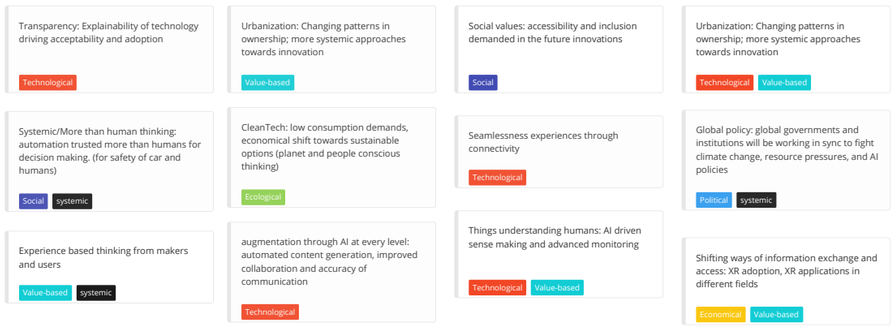



*Fig 6.4 Identified drivers of change*





The drivers are identified based on analysis on a personal scale and then were discussed with experts and peers (fellow design students). The drivers deviced in other works involving blockchains, Future AI, Future of work, autonomous mobility, and immersive technology (Eg. Institute of Futuring, 2022; *What's the Future of Generative AI? An Early View in 15 Charts*, 2023) in order to validate the identified drivers of change.

Drivers of change helped to understand the projected futures. They also informed the process of thread roadmapping i.e future narratives, (discussed later in this chapter). To integrate creative future narratives, provocative question frames connecting to the the research questions/ gaps/ challenges and the company's interest, *tensions* in the space were also analysed.

### Mapping Tensions

In this context, "*tension*" refers to conflicts that arise from integrating immersive technologies into autonomous vehicles as a result of divergent interests and integration facets. These tensions highlight the difficulties in integrating immersive technologies harmoniously for successful implementation (Tatar, 2007).

Practitioners deal with these tensions in order to imagine alternative futures, allowing stakeholders to assess technological implications (Mitrovi et al., 2021, p. 94). Divergent stakeholder objectives can cause conflict. Beyond surface-level discussions, speculative design broadens possibilities, if these tensions are leveraged.

The balance between immersion and safety is an important example, as immersive experiences may distract users from driving responsibilities. Similarly, given the potential data collection that may jeopardize privacy, balancing immersion and privacy is critical. These tensions highlight the importance of finding solutions that address the needs of all stakeholders and resolve these tensions. The ideal integration improves user experience, ensures safety, protects privacy, and meets the goals of autonomous vehicles.

### Process of Mapping Tensions

Tension help to understands the complexity of the emerging space. In order to recognize these tensions, a comprehensive process was carried out. This process combined trend analysis and stakeholder mapping in order to gain valuable insights into the underlying conflicts and challenges associated with the incorporation of XR technology in autonomous mobility.

The categorization of trends or signals into STEEP+VS facilitated a focused analysis of tensions, value similarities and challenges within each dimension. Critical analysis was performed to examine the impact of each trend, encompassing its advantages, disadvantages, conflicts, and challenges. This resulted in the recognition of internal tensions within each aspect. Interconnections between trends were analyzed to uncover interdependencies and mutual influences, thereby highlighting previously unnoticed subtle tensions like usability vs complexity. Studying these interconnections provided valuable insights into the intricate nature of integrating XR and autonomous mobility. Stakeholder Mapping was the next phase in the process.

Stakeholder (in the space of XRinAVs) perspectives, objectives, and concerns were assessed through various methods such as interviews, and literature reviews, enabling a comprehensive understanding of potential conflicts and diverse interests. Users, regulators and carmakers were central to this process. The power dynamics and influence of each stakeholder group were evaluated qualitatively, revealing tensions arising from disparities in resource allocation, conflicting agendas, or competing interests.

The values were derived from the analysis of trends and the interviews with subject-matter experts. These current or future values were evaluated side by side and found to be either comparable, contradictory, or independent. The focus was on identifying conflicting interests in order to understand their dynamics by using future scenarios to elicit those tensions.

The discovered value tensions were as follows: (Colour codes show the category of sources in tensions.)

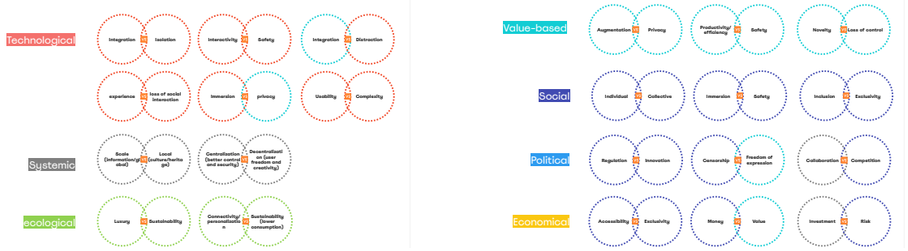



*Fig 6.4 Identified Tensions (orgonised by STEEP+VS)*

## Rationale to work with tensions

Navigating the integration of immersive technologies in self-driving cars necessitates a nuanced approach. To foster collaboration, it is critical to understand users' perceptions and address their needs while also recognizing stakeholders' diverse interests. Identifying the underlying conditions that fuel biases in tensions is also critical, as is acknowledging that the intensity of tensions varies by context. To effectively address these challenges, proactive solutions, whether technological or design-focused, are required. Therefore, it was decided to leverage tensions in the provocative frames (in speculations). Furthermore, a focus on ethical issues, particularly safety, privacy, and equity, ensures that technology is not only functional but also responsibly integrated, protecting both individual and societal interests.

## Factors contributing to tensions

There are a number of variables that can affect the tensions involved in integrating immersive technologies into autonomous vehicles. Here are some parameters (Kempeneers, 2022; Davis and Nathan, 2015; Tatar, 2007) that can affect these tensions:

**Maturity of Technology:** The developmental stage of immersive technology can result in trade-offs between realism and safety. Distractions may be introduced by underdeveloped technology, compromising the driving experience.

**Regulations** address issues such as safety, privacy, and potential distractions. Clear guidelines can help to balance the benefits of immersion with safety concerns.

**Preferences:** Passengers in self-driving cars have a variety of immersion preferences. While some may prioritize security or community, others may prefer a high level of customization.

**Multi-sensory Integration:** Combining immersive technology with existing vehicle sensory systems such as sight and sound can help to reduce distractions. A poor integration, on the other hand, may degrade the overall experience.

**Nature of Intervention:** The rationale and setting of the integration, as well as the vehicle's context, have a significant impact on tensions. In driving-focused events, safety may take precedence over immersion, whereas in leisure settings, a more immersive experience may be desired.





**Calibration of Trust:** It is critical to calibrate trust between users and the vehicle system. Transparency and user input into system decisions can shape the balance between autonomy and control.

**Human-thing Interaction Design:** The design interface is critical. An intuitive design that reduces distractions and encourages communication can reduce tensions and improve user experience.

The interplay of these parameters and their temporal evolution can have a significant impact on the tensions and resultant effects that arise in the integration of immersive technologies within autonomous vehicles.

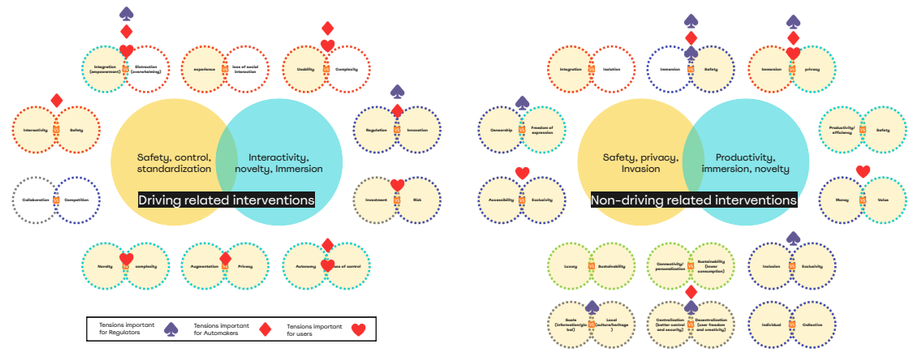



*Fig 6.5 Interpreting the biases in Tension values from various points of views*

## Prioritising tensions to be leveraged

In initial attempts to prioritise tensions, they were clustered. Later, they were viewed from users perspective, being a key actor in the assignment, to interpret the user tendencies. The knowledge of different personas (previously discussed) came handy in this analysis. The yellow filled values mark the preferences/biases users might have towards one face or both the faces of the conflict. Later they were also viewed from car-makers' and policy-maker's perspectives.

With this understanding, the criteria formulated for the selection of tensions revolve around the adoption and acceptance of XR interventions.

**Key Criteria for selecting tensions**

1. The tensions being examined present a significant challenge in terms of interpretation for individuals, highlighting the inherent complexity within them.
2. Extended Reality (XR) emerges as a crucial intermediary for the tensions.
3. Resolution of these tensions is in direct alignment with the interests of the client — The incorporation of software in automobiles continues to be a primary focus for consumers, with a strong emphasis on safeguarding *privacy* and prioritizing *safety* within the design philosophy.

# The following tensions were prioritised

**immersion** VS **safety**

The tension between **immersion and safety** is a pertinent issue in the context of augmented reality (AR) experiences, as the latter has the potential to divert drivers' attention and thereby compromise their safety. Although augmented reality (AR) has the potential to aid drivers by offering up-to-date information about their environment and facilitating navigation on unfamiliar routes, it may also pose a distraction and divert their focus from the road. The conflict issue concerns the tension between the aspiration for a fully engaging encounter and the imperative to guarantee the protection of the driver.

**autonomy** VS **loss of control**

The dichotomy between **autonomy and loss of control** is a salient issue as users may experience a sense of relinquished control (with associated values like competence, confidence) when utilizing autonomous vehicles. Augmented Reality (AR) has the potential to mitigate this conflict by offering instantaneous feedback on the automobile's functioning and behavior, including velocity and orientation, thereby fostering users' trust in the vehicle. The present conflict pertains to the competing interests of self-governance and apprehension over relinquishing authority.

**integration** VS **distraction**

The conflict between **integration and distraction** is a pertinent issue in the context of Augmented Reality (AR) technology. The concern stems from the possibility of AR causing driver distraction, which could potentially jeopardize their safety. The integration of augmented reality (AR) technology in vehicles has the potential to offer valuable information, such as speed limits, potential dangers and navigation directions. However, it may also serve as a source of distraction, diverting the driver's attention and intuition from the primary task of driving. The conflict revolves around the competing interests of assimilation and the imperative to circumvent diversion.

**usability** VS **complexity**

The dichotomy between **usability and complexity** is a notable issue in the context of AR interfaces, as these interfaces may be ephemeral and necessitate a period of acclimation to achieve proficiency. Although augmented reality (AR) has the potential to furnish valuable insights to drivers, its complexity and usability challenges may impede its effectiveness, resulting in user frustration and errors. The conflict pertains to the dichotomy between the inclination towards user-friendliness and the likelihood of intricacy.





**Final forms of speculations (96)**

**immersion** VS **privacy**

The tension between **immersion and privacy** stems from the aspiration to provide a fully immersive augmented reality encounter while simultaneously safeguarding the privacy of the user. From one perspective, the immersion of AR experiences in self-driving vehicles can be enhanced through personalization that caters to the user's individual preferences and environmental context. However, it is possible that users may be disinclined to divulge personal information or grant the vehicle permission to monitor their movements. The conflict relates to the tension between the inclination towards a customized and engaging encounter and the imperative to safeguard the confidentiality of user data.

**social interactions** VS **isolation**

The conflict between **social interactions and isolation** is related to the ability of augmented reality (AR) in the context of autonomous mobility to both foster and hinder human connections. On the one hand, augmented reality (AR) can enable passengers to interact, share experiences, and even connect with others outside the vehicle, effectively bridging the physical and digital worlds. An over-reliance on augmented reality experiences, on the other hand, may lead to feelings of isolation as people become engrossed in their own virtual worlds, reducing face-to-face interactions and shared experiences with fellow passengers. This conflict highlights AR's paradoxical ability to both augment and degrade human connections in contexts of shared mobility.

**personalization** VS **invasion**

The balance between **personalization and invasion** comes to the fore as XR technologies seek to improve user experiences through customized AR interfaces. Personalization entices users by implying that augmented reality (AR) can provide them with tailored information and experiences based on their preferences, habits, and needs. However, an underlying tension exists here: how intrusive does this personalization feel? As AR systems collect more data to fine-tune the user experience, concerns about invasive surveillance, unwanted data collection, and potential misuse of such data become more pressing. This tension highlights the trade-off between wanting a personalized AR experience and being concerned about privacy.

**accessibility** VS **exclusivity**

The struggle between **accessibility and exclusivity** emerges as XR technologies become more integrated into autonomous mobility. While the goal of augmented reality is to democratize information and create universally accessible interfaces, these technologies may cater to specific demographics due to economic, technological, or educational barriers. For example, advanced augmented reality features could be restricted to luxury autonomous vehicles or require premium subscriptions, potentially creating a divide between those who can and cannot access them. The pull here is between AR's democratizing potential and the risk of encouraging socioeconomic exclusivity in its application.

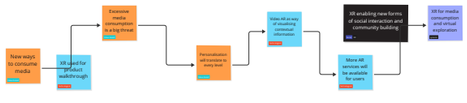
# 6.2 MAPPING FUTURE SCENARIOS

## Mapping threads

After a thorough search for signals and sources that are associated with your project by this point, and found a number of patterns were found. The next stage was to design the future narratives i.e playing with future sequence of events and their impact. A thread is formed by sequence of events.  The sequence is created by connecting several signals together. This process of forcefully or naturally connecting the signals or trends is also called roadmapping. The result is a thread. Example of threads as follows.




A person is immersed in work with AR-slides, when all of a sudden a car he is sitting in comes to an halt due to connectivity malfunction. Immediately next available car comes for the pick-up. You login with your AV-OV chipcard, and the new vehicle gets your digital identity and learns your preferences. A person continues to work on AR-slides in the same way as before.




The personalization in the vehicles is at the extreme, the things to remember for driving are being forgotten due to point of view visualization with AR. As a result of this, users are choosing to invest more and more time in NDRTs.

*Fig 6.6 Example of thread framing*





### Balancing novelty and familiarity

Speculative designs should utilize ambiguity and open-endedness in order to spark the audience's curiosity. They can generate a sense of wonder through unexpected and imaginative concepts. Developing this relatedness could come with various strategies. Employing humor and irony is an effective way to make complex or obscure ideas more accessible to audiences. Provocative or challenging elements can stimulate debate by pushing viewers to question their assumptions. Establishing emotional connections helps audiences better understand abstract themes or issues in a more concrete manner.

> ***"By observing and taking advantage of mundane, subtle, quirky but ultimately familiar behaviours or perceptions, the speculative designer can take the viewer on a journey to a technological future or alternate present that, whilst potentially alien, makes perceptual bridge/sense." (Auger, 2013)***

The perceptual bridge can be created in a variety of ways, for as by using identifiable items, well-known stories, or conventional design elements. The perceptual bridge's effectiveness hinges on striking the correct balance between novelty and familiarity. Although too much novelty might make it challenging for viewers to relate to the scenario being portrayed, too much familiarity can make a speculative design look routine or dull. In order to generate tension or dissonance between the probable future and the present, the perceptual bridge can also be deployed. Designers can call attention to the presumptions and attitudes that underlie the present and ask viewers to challenge them by emphasizing the disparities between the two.

Another challenge is to create futures that are plausible and have a sense of relatability with the involved stakeholders especially the client. The the future narratives should be compelling and detailed. preserving the realism of the technology is critical for the study to be effective and yield actionable results (Holmquist, 2005). In order to find a balance, the plausible and preferred future framing of the thread was critically considered. Certain elements of the scenario, such as end-users, tensions at play, and timelines, were predetermined, while other aspects, such as context and threads, were intentionally left open to allow for radicality or provocativeness.

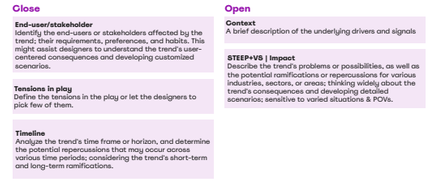



*Fig 6.7  Thread framing strategy*

Furthermore, the forms for presenting the scenarios were critically considered—how could they affect the perception of future narratives? The format of the scenario might provide a sense of reality or familiarity with the projected future vision. It can also influence participants' emotional engagement and personal significance of the experience. To leverage this, various forms were tested in collaborative settings.

One of the key points learned through literature and client expectations were the division of narratives or 'meaningful experiences' into driving-related interventions and non-driving-related interventions. For driving-related interventions, there is going to be a need for judgment and knowledge building. Advanced monitoring systems could make driving more informed and assistive for drivers. The systems will become intelligent with embedded AI. Digital ecosystems in cars will gain popularity and drive heavy economic shifts. The traces of such insights could be found in the signals as well.

## Collaborative setting boosted thread roadmapping

For threads roadmapping the database were transferred to Miro from Notion for easier visualisation, manipulation and collaboration. Thread mapping was done individual and collaborative setting. A creative session was conducted with fellow design students (three participants) to speed up the process and bring novel perspectives to the futures.

The session started with clustering exercise which allowed participants to touch upon various signals and open a space for creative exploration. The starting points for clustering were chosen to be technologies. Then subclusters were titled. This resulted in hierarchical structure.

Next, with hits and dots exercise, interesting signals were chosen. Lawson et al, 2015 recommended that plausible yet fictional futures lead to most effective patterns for analysing emerging patterns in the modern technology design. Therefore, more focus on plausible-horizon 2-3 zone (refer to figure 6.8). Each participant got 19 dots, with distinct colours.

Finally, threads were created by connecting the signals in creative way. The thread description was written as a starting point for future narrative. After few iterations, free ideation and brain sketching was done. Sketched results are presented in appendix I. Following are some of the results of the collaborative exercise.

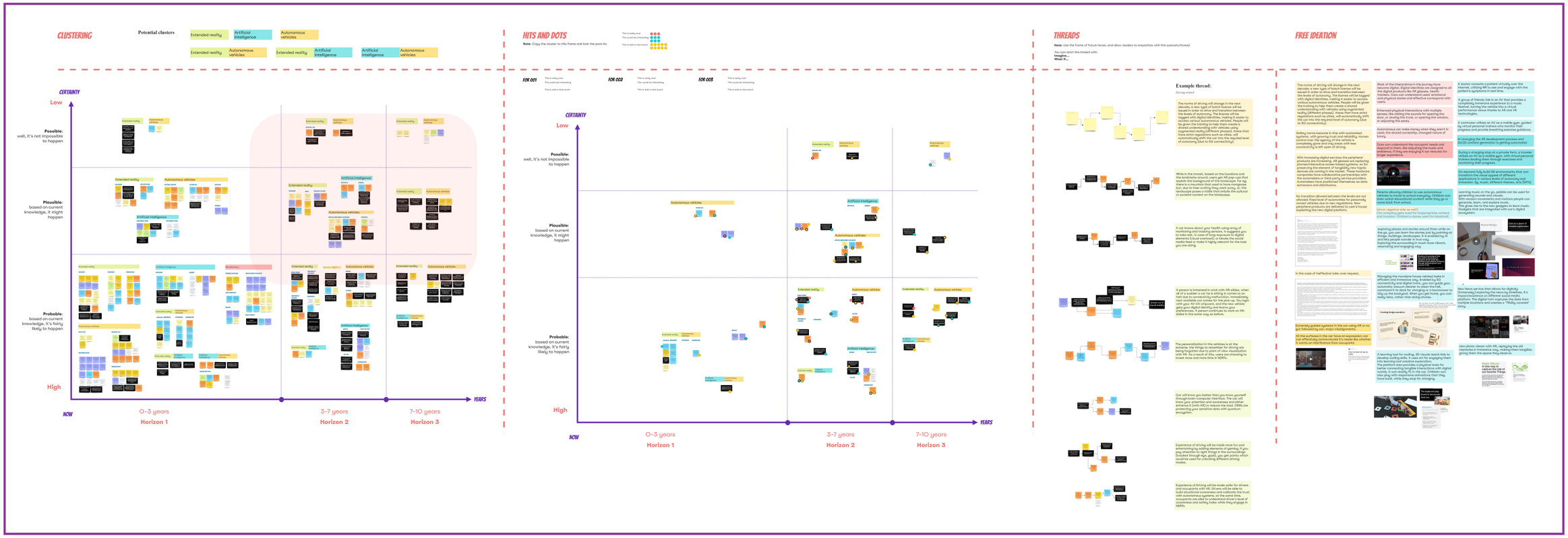



*Fig 6.8 Threads roadmapping creative session*

# Narrowing down

Using the following requirements, a few future scenarios were chosen by juxtaposing ideated threads. This aided in determining which approach would be most effective.

| Requirement | Source of req. |
|---|---|
| Should address some aspects related to the immersive technology in the space of autonomous mobility | Client's interest |
| should draws attention to the selected tensions (Object's context, aesthetics and presentation of scenario \| generate meaning that aligns with RF) | Literature, Client's interest |
| should not be designed for functionality; rather rhetoric or representation of tension | Literature, Contextual |
| should stimulate user's imagination through interactions or provocations | Literature |
| should entail imagined interactions making the scenarios believable and relatable | Literature |
| should allow for multiple interpretations; yields in questioning the qualities | Literature |
| should user the elements in the research question explicitly or implicitly | Contextual |

*Table 6.3 Thread selection criteria*

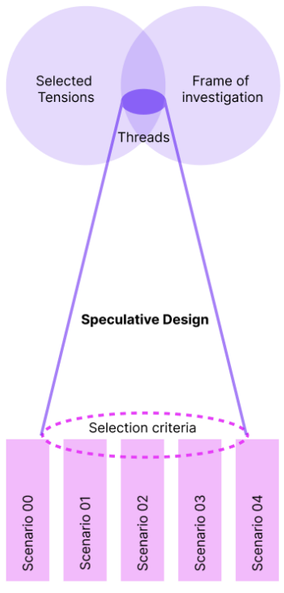



*Fig 6.9 Overview of scenrio mapping*

## Selecting the right form for scenarios

Given the requirements, visual storyboards or systemic visualisations should have been the most effective solution. The researcher's narration (which included gestures and role playing) supplemented the visuals storytelling.

Scenarios allow participants to empathize with future narratives. Narratives were presented through visual means: storyboards, narration (audio story), experience maps, or system maps. Scenarios were followed by provoking question frames (See appendix J).

Both the textual story and the visual rhetoric were well thought out and went under iterative developement. The supposed benefits of the technologies were explained in a friendly and optimistic (techno-utopian) way, but how the systems actually worked was kept irrelevant. Pilot tests revealed that people thought that it was important to pay attention to how scenarios were set up in order to tell a clear story about technology in the near future. Lastly, five scenarios were made by putting together threads, details learned from reading, selected tensions, personas, and behaviors on the cutting edge.

# FINAL FORM OF SPECULATIONS

*This chapter showcases the final speculative forms refined through iterative processes after employing a methodical approach to crafting speculations, that highlight the inherent tensions in the realm of XRinAV and future interventions in both driving and commuting tasks.*



7.0

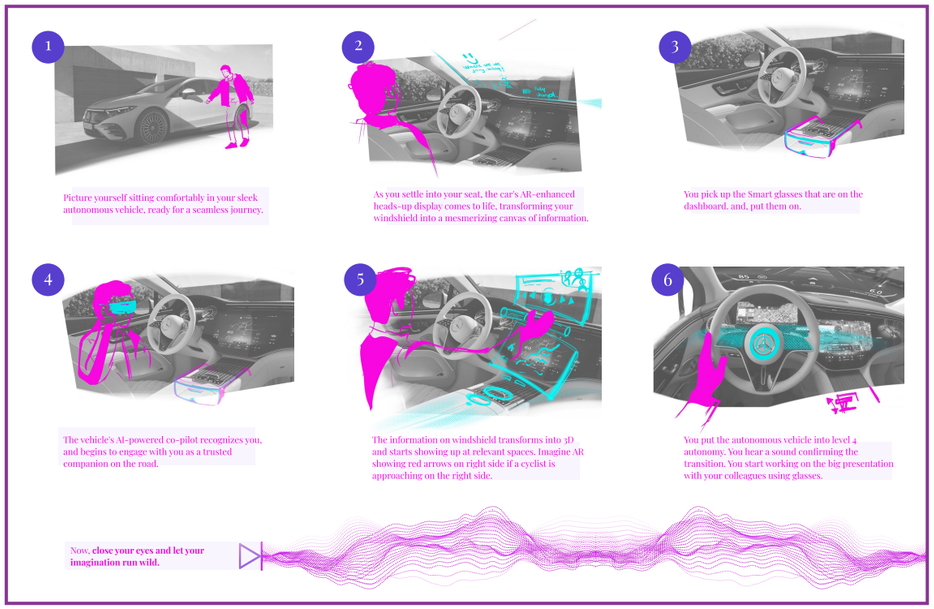
# FINAL FORMS OF SCENARIOS

## an iterative and on-going process

The process of scenario building was iterative and was done parallel with design of the user research. The possible questions frames were explored for each technology in the space of XRinAVs Appendix D. The research focus and problem statement was visited time to time in order find the investigative frames.

Note that, the process of futuring is considered to be ongoing, as it persists as long as there are novel possibilities for the future that require further exploration and analysis. By adopting this methodology, individuals can enhance their preparedness for multiple potential outcomes, rather than solely focusing on a single anticipated future.

# 0. The hyperconnected copilot




**Rationale for the thread:** This scenario draws from Insight 5 in the literature, suggesting AR can add value in TO scenarios through point of interest visualization.

**Form:** A visual storyboard, followed by a narrated role-play of the story.

**Description:** In a Level 4 autonomous vehicle, when an obstacle is detected, the driver is alerted via the dashboard and AR glasses. If the driver is not paying attention, the glasses refocus their attention. The glasses then guide the driver to assume control, transitioning to Level 3 autonomy. After resolving the issue, the driver continues, seeing the road conditions through AR. Once resolved, the car reverts to Level 4, confirmed by an AR notification.

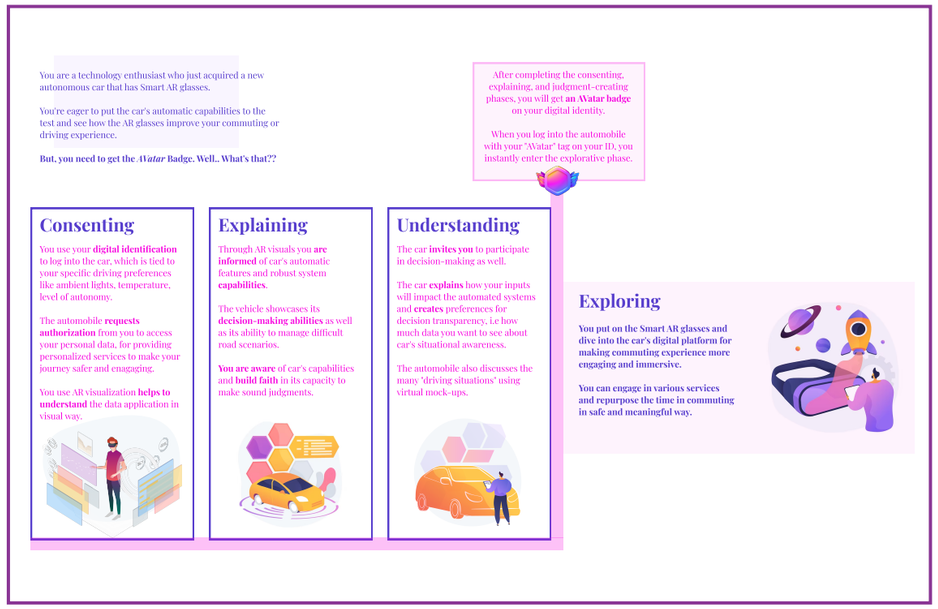
**Tensions being addressed:**

| | | |
|---|---|---|
| autonomy | VS | loss of control |
| Integration | VS | Distraction |
| Immersion | VS | Safety |





# 1. Onboarding with Extra eyes




**Rationale for the thread:** This scenario builds on Insight 8, addressing the need for new knowledge and understanding to operate autonomous vehicles.

**Form:** A visual chart, accompanied by a story narration and thought-provoking questions.

**Description:** This scenario introduces the "AVatar" badge, signifying users have completed the onboarding phase. This phase educates them on the system, gains their data consent, and informs them of driving protocols via AR experiences. Once onboarded, they receive the badge, enabling direct access to novel experiences.

**Tensions being addressed:**

| | | |
|---|---|---|
| Novelty | VS | complexity |

# 2.Hyper-personalisation with AR

"You're on your way to drop off your child or nephew at school on a beautiful, sunny morning. Your self-driving car, which is at level 4 of autonomy, has taken over as usual. You're driving, and the child sits next to you.

You put on your smart glasses, which are linked to the car's operating system and show you the information in your line of view.

While you are driving on the freeway, the car's sensors suddenly pick up on something in the road, and the car starts to slow down. The seat belt on the child gets tighter, and the seat is moved back. When your speed suddenly changes, the child notices and asks you what's going on.

After analyzing the situation, the car lets you know that a small crash is likely to happen. The algorithm is designed to minimize human interference in driving in safety-critical situations, so it chooses to handle the situation by itself.

Through AR visuals, the dashboard is highlighted in red to show how hard the car is braking, and the route chosen by the algorithm is shown in front of the car.

Because of the onboarding phases, you know that it can handle these kinds of situations. But you are worried about the safety of the child. So you try to get in charge of the car. But the glasses monitor your movement and inform you to sit back using guide signals.

A car crashes into a barrier and only has minor damage. The system notices that a sensor in the front isn't working, so it changes the level of autonomy to level 2. After the crash, it reports the incident to you. It informs you that the car was tracking your eyes through glasses and understanding your emotional state. It also indicates that the algorithm was taking into account your subconscious preferences, which it has learned over time. It shows that it chose a path to minimize the impact on the child as much as possible.

You realize that the car has learned your preferences without you even knowing it. You're impressed that the car can learn your deep preferences and match them with your gut feelings. You're okay with the car being able to read your subconscious choices.
Does this resonate with you?"

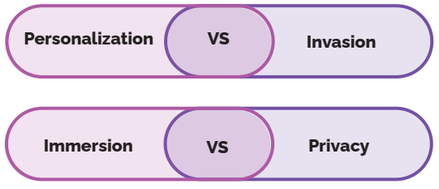


**Rationale for the thread:** This scenario explores the challenges and opportunities of personalized experiences.

**Form:** A narrated story, paired with provocative questions.

**Description:** This scenario challenges users with a high level of personalization, made possible by data from XR devices and car monitoring systems. The idea is that hyper-personalization enables cars to better understand users, thereby making critical safety decisions. It invites participants to question their instincts and deeper preferences.

**Tensions being addressed:**








# 3. Future platform: XR4AV



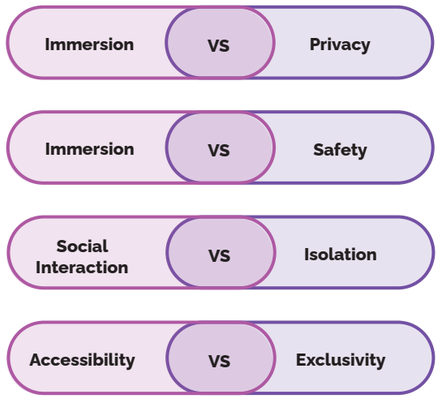

**Rationale for the thread:** Building on Insight 4, this scenario envisions a platform emerging from current technological and economic trends.

**Form:** A visual map outlining the architecture.

**Description:** This scenario reveals a potential expansion of the MB.OS platform, positioning how Mercedes might fit in such an ecosystem. It integrates key players and offers users an insight into immersive in-car services.

To ensure realism, the scenario was shaped by interviews with XR stakeholders, and strategic partnerships were visually emphasized for credibility.

**Tensions being addressed:**



# 4. Immersive services

## Healthcare Services

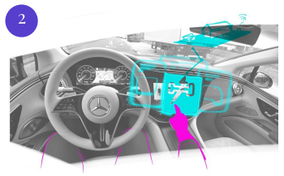
Third party providers may offer custom diet plans and virtual personal training lessons with well-known exercise pros to create healthcare experiences. Users also have access to a wide range of ways to relax, such as guided exercises and virtual spa services. One such service is **Exercharge**, by **Basic-fit.**

1



What if: Your autonomous vehicle informs you of a charging stop and you ask it to find a station with a workout option.

2



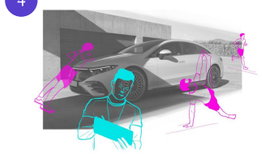
"ExerCharge", a service through the integrated platform connects you to a virtual personal trainer via a car interface dialogue box. The trainer evaluates the farm's facilities by accessing farm's digital twin and creates a customized workout plan.

3



As you reach the charging station or private farm, the virtual personal trainer greets you at the farm gym. Using bodyweight and equipment exercises, the trainer creates a customized workout. You do box jumps and push-ups against the car.

4



The farm's outdoor space is perfect for yoga on the grass or jogging. To prevent injuries, AI-enabled smart glasses track your movements and offer real time suggestions.

5



The virtual personal trainer gives you a workout summary and progress report afterwards. You can review this information on your own devices.

6



After 30-40 mins, the car is fully charged. You continue your journey feeling refreshed and satisfied with your workout.

**Rationale for the thread:** This scenario expands on Scenario 3, detailing the immersive services offered via in-car platforms.

**Form:** Visual storyboards and descriptions, utilizing AI-generated imagery.

**Description:** This scenario showcases the range of immersive services, from navigation to healthcare and music instruction, all made possible by the immersive platform. The content was crafted through intensive brainstorming with design students and was anchored in tangible evidence. A variety of services was devised to appeal to a broad range of participant interests

**Tensions being addressed:**

- Immersion VS Privacy
- Immersion VS Safety
- Social Interaction VS Isolation
- Accessibility VS Exclusivity





## Infotainment

Mercedes-Benz can give you a unique and engaging media experience through a virtual reality theater. Users can choose from a wide range of engaging experiences, such as watching a movie in a luxurious private theater or going to a live show in virtual reality.

### New headspace

Imagine getting into your self-driving car after a hard day. While relaxing in the plush seat, smart glasses activate the car's therapeutic environment. Transparent screens replace the car's windows, showing tranquil landscapes that relieve stress. The virtual walk through the woods sounds and feels real.

It's more than a pretty picture. Smart glasses and car technology cause sensory overload. The seat's haptic feedback system massages you to the virtual forest's rhythm. Car ventilation system air scents the experience.

A soothing voice guides you through breathing and relaxation exercises to find inner peace in the midst of daily chaos. The glasses monitor heart rate and stress levels to create the most relaxing environment.



## AV centered services

Mercedes-Benz could offer a variety of soothing massages and sitting options, as well as personalized lighting, music, and smells, to make a trip feel truly luxurious. The car might have virtual trip experiences that let people see the world while they're driving.

### The second skin

What if... you could customize your vehicle's Second Skin to suit your tastes and desires.

Want to feel like you're driving a vintage roadster from the 1960s? No problem.

The interior transforms, complete with analog dials, retro styling, and even artificially generated 'old car smell.' Or perhaps you're in the mood for a futuristic cyberpunk vibe, with neon lights and holographic displays surrounding you.



Imagine driving through a city, and your car's Second Skin interacts with the urban environment. Street art comes to life, dancing across the vehicle's surfaces.

Local landmarks and historical information are projected onto the walls of your car, providing an immersive tour guide experience.

The car itself becomes a canvas for artistic expression and a medium for storytelling.

## Edutainment

Depending on the needs of each user, Mercedes-Benz may offer a variety of training tools, such as cooking classes, language learning, or art history studies. Customizing the learning options to the user's hobbies and preferred ways of learning can make the learning process more interesting and effective.

### A musical touch

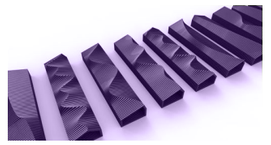
what if you could follow your passion anywhere like learning music during the commute.

Pebble, is a fascinating services that comes with a physical device that can be integrated into your car and is prepared to open up a world of musical exploration.

It comes in various organic forms with a patterned surface that invites you to explore its sonic depths. This magical tool comes to life when touched, with each section representing a different musical note or chord progression.

The Pebble acts as a map to an endless variety of songs as you set out on your commute. Melodies flow from your car's speakers at the touch of a finger, and smooth harmonies come to life at the swipe of a finger.

The simple layout of Pebble invites you to play around and express your individuality. Integrate elements from multiple disciplines to create seamless compositions, fusing melodies into breathtaking harmonies.



## Navigation

Mercedes-Benz may offer a high-end personal service that customizes trip ideas based on what the customer wants, such as beautiful paths or recommended places to eat. Users can add their own voice to the guidance system to make it feel more personal and fit their style.

### A serene oasis: Explotura

What if... You're on a road trip, and your car's AI assistant notices your energy levels are dwindling. It suggests pulling over at a nearby scenic spot for a revitalizing break.

The windshield displays breathtaking vistas and points of interest, immersing you in an augmented travel experience. Or, if you're feeling stressed, the car might recommend activating a calming MR simulation, transforming your interior into a serene oasis.

You can also explore places and stories around them while on the go, you can learn the stories just by pointing at things, buildings, landscapes. It is enabled by AI and lets people wander in true way. Exploring the surrounding in much more vibrant, resonating and engaging way.





**Tensions being addressed:**

## Productivity

To improve the luxury experience, Mercedes-Benz may offer a personal helper service that helps with things like making bookings or setting up meetings. When making the helper, the user's preferences, such as their favorite language or personality type, could also be taken into account.

### the work-pod

Step into the future of work and imagine a world where commuting is no longer a mundane chore but **a productive sanctuary.** What if, your autonomous vehicle has transformed into a mobile office, an extension of your workplace. Equipped with intelligent glasses that seamlessly merge the digital and physical realms, you can truly redefine how you interact with your car.

As you enter the vehicle, you put on your intelligent glasses, and the world around you comes alive with information. The windows become dynamic displays, projecting virtual screens that allow you to seamlessly access your emails, calendars, and virtual collaboration tools. With gesture-based interactions and voice commands, you can manipulate these virtual interfaces with ease, even while on the move.

Immersed in mixed reality, your car becomes a haven for creativity and productivity.

Need to brainstorm ideas? Virtual whiteboards appear, allowing you to sketch and collaborate with colleagues in real-time, no matter where they are in the world.

Have an important presentation? Your autonomous vehicle's AI analyzes your audience and provides you with real-time feedback, enhancing your delivery and boosting your confidence.



RESEARCHING

# DESIGN OF USER INTERVIEWS

*In this chapter, a user study that was conducted with participants to investigate their responses to speculated scenarios is presented. The aim of the study was to gain a comprehensive understanding of how participants interpret interventions in commuting when they are presented through a typical techno-utopian perspective.*



## Research focus

As stated before, the central problem statement was *"How might we design safe and meaningful AR interventions for users (in in-journey experiences) with different levels of immersion and autonomy?"*.

The focus of the user research is on understanding the desirability, i.e., perception, of future interventions. The purpose of the interview sessions is to gain

- Insight into the potential opportunities, challenges, and long-term consequences
- Insights into the acceptance and adoption of such interventions
- Insights into potential values, concerns, and frictions

This investigation will serve as a foundation for understanding future visions and research directions. This also builds an understanding of perceptions of selected tensions and how user preferences/tendacies affect those tensions. It also helps to answer the question of which tensions need to be prioritized and investigated further. They could be used as a foundation to design interactions and experiences that are desirable in the space of XRinAVs.

This research attempts to make a valuable contribution to the field of design by generating new knowledge that can enhance current advancements in designing interventions — cross-platform integration practices, in-journey experiences, and digital interactions — within the automotive industry.  It shows potential to craft future regulatory frameworks. Furthermore, it serves to exemplify the utilization of speculative design as a research methodology.

## Research Approach

As seen in previous sections, the approach blends Context-mapping (Sleeswijk Visser et al., 2005) and Speculative Design to investigate end-user perspectives. Context-mapping helps investigate contexts of user-car relations in which latent knowledge is tapped. Sensitizing allows for reflection on past experiences and establishes the groundwork for interview session. Speculative design acts as an effective tool for initiating conversations and build understanding of the space (XRinAVs). Thoughtfully designed scenarios, aligned with the research objective, enable users to connect with their future selves on an emotional level and stimulate a series of inquiries through thought-provoking prompts.

## Participants recruitment

Participants were recruited through a word-of-mouth approach in order to investigate "the user perception of future AR interventions within the space of autonomous mobility. They were hired through convenience and purposive sampling. Emails, LinkedIn and WhatsApp were the primary sources of communication. To reach the target audience, several other strategies were used. A website was developed with the intention of targeting individuals within corporate organizations who possess a strong inclination towards owning luxury vehicles.

In order to understand the relevancy of a participant (based on criteria explained later) and their commitment towards the research, on-board calls were made (around 15–20 minutes). With a few questions on commuting habits and needs, they were also associated with the personas mentioned in the previous section. This helped in the analysis and opens up more explorative opportunities for discovery. After receiving confirmation of participation, participants were sent an confirmation email with time (calendar invite) and place of the interview.

| Participant ID | Country | Age/persona type | Description | Date and time | location | Time (mins) | Sensitizing... | Sensitizing booklet | Particip... |
|---|---|---|---|---|---|---|---|---|---|
| MB_01A | US | Age 21-30<br>The status-oriented trendsetter | He likes driving and commutes by car almost everyday. He has keen eye on driving comfort and for digital technologies | May 10. 2023 | Online | 85 | ☐ | https://docs.google.com/presentation/d/1kcyGPBgYzncfmZcyG5_byh0Aw2WY4YFJpbBj82HGDvOA/edit?usp=sharing | Pilot |
| MB_15A | Europe | The status-oriented trendsetter<br>Age 21-30 | He likes the space with Extended reality; very tech-savvy and picky. He is a avid traveller; luxury seeker; active gamer. He likes driving and has a lot of experience with driving. | May 15, 2023 10:00 AM | IDE | 91 | ☑ | https://docs.google.com/presentation/d/101XiiPmYuJTZKttaHEhyhCg5zhdzNXhPma0zWXwxEpM/edit?usp=sharing | Pilot |
| MB_16A | Europe | The status-oriented trendsetter<br>Age 21-30 | Massive mobility enthusiast. He and his brother are building a car. He shows a particular taste in technology. | May 16. 2023 10:00 AM | IDE | 93 | ☑ | https://docs.google.com/presentation/d/1GYrHPXlJic-hiujR2Dh7GoarfmvVEdOKTN7VRWYJ77Z8/edit?usp=sharing | Ideal |
| MB_17B | Europe | The status-oriented trendsetter<br>Age 21-30 | He owns a luxury car. He likes the utility of the car on everyday basis. He is a dj so often travels. Enjoys the multi-sensory in car experiences. | May 17. 2023 12:30 PM | IDE | 46 | ☑ | https://docs.google.com/presentation/d/15nxJiqXeGKxnzmlvdu4uU5EzaL7W9uY5Uoo5fUO_07jY/edit?usp=sharing | Ideal |
| MB_18B | US | Age 21-30<br>The open-minded co-pilot | She has comparatively lesser experience with driving, but she imagines herself using car regularly when she gets back to US | May 18. 2023 3:00 PM | IDE | 73 | ☑ | https://docs.google.com/presentation/d/1TUjGKE76ih4bZGrYBWesUiLJ0qgBsKEEeL4FrBrAE8Q/edit?usp=sharing | Ideal |
| MB_23C | Europe | The tech-savvy passenger<br>Age 21-30 | She works in a design consultancy; frog by Capegemini. Loves travelling by road. She doesn't know how to drive but often travels with friends. She puts experience over cost. | May 23. 2023 8:00 PM | Resident | 73 | ☑ | https://docs.google.com/presentation/d/1CmM6iRQLwIQOsYvgdk6jfNORZ2LxLhrkkwogm5W9L30/edit?usp=sharing | Ideal |
| MB_24A | Europe | Age 21-30<br>The safety-oriented reluctant | She likes having an independence in driving, quite conscious in making her travel choices. | May 24. 2023 10:00 AM | IDE | 66 | ☑ | https://docs.google.com/presentation/d/1anOZmd2kxWOEMhb2F8S3YhFca0HypBeJD3So5NMWViM/edit?usp=sharing | Ideal |
| MB_24C | Europe | The open-minded co-pilot<br>Age 31-45 | He works in IT industry over a decade; has a family of three. Owns a tesla and knows it's offerings. Very enthusiastic about cars as well | May 24. 2023 6:00 PM | The Hague | 48 | ☐ | https://docs.google.com/presentation/d/1wwQ6DpMmXKuJlQp5A_NKwR59N6d1fpBOdtm5zDXjtOc/edit?usp=sharing | Ideal |
| MB_25A | Europe | Age 46 & above<br>The open-minded co-pilot | He owns a Mercedes. loves cars and shares stories about cars enthusiastically. He has heard of new technologies and shows interest in knowing more. | May 25. 2023 10:00 AM | The Hague | 52 | ☑ | https://docs.google.com/presentation/d/1Fs4DoBQMUhXOFilmTuf9sE1g809anIW54d5uEKm1H1g0/edit?usp=sharing | Ideal |
| MB_25B | US | The status-oriented trendsetter<br>Age 21-30 | He loves sound of engine, but still enjoys exploring new technologies. He wants to own wide range of vehicles in future. Family owns a tesla | May 25. 2023 3:00 PM | IDE | 84 | ☑ | https://docs.google.com/presentation/d/1xiNDn8OE9HHEEzne_q1jDuuxCioBqswrAdhYshGTzcM/edit?usp=sharing | Ideal |
| MB_29C | US | The open-minded co-pilot<br>Age 31-45 | He works in IT industry (Icertis) at an executive position over a decade; has a family of six. Owns a kia and knows it's offerings. not an enthusiast of cars but knows about technology. | May 29. 2023 6:00 PM | Online | 57 | ☑ | https://docs.google.com/presentation/d/19Z2e_ccqyWwOtOxKjUFaPWmtwKqXwlSCF0VSAl6o8M/edit?usp=sharing | Ideal |
| MB_08B | Europe | The tech-savvy passenger<br>Age 31-45 | He is an Auto Journalist, not his main job but a hobby. Has experience with very luxurious vehicles from RR, MB | June 8. 2023 3:00 PM | Online | 64 | ☑ | https://docs.google.com/presentation/d/1jQhr1wv5jZtFLGzawhu70Vg-2RBj0jOuzwUSUY5Q/edit?usp=sharing | Ideal |
| COUNT 12 | | | | | | AVERAGE 69.33333 | | | |

*Table 8.1 Participant Overview*

### Selecting the participants

We meticulously set selection criteria for this user study to ensure that participants represented our intended demographic and provided meaningful and relevant insights. To begin, the participants were chosen based on their geographical location; they either live in or are from Europe or the United States. There are several reasons for this preference. Our client's initial focus is on these regions, but there is talk of shifting to the Chinese market due to its burgeoning market capitalization in electric vehicles and expansive digital offerings. Furthermore, Europe has been instrumental (and critical) in the development of many critical regulations surrounding autonomous mobility (Automotive regulatory guide (ACEA), 2021; ERTUG, I., 2022; *connected and automated mobility*, 2022) and has a significant level of digital exposure and literacy (CBS, 2020a).

Another important factor in our selection process was age; participants had to be between the ages of 24 and 60 (+/- 2). Participants that belong to the 21–30 age group have the most relevance to the viability of future interventions and also have the highest digital literacy (Eurostat, 2021). Participants were not hired from the automotive industry deliberately, except *MB08B*, who was selected due to his extensive experience and exposure to luxury vehicles. The participants' gender wasn't considered; it was deemed irrelevant ("Mckinsey", 2023). Fluency in both spoken and written English was required to ensure that participants could understand the scenarios presented, articulate their thoughts, and navigate the sensitizing booklet with ease. Participants were required to own, lease, or have ready access to high-segment vehicles, specifically those classified as D-segment (mid-size sedans or family cars), E-segment (executive luxury cars), and J-segment (SUVs, sport utility vehicles). Furthermore, because the study is centered on automotive experiences, participants were required to commute by car on a regular basis, at a minimum of twice a week, regardless of the underlying reason.

### Consent and ethics

Most of the interviews were conducted in person. There is no incentive to participate in the form of a financial contribution. However, after the study is over, they are given a token of appreciation.

Participation was strictly voluntary. Participants received information about research setup, code of conduct, data collection, and storage through onboarding calls and confirmation emails (the email draft can be found in Appendix K). Consent forms were sent to them through email prior to the interview (See Appendix L). The research activities and the participation of the participants were approved by the Human Research Ethics Committee of Delft University of Technology, which involved data management plan as well.

## Interview session

There were 10 interviews in total (n=10, 8 male and 3 female) with 2 pilot interviews over a span of two weeks. Each interview lasted for one hour ten mins on average. Using the path of expression line of inquiry (described in chapter 5), semi-structured interviews are conducted. In addition, everyone is made aware of the context of the topic and encouraged to reflect on it through various generative exercises before the interview. This is further elaborated later.

## Building a flow for investigation

The research question was used as the main pillar to show how our investigation moved forward and how far it went. This question wasn't looked at in a vacuum. Instead, it was broken down into smaller questions, each of which added to the depth of the inquiry. Selected threads ("scenarios"), tensions, and present-future interaction relations were key to expanding the main research question. This method helped the investigation go in a better direction. The selected threads were organized in such a way that they hinted at the possible phase and activity structure of the interview. The figure 8.1 below illustrates this. They weren't just one-off scenarios; instead, they showed how the interviews might be set up and what they might involve.




*Fig 8.1 Scenarios leading to design of activity through priorotised tesnsions*

This resulted into a phasing as shown in table 8.2. Phases also considered the pre-interview and post-interview tasks.

**Time Division of the Interview**

| Phase title | Interview phase | Time (mins) | People involved |
|---|---|---|---|
| Going over script, planning the interview | Pre-interview | 30 | Interviewer |
| Checklist (consent, recording, online meeting set-up) | Pre-interview | 5 | Participant (with Interviewer) |
| Introduction to the research | Pre-interview | 5 | Participant (with Interviewer) |
| Driving needs, roles, relationships and behaviors | Interview phase 1 | 7 | Participant (with Interviewer) |
| Introduction to Avs and AR/MR | Interview phase 1 | 7 | Participant (with Interviewer) |
| Scenario 0: AR assistance in driving | Interview phase 1 | (3)+ 10 | |
| **Scenario 1A:** Onboarding with AR for trust calibration | Interview phase 1 | 5 | Participant (with Interviewer) |
| **Scenario 1B:**Personalization through data | Interview phase 1 | 5 | Participant (with Interviewer) |
| <tea/coffee Break> | Break | 3 | Participant (with Interviewer) |
| Digital Interactions | Interview phase 2 | 4 | Participant (with Interviewer) |
| **Scenario 2A:** Digital Platform explanation | Interview phase 2 | 5 | Participant (with Interviewer) |
| Generative exercise: values in XR in AVs | Interview phase 2 | 3 | Participant (with Interviewer) |
| **Scenario 2B:** 3/4 Services and Peripheral products | Interview phase 2 | 15 | Participant (with Interviewer) |
| Having a casual talk with participants | Post-interview | 15 mins | Participant (with Interviewer) |
| Insights dump | Post-interview | 15-20 mins | Interviewer |

*Table 8.2 Overview of interview session*





With a plan in place, the kinds of questions to be asked were split in two. There were two main groups:

- Interview Questions: These are questions that were designed to be asked during interviews. They were designed to provide direct insights into main research focus.
- Sensitizing Booklet Questions: On the other hand, these questions were compiled into a booklet. The booklet served as an extra way for respondents to learn more about the topic and acted as a primer for other question category. This also demonstrated when and when not to bring up the sensitizing booklet.

The meticulous organization eventually resulted in the formation of a hierarchical structure. The hierarchical structure not only allowed for a smooth flow during interviews but also ensured that each level of the question contributed meaningfully to the overall research goal.

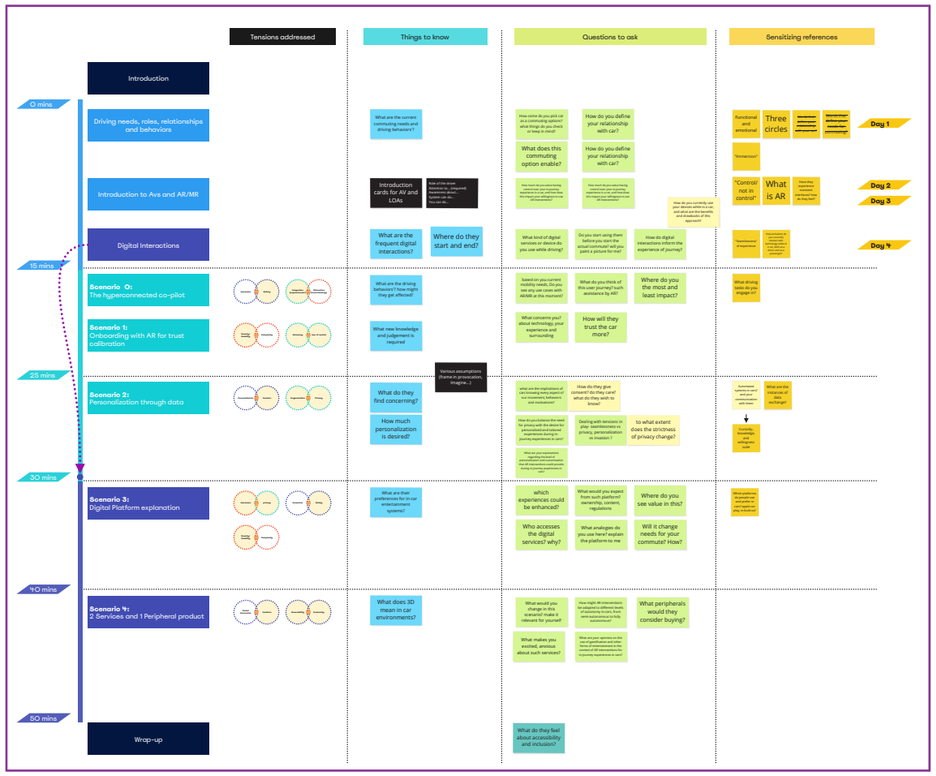



*Fig 8.2 Deatiled overview of interview and sentizing question*

The frames of the questions were improved further through iterations and were validated through pilot interviews. Finally, the interview script was created to assist the researcher (found in Appendix M). It was also critically assessed by peers and supervisors. The script was updated after first pilot session and tweaked a little bit after the second. It wasn't modified later. Every section contains the questions/prompts, goals of each section, sensitizing references, and scenario references. The script also had a backup action plan, if sensitizing work was not done prior to interview.

**The interview guide is presneted in Appendix M.**

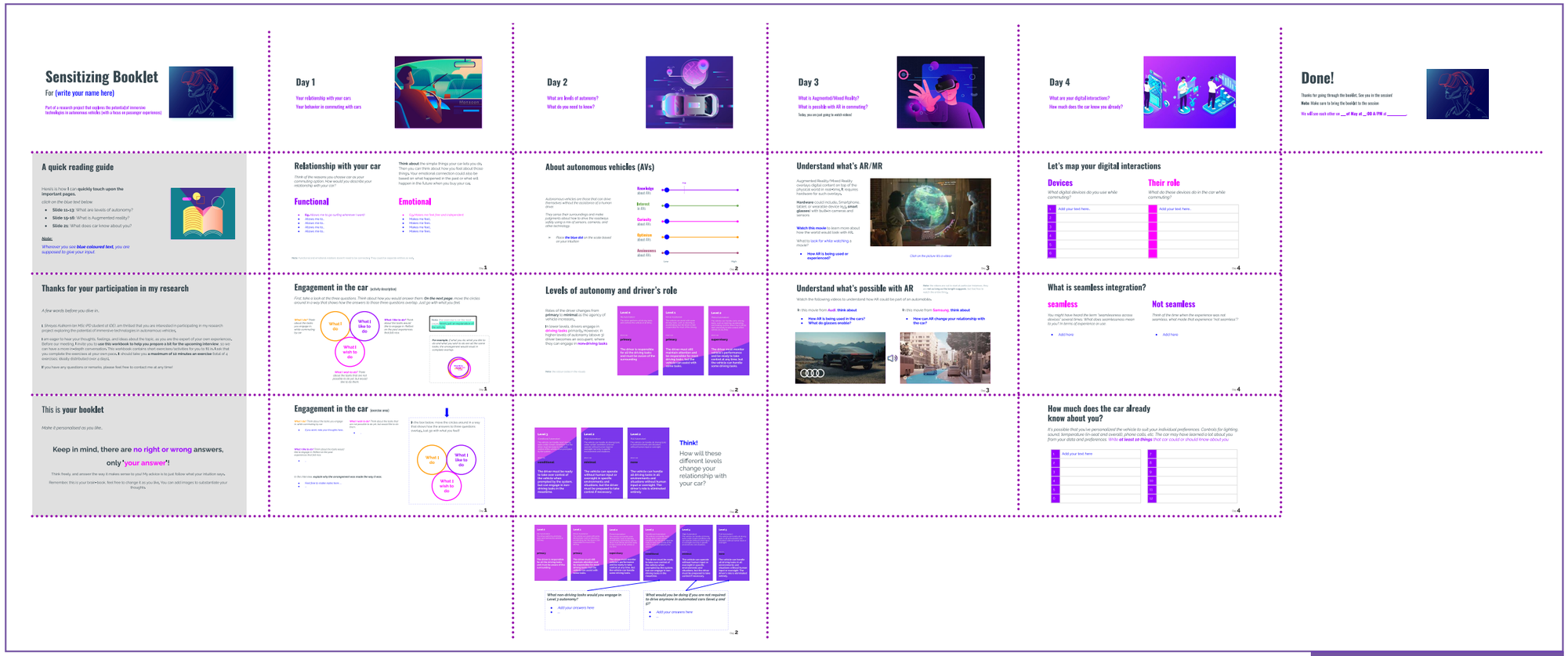
## Adaptive structure of the interviews

Pilot interview sessions were held during the initial phase, which helped make changes to the flow and the way scenario descriptions were framed. The flow of the interview had to be changed to accommodate the different levels of knowledge of the participants. This realization prompted the choice to employ semi-structured interviews. The scenarios were arranged in the order that people responded to the sensitizing activities on the first and second days. For example, if a participants (like MB_23C) saw themselves primarily as a passenger, scenarios 3 and 4 were weighted more heavily because they dealt with NDRT (non-driving-related tasks). Moreover, the time spent on each scenario was not consistent.

# Sensitizing booklet

The sensitizing phase is the period preceding an interview session in which participants engage in activities such as gathering personal experiences and improving their understanding of the topic at hand. This process is frequently aided by the use of assignments or a workbook. The primary goal of sensitization is to adequately prepare participants laying the groundwork for the interview and cultivate a receptive mindset. Generative exercises are used to gain access to tacit knowledge that is typically inaccessible through traditional research methodologies. It also (reportedly) provided participants a peek in the interview, reducing surprises.

The sensitizing workbook, or activities workbook, was sent to participants a week prior to the interview. It was shared using google slides, with a quick reading guide. It was designed in a way that had 10 minutes investment a day for four days, at participant's convenience. They were allowed an option to club all days and go through it all at once, taking 35 mins maximum.




Outline of the sensitizing booklet

## Outline of the sensitizing booklet

### Orientation Section

The sensitizing booklet started with a quick reading guide. It offered participants the chance to touch upon the most important things if they didn't have time. They were also informed about where their input is needed in the booklet. Subsequently, participants were informed of the setup and purpose of the booklet. They were also informed that "there are no right and wrong answers, only *your* answers". This created a non-judgmental space for participants.

### Activity Design and Intentions

Activities for each day were designed with specific intentions.

*Day 1: Understanding Relationship with Cars*

**Day 1** explores participants relationships with their cars by reflecting on behaviors in the car through two quick exercises. The first exercise asks them to track their functional and emotional relationships. The next exercise tracks their commuting needs and wishes. There were three circles: they do, like to do, and wish to do. They were asked to arrange circles in a way that showed their division. *For example, if what they do, what they like to do, and what they wish to do are all the same things, the arrangement would result in complete overlap.* This was a tool for voicing their thoughts about what elements of commuting are satisfying and what gaps could potentially be filled by AVs. The wishes part is the first link that connects to future experiences.

*Day 2: Perception of Autonomous Vehicles*

**Day 2** explores their stance with AVs and introduces levels of autonomy. The exercise contains a scale that tracks their knowledge, curiosity, interest, optimism, and anxiousness. This scale is not a quantitative measure by any means, but its main purpose is to act as a probe to trigger thoughts. Later, they were introduced with levels of autonomy through illustration. It elucidated the changing nature of tasks and roles at various levels of autonomy. They were also made to think about what they would do in levels 3, 4, and 5. This led to their wishes and questions about LOA embodiments.

*Day 3: Exploring Extended Reality (XR)*

**Day 3** introduces extended reality and what it means to have it in the car. The pre-exiting techno utopian commercial made by Audi (The Audi activesphere concept, 2023) was used as a provocative scenario to show one of the possible embodiments of the XR in future vehicles. This was reportedly very provocative for participants. Another video from Samsung (SAMSUNG - the future of the car with AR, 2022) showed how AR could be integrated for driving tasks. Participants were also provided with things to look for in the video.

*Day 4: Digital Interactions in Cars*

**Day 4** explores users digital interactions in cars through three exercises. First, track what devices they use in cars and what roles those devices play in commuting. Second, it focuses on understanding what seamless and immersive mean for them. And finally, third, it tracks how much a car already knows about users and what users want their cars to know.

The place and time were strategically mentioned on the last page of the workbook. Appendix N contains the sensitizing booklet and additional materials.

## Improvements through iterations

With several iterations, the smooth blend of the interview guide and sensitizing exercise was evaluated multiple times. Pilot sessions and peer reviews helped to improve the flow of the booklet. The layout and framing of the instructions were greatly simplified for easier comprehension and visual hierarchy. For example, additional footnotes clarified the relationship between functional and emotional relationships with cars for day 1 exercises. On day 2, the illustrations — levels of autonomy — were improved for better visual hierarchy and appeal.





# Synthesis

## Data collection (refinement) and storage

The majority of the interviews were conducted face-to-face. The online sessions were conducted using video conferencing platforms such as Zoom and Microsoft Teams. These sessions were recorded and transcribed using Otter.ai, an automatic transcription tool widely recognized in the industry. While Otter.ai's transcription is generally precise, it necessitated manual editing to accurately capture the intricate nuances of communication, such as the natural rhythm of conversation, variations in tone, and emotional expressions. Due to researcher's active role as facilitator during the session, no notes were taken. In order to safeguard the privacy of the participants, no photographic or video material was captured. Participants submitted sensitizing booklets following the interview session.

During the processing phase, the recordings, transcripts, and sensitizing booklets were stored on local drives. The privacy policies were carefully reviewed prior to selecting the transcription service.

## Data analysis

The process of thematic analysis involves an iterative approach to transforming disorganized data into a comprehensive representation of the most significant themes present within the data (Mortensen, 2020). The procedure comprises six distinct stages:

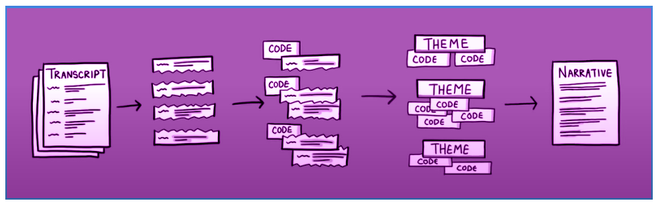



*Fig 8.3 overview of thematic analysis (Delve, 2020)*

## 1. Familiarisation

During this stage, all of the data from the interviews was thoroughly examined and annotated. This is the stage at which preliminary ideas for codes that can effectively depict the content are identified. A very few parts of the transcript were rephrased (for contextual adjustments) or reframed (for clarifying pertinent topics and improving legibility).

As this was a comprehensive and investigative analysis, it was deemed necessary to transcribe all verbal communication that occurred during the interview. This was due to the uncertainty of the researcher's objectives and the need to capture all

relevant information. However, this descriptive coding strategy was inefficient due to a lack of structure and code organization. To fix this, a prescriptive coding strategy was employed by using an interview script and a sensitizing booklet as starting points.

## 2. Generating Initial Codes

With a prescriptive coding strategy in place, initial codes for the data for the purpose of content description were allocated.

**Code hierarchy**

The analysis's goal was to find qualitative insights in the data. The coding was done with **ATlas.ti**. Codes are descriptions rather than explanations. It is a method for generating preliminary classifications of data. Grounded theory as a source of inspiration Method informed the coding protocol and aided in the organization of the code hierarchy.
A typical project of moderate complexity should not require more than ten top-level categories to adequately cover the subject matter (Bazeley, 2020). In order to remember, locate, and use subcategories effectively, no more than two or three levels of depth were created in the coding system.

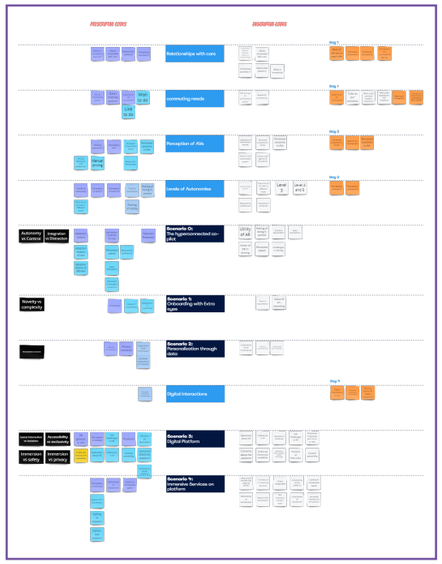
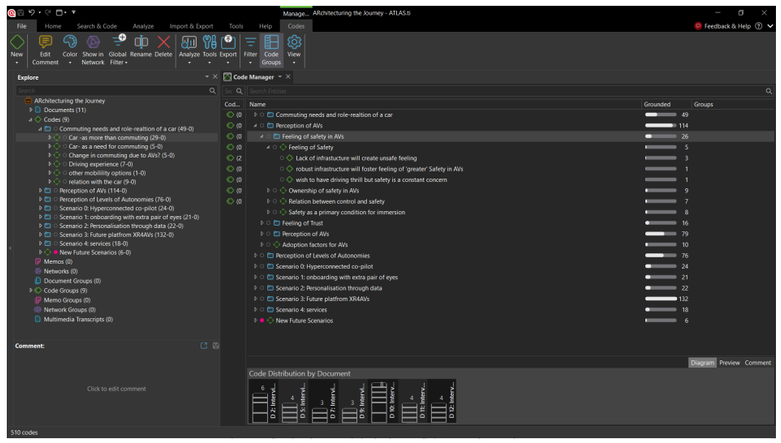



*Fig 8.4 Prescribing codes*

*Fig 8.5 Code hierarchy in Atlas.ti*




## 3. Developing Themes

Finding threads was a trial-and-error process that entailed exchanging codes back and forth to see if new patterns emerged. There may be hidden themes that are only hinted at. In this process, not every code can be combined with every other code. If a particularly compelling set of codes was discovered, it was made into its own theme.

## 4. Reviewing Themes

Phase 4 involves an iterative approach that involves a cyclical movement between themes (subcategories), codes, and extracts until the coder believes that all relevant data has been coded and the appropriate number of cohesive themes has been established to accurately represent the data (Braun and Clarke, 2006). It was made certain that the information contained within each subcategory made sense when taken as a whole, and that the differences between themes were obvious. If a theme contained too many contradictions or was too broad, it was split into separate themes or some codes were moved to a better-fitting theme.

It is critical to acknowledge that determining the boundaries for the subcategories, particularly in terms of inclusion and exclusion criteria, posed difficulties, owing to the researchers' limited perspective. Another limitation that should be mentioned is the lack of peer review for the coding process, which can be attributed to time constraints.

## 5. Defining and Naming Themes

When possible, Blandford et al. (2016) advise making sure that the names assigned to themes are both descriptive and captivating. The use of predetermined subcategories— the prescriptive coding method— was determined to be too simplistic for the comprehension of results.

## 6. Generating the report

Finally, for easier navigation through results a theoretical framework for qualitative insights and themes was created in Miro (which provided better visual support). And results were reported (see the next section)

A theory that emerges from thematic analysis must be affirmed by additional inquiries, whether through a qualitative, quantitative, or mixed methods study.

# RESULTS OF USER RESEARCH

*This chapter reveals the key findings from our user research, laying the groundwork for the design's direction. We discuss our findings, which are organized into broad themes and supported by participant quotes. Furthermore, we present the final coding structure as a navigational guide.*

## Framework: to navigate through insights

Thematic analysis, which revealed a plethora of themes, formed the basis of the analytical framework presented in Fig. 9.1. The preceding chapter explained how these themes are rooted in several codes and quotations. For simpler navigation, the themes are strategically organized to provide quick navigation through the code hierarchy.

The analysis of the data obtained from the sensitizing booklet serves as a starting point for navigating the acquired insights. Day 1, Day 2, Day 3, and Day 4 (each day had exercises in the sensitizing booklet, which collected users' opinions and thoughts) are the central starting points. Every starting point connects to the central overarching themes, which are then linked to clusters of sub-themes. The starting points are also linked to the scenarios.

The visual layout serves two purposes: *Understanding Interconnectivity*— It reveals the inherent connections between the themes, and *Enhanced Accessibility*— It provides readers with a structured and intuitive path through the codes. It is critical to emphasize that this framework is not a comprehensive theoretical or network-based construct. Instead, it functions as a visual digest. Nonetheless, it has the potential to evolve into a more elaborate theoretical framework with further code refinement and network-based analysis in Atlas.

Jump to discussions (135)

# Framework to navigate insights

We will primarily go into details on the upper right quadrant of the insight map in the following discussions, as it connects with the eventual design direction. All other results are presented in Appendix C in detail.

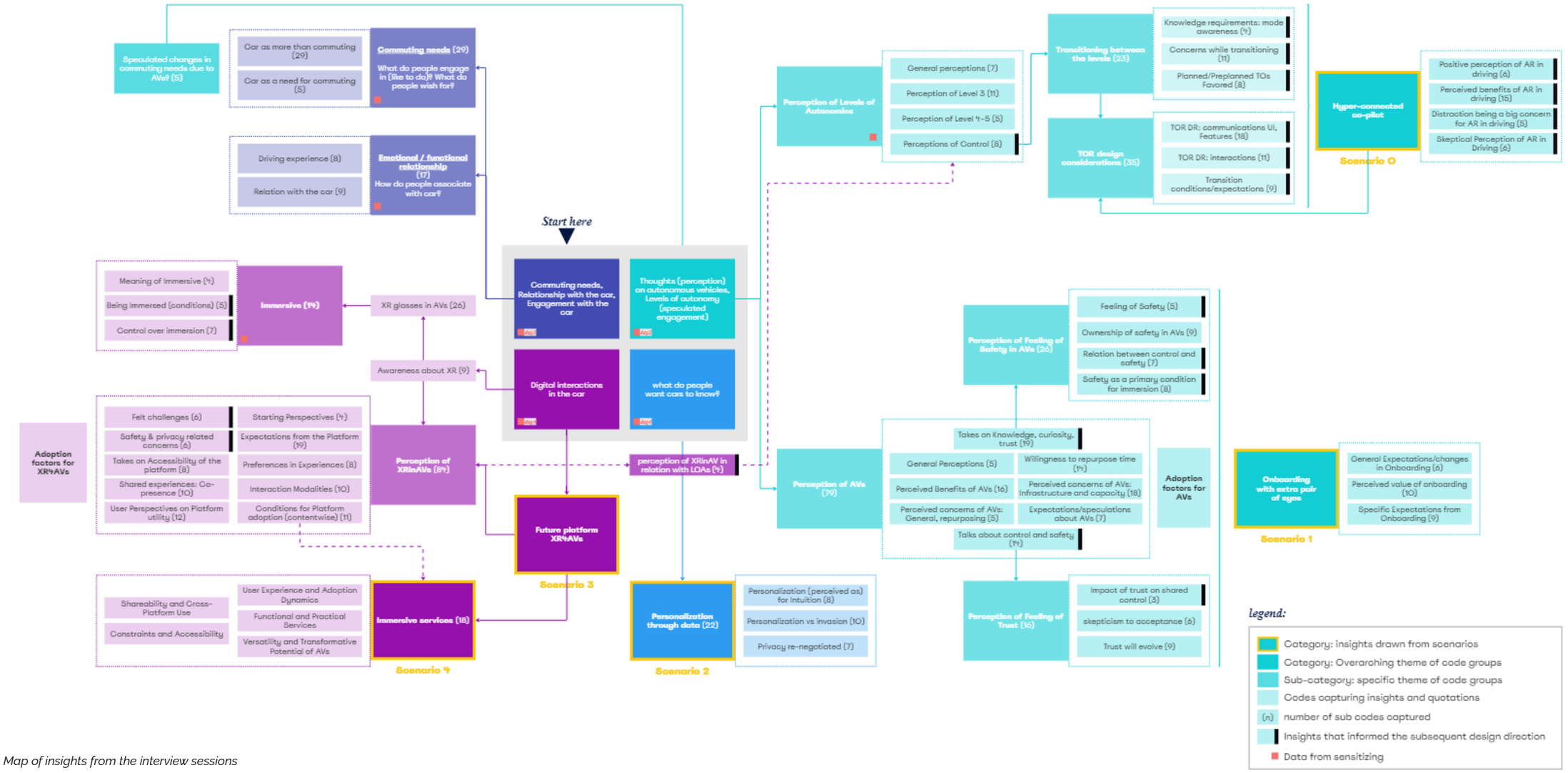



*Fig 9.1 Map of insights from the interview sessions*

# Results overview & setup

The principal aim of our interviews was not to mine requirements or feedback for iterative design but to delve into people's perceptions of technology-infused futures through provocations. Specifically, we employed thematic analysis to dissect the complexities surrounding the evolving relationship between humans and automobiles in the era of emerging technologies. One overarching question guided our inquiry: What conditions must be fulfilled for a certain envisioned future to be plausible? This question subsequently led us to explore the intricate dynamics of tension as perceived by the user. These tensions were spoken of/depicted in various forms during the interview sessions; Some were mentioned directly, others were implied, and it was necessary to compare the interests of various parties in order to spot the distinctions.

The results are systematically arranged according to distinct scenarios, each characterized by its own set of tensions. Keep in mind that the results are written using context mapping guidelines, allowing readers to empathise with users.

**Commuting and the Car Relationship**

We begin by examining fundamental aspects of daily commuting. This includes understanding individuals' engagement during commutes, their relationship with vehicles, and speculate how these elements will morph in the world of autonomous vehicles (AVs) creating a bridge to move discussion towards AVs.

**Perception of Autonomous Vehicles**

A deeper dive into public opinion about AVs covers several facets:

1. **General Perceptions:** Initial sentiments and thoughts regarding AVs.
2. **Time repurposing:** willingness to repurpose time in commuting with AVs.
3. **Perceived Benefits:** perceived advantages and utilities of AVs.
4. **Future Expectations:** Speculations and assumptions about AVs' trajectory.
5. **General Concerns**: Issues tied to repurposing time and potential challenges.
6. **Infrastructure Concerns**: Concerns about the readiness of infrastructure and systems' capacity.
7. **Trust Dynamics**: From skepticism to acceptance, and the fluid nature of trust in this context.
8. **Safety and Control**: The intertwined relationship between feeling safe and having control.

This in-depth exploration naturally leads us to uncover the primary factors that might influence the widespread adoption of AVs.

**Autonomous Levels and transitions**

The discussion then shifts to perceptions around varying automation levels, particularly levels 3, 4, and 5. Which extends to understanding the perception of transitioning between the levels. Here design considerations and design requirement cum wishes about the TOR are drawn. Furthermore, Using scenario 1 as a foundation, we explore the public's views on AR's role in driving.

**Personalization and Privacy**

The narrative then moves to understanding users' desires for personalization in their vehicles and balancing these with takes on privacy within our project's context.

**Future of Extended Reality (XR) Platforms**

Te latter half of our exploration leans into the future of Extended Reality (XR) platforms

- **XR Glasses and Immersion**: Initial perceptions about XR glasses, desired immersion levels, and the sought-after control over such immersive experiences.
- **Challenges and Awareness:** Recognized challenges and overall familiarity with XR.
- **Safety and Privacy:** Anticipated concerns around XR safety and privacy implications.
- **Platform Expectations:** Users' aspirational benefits from the XR platform.
- **Accessibility and Preferences:** Accessibility issues coupled with preferences in XR experiences.
- **Co-presence**: The intrinsic value of shared XR experiences.

This leads us to uncover the primary factors that might influence the widespread adoption of XRinAVs.

**Immersive services**

Concluding our exploration, we touch upon user insights into the platform's utility and adoption conditions, mainly content-centric, setting the stage for further discussions on immersive services' perceptions.

**Note:** that some of the quotes are adapted for length and ease of comprehension. Codes and quotes can be seen in the Atlas project file provided. Anonymised data from sensitizing booklet is made available to client and supervisory team.

**The primary focus on the following pages is on the insights that inform the subsequent design direction. Black bars indicate the connecting sections.**

**In the flow of overview, all other results are presented in Appendix C.**

# Perception of AVs

### Talks about control and safety:

The user believes autonomous vehicles (AVs) will be safer than human drivers because they will follow traffic laws. However, they believe that uncertainty about safety prevails, due to technology's struggle with real-world traffic and unexpected situations. They stress that manufacturers, the government, and the ecosystem should share AV responsibility.

Mb24c trusts regulatory bodies to ensure AV safety before widespread use. They also say they wouldn't trust an autonomous vehicle unless they knew all the nearby vehicles' capabilities. The user blames the human driver who activated the self-driving system for AV accidents. They do note that AV designers and manufacturers should consider safety.

User shows ambiguity if AV accidents are worse or better than human driver accidents. They believe AVs' faster reaction time and better brakes could reduce accident severity. They emphasise the importance of Human-vehicle collaboration — "they must work together".

The user is cautiously optimistic about AVs but believes they must overcome obstacles before being trusted. They feel that regulations will bolster their trust and adoption tendencies.

> ***"I understand the challenge, so I am critically optimistic"*** */ mb24c*

> ***"It's very challenging but I have trust in regulatory bodies to ensure my safety"*** */mb24c, mb29c, mb15a, mb16a*

### Takes on knowledge, curiosity & trust:

People are critically optimistic about AVs. The prospect of revolutionising personal mobility piques the curiosity for Tech-savvy users. The evidence (supported by regulations, insurances) will build knowledge and reduce anxiety. This will result in gradual increase in adoption. As seen before, trust is crucial factor. Users say, trust is required to fully disengage and re-engage in NDRTs– unlocking full potential. The user's anxiety/distrust stems from the fact that he or she is unable to fully commit to a task and must remain alert as a passenger.

> ***"My knowledge comes from the documentary"*** */ mb18b, mb25a*

> ***"If engage into something else, i don't have to pay attention"*** */ mb24a, mb16a*

> ***"....if I always have to be aware, the minute I know I can completely turn my attention off, I will swivel my chair, talk to my family in the car, take a nap. and let the car just drive..."*** */ mb08b*





# Perception of Feeling of Trust

### Impact of trust on shared control

People compare AV algorithms with chauffeurs or someone else from a family member driving the vehicle. They speculate that their trust in the vehicle's driving style will be affected. It would be interesting to see how the personalities and driving styles of autonomous vehicles affect trust. Their trust in self-driving cars will be influenced by how they interact with them. This conveniently informs us that the effectiveness of communication between users and systems can build or break trust. People feel more in control when they are responsible for safety.

> ***"to trust, I have to be in control ... Self driving cars a like child, in terms of liability"*** */ mb25b*

> ***"I am a defensive driver, when my dad is driving I am more aware, driving style can break or build trust"*** */ mb18b*

# Perception of Feeling of Safety

### Relation between control & safety

People feel that safety and control go hand in hand. They suspect lack of logic alignment in shared control could be a hurdle to feel secure. They think seeing what the car sees will boost this alignment. The feel conflicted to let car critical decisions, hence demand for manual override.

> ***"I feel secure when I am are controlling the vehicle, but don't necessarily feel safe"*** */ mb15a. /mb29c*

> ***"....Sometimes i feel resistance in steering wheel when lane assist is active, its really frustrating and dangerous...."*** */ mb08b*

### Safety as a primary condition for NDRT

Users express reservations about participating in NDRT. They believe it will be exhausting and distracting for them to come out of the state of immersion and take control. For obvious reasons, they believe that safety comes first. As a result, they believe that complete immersion is not a good idea. Immersion vs. safety tension is a high priority for users and clients (as it is the primary condition for participation in NDRTs).

> ***"nothing comes before safety!"*** */ mb29c*

> ***"....full immersion is not a good idea (due to safety)...."*** */ mb18b. mb25b*

# Perception of LOA, transitions

### Perception of Control

Users prioritize the ability to switch off autonomous features and have control over the car. They suggest a manual override option and emphasize the importance of quick response in emergency situations. They are willing to give up control if autonomous driving can prove to be significantly safer than human drivers. This also extends to their willingness to take shifts with vehicles in long journeys.

> *"I will have zero qualms about being in control in AVs, once policies give clearances"* /mb24c

### Concerns while transitioning

Given that they are engaged in something else, one of the primary concerns people have is cognitive load switching. Furthermore, they are concerned that the time they have to act will be insufficient. Again, ignorance casts doubt on the system's ability to assist and predict control transfers.

> *"lack of knowledge when car can assist and how much...creates insecurity"* / mb08b

> *"I don't think i will be able to do high concentration tasks"* /mb25b

### Knowledge requirements: mode awareness

Users believe that using automated vehicles necessitates new types of judgment and knowledge. Their mental models are untrained; they have no idea what automated systems are or what their capabilities are. Users expect a steep learning curve to develop such judgment over time.

> *"(I have used level 2 vehicles).... non-intuitiveness result in frustration"* / mb25b, mb08b

> *"I think there will be a steep learning curve to build judgement"* /mb24a

### Planned/pre-planned TOs favoured

Users prefer to know when the TO is expected to occur during the journey. This would assist them in effectively repurposing time and preparing a positive mindset for the journey. Unplanned TORs may jeopardize the overall engagement due to an unexpected interruption.

> *"I think it should tell me before we leave so I can prepare. So I need that information beforehand. For instance, I commute to work. I've scheduled a meeting. It cannot tell me two minutes before the meeting that I need you to drive, or I will be furious. For instance, I would have to stop and take my meeting"* /mb08b, mb29c

> *"unplanned TORs would be annoying (while engaging in NDRT)"* / mb25a, mb29c, mb08b





# TOR considerations

Various TOR design considerations were drawn based on codes developed from scenario 0 and the perception of transitioning between levels. These factors influenced the subsequent design direction significantly. These codes are organized into three major themes. Note that, these requirements are based on codes connected with quotations; for more information, see the Atlas project file. The three themes are as follows:

### Communications UI and Features

A clear and intuitive user interface is critical for effective collaboration between vehicle and users. Communication between the system and the driver, particularly during critical transitional moments, can have a significant impact on safety and usability. The following are the design requirements for optimizing this interaction:

**System Calibration:** The system should be calibrated to provide guidance that is either minimal or complete. Adaptive Guidance: The system is expected to adapt its guidance for experienced users, reducing repetition once understood.

**Strategic Starting Point:** The system should determine an optimal starting point for TOR based on users' attention and cognitive load.

**Clear Communication:**

- The system should be designed to communicate available Levels of Automation (LOA) effectively when prompted.
- It should convey the Operational Design Domain (ODD) clearly to enhance safety.
- Proper steps should be communicated during transition phases.
- The system is expected to provide a countdown timer or similar aid for conveying action timings.

**Guidance for New Users:** The system should be designed to assist new users during initial takeovers, guiding them to a baseline performance level before a takeover.

**Attention Management:** The system should consistently monitor users' attention, offering guidance as required.

**Pre-TOR Preparations:** The system is expected to provide a 'clean break' before TOR initiation and should facilitate user feedback.

**Authentic Communication:** The system should only put forth genuine and valid takeover requests.

**User Positioning:** The system should position users in commanding roles, minimizing any system-user negotiation.

**Adaptive UI:** The system's UI should adapt to mitigate potential distractions, including effective communication with external stakeholders.

**Stakeholder Preferences:** The system should tailor its communications with stakeholders based on set preferences.Interactions

### Interactions

User-automated driving systems build trust and usability. As tasks increase, users must interact with automated systems intuitively, familiarly, and minimally. These interactions, from tactile feedback to visual prompts, can affect user confidence and system understanding. Design specs show this relationship:

**Simplicity:** Interactions should be designed simply, acknowledging users' proficiency in driving.

**Cognitive Load:** The overall takeover experience should be designed to demand low cognitive load from users.

**Nature of Interactions:** System-initiated takeovers should be more conversational than instructional.

**Visual Preferences:** The system should offer opportunities for users to set theme-based visual display preferences.

**Tactile Modalities:** Tactile interactions should be expected during takeovers.

**Efficient Takeover:** The system should facilitate users gaining control through the least number of interactions.

**Natural Instincts:** The system should accommodate users' instinctual actions, like reaching for the wheel. Traditional Controls: Traditional controls should be present during takeover scenarios.

### Transition Conditions and Expectations

Transitioning from human control to automated systems is critical. The fluidity and clarity of these transitions can significantly improve user safety and trust. System-initiated handovers and user requests require smooth, predictable, and transparent transitions. The requirements that follow discuss these handover moments and their significance to the driving experience:

**Collaborative Engagement:** Users should maintain mode awareness and an understanding of ODD to foster collaboration with the vehicle and calibrate engagement in NDRT.

**Safety-Centric Preferences:** In safety-critical situations, pre-defined preferences should not be relevant, and drivers should maintain control over decisions.

**Standardized Handovers:** A standardized and regulated protocol should be instituted for handovers.

**Complex Strategic Tasks:** As automation advances, users should be prepared for strategic tasks to grow in complexity.

**Progressive System-Initiated Takeovers:** System-initiated handovers should progress in a logical and user-friendly manner.

**Dynamic Driving Task (DDT) Assurances:** The system should assure users of its capability to handle DDTs during handovers.

**Guided System Handovers:** If the system initiates the handover, it should provide guidance.

**User-Initiated Control:** During user-initiated takeovers, the system should recognize the elevated control and attention of the user, allowing for faster transitions.

**Unrestricted Control:** At any given moment, users should be granted the ability to assume control over the system.





# Scenario 0: The Hyperconnected co-pilot

**Tensions**: Autonomy vs control; Integration vs Distraction.

### Positive undertone of AR in Driving

For many, the incorporation of AR into the driving experience represents a fascinating evolution. Phrases like "AR is cool" capture the allure of this technology. Beyond aesthetics, users find value in the idea of customizable, non-intrusive AR features, especially during takeover sequences. There's a sense that, iff/when done right, AR could blend seamlessly into the driving routine, enriching the overall experience.

> ***"AR is cool, assistance by AR could be interesting"*** */mb15a, mb29c, mb24b. mb18b*

### Perceived Benefits of AR in Driving

The prospect of AR in driving is seen as intriguing and potentially advantageous. Users believe AR could be a powerful tool for enhancing situational awareness, especially in traditionally challenging areas such as blind spots. They also anticipate that AR would allow for heightened inherent awareness, with a particular appreciation for point of interest visualization. The idea of utilizing AR for heads-up displays that relay car-specific data is seen as an effective strategy to streamline information and potentially reduce distractions.

> ***"(talking about AR glasses) I wouldn't expect it to create situational awareness, I think it would just allow me to preserve my own inherent situational awareness. Because as soon as you draw your attention away from the outside to somebody in the inside the car, your vision narrows, you're not looking at the mirrors, you're not looking at the road, you're focused on something very close in front of you."*** */mb25b, mb24a*

### Sceptical of augmented reality in driving

Despite the excitement surrounding augmented reality in driving, some are skeptical. A segment questions the monetary worth of augmented reality. They compare it to a flashy 3D speedometer when a 2D speedometer will suffice. AR users have also expressed concerns about the perceived complexity of the technology, comparing it to piloting a spaceship, which they believe is too complex for daily driving. Control and autonomy are two other conscious reservations. Users emphasize the importance of having complete control over their vehicles, free of any restrictions imposed by the AR system. Finally, if a user is unfamiliar with AR glasses, a manual driving experience should be provided. This faction should not be allowed to drive.

> ***"(referencing to hand on the wheel visualisation) That's something you can do only with AR But I don't I don't think it's necessary.."*** */mb15a, mb18b*
>
> ***"it feels weird, kind of abnormal, in driving, right?"*** */mb15a, mb17b*

### Distraction being a significant AR driving concern

Users are adamant about avoiding distractions while driving. Augmented reality (AR) may distract them, putting their safety at risk. The general consensus is that while adding new features, AR should not dilute the driving experience. They distinguish between real and virtual driving and warn against using screen-based controls, which they believe are dangerous and inefficient. For them, driving has becomes a subconscious act, new interactions (if AR glasses used) must be intuitive and simple. For a seamless experience, virtual augmentations and driving should be clearly separated with "a clean break" (mb24c).

> ***as long as it's customizable, which I'm guessing it would be. And it's not that intrusive, then it's fine...autonomy over immersion critical for reducing distraction"*** */mb18b, mb25a*

# Scenario 3: Future platform XR4AVs

**Tensions**: Immersion vs safety; Immersion vs privacy; Social Interaction vs Isolation; Accessibility vs exclusivity

### Felt challenges

While XR has great potential, its pervasive integration into all aspects of life may overwhelm some users. This emphasizes the platform's need for balance and discretion. Users feel that XR will add another layer of complexity/clutter to the overall commuting experience; requiring extra safety and privacy features. Car's digital ecosystem as central control unit for digital devices is a strange idea for some users. Additionally, users question the position of Mercedes in such ecosystem, as they are not known as a tech company (like apple google or meta). However, strategic collaborations do add to plausibility of such platform in user's eyes. Users do like the value proposition but fear the utopian vision.

> ***"it's just the Mercedes' position sounds a bit weird. Like it's not is weird exactly, but It just sounds a bit strange. for instance, if Netflix does his operating system..."*** */mb15a*

> ***"I assume sometime in the future, we're going to have AR XR glasses that do function the way I described.. sometime technology over-promises and under delivers"***/*mb25b*

# About immersion

### Conditions for immersion

Some of the conditions users mention are — full immersion must retain Situational awareness through multi-modal cues, immersion should be broken by the interaction in digital space, and Being Immersed (conditions): anything that breaks immersion will be annoying; "one should be able to forgive the car" (mb25b). It was interpreted that users like enhanced reality than "virtual/fake/unreal"(mb24b, mb29c) reality, therefore, there is a need to focus on "looking more than looking different" while wearing glasses.

### Control over immersion

Users mention the importance of being able to control the level of immersion and accessing necessary information when needed. Users think autonomy over immersion would depend on their personal preference and how customizable the experience is.

Control over the immersion (autonomy over immersion) depends on the cause and entry point of the experience. If the experience is unexpected/unplanned, for e.g. deep conversations with friends, impromptu sing-along contests with kids (and parents), then the control over the immersion is not desired from users. Whereas, in the work-related tasks, getting into deep immersion is demanded by users, therefore, the control /autonomy over immersion is also required.

### Exiting immersion

Users show concerns about exiting the immersive state that is digitally mediated. They believe exiting the immersion could be cognitively demanding. Therefore, it is essential to design this state in smooth and guided way for better user retention/ repeated use.

DESIGNING

# 10

# PICKING A DIRECTION FOR DESIGN

*This chapter reflects on our research findings and their implications for choosing the next design direction. We present expert interviews that were crucial in shaping the design phase, synthesizing these discussions into key considerations and challenges for designing the ideal takeover. The chapter concludes by highlighting key decisions and contextul factors that influenced the subsequent design.*



## 10.0
# REFLECTING ON RESEARCH RESULTS

### Discussion on earlier results

The results from phase one provided a comprehensive understanding of the intricacies tied to XR interventions in the context of autonomous vehicles. With the synthesis of the feedback from users, it became evident that some preconceived notions were challenged; The tensions initially believed to be pivotal in shaping user behavior and acceptance showed some deviation.

While it was originally postulated that immersion vs. safety and immersion vs. privacy would be paramount in user acceptance and adoption, a shift in these dynamics was observed during the study. Privacy, a cornerstone of user experience across many platforms, was perceived differently within this XR intervention context. Reasons such as increasing trust in technology, the evolution of personalized and user-centric data

handling methods, and a growing familiarity with integrated digital ecosystems seem to have recalibrated the value of privacy for many participants. However, it's worth noting that the importance of privacy, while perhaps diminished, still remains.

Discussions on control and safety provided reassuring insights into an underlying concern: trust. Trust in technology, trust in its application, and trust in the idea of relinquishing control to an autonomous entity surfaced. Users' emphasis on the need for an override mechanism, cautious optimism about AVs' potential, and the desire for clarity on an AV's decision-making process all echo the profound need for trust. Thus, building this trust becomes an important focus.

Moreover, as user feedback was analyzed, an unforeseen element emerged: the value of co-presence. The realization that users not only prioritize their individual experience but also value shared experiences was enlightening. The importance of 'being together' in a digital space, especially in a time of decentralized interactions, emerged as a fresh avenue of exploration.

When it comes to user experience in autonomous vehicles equipped with XR systems, the tension between safety and immersion remains a major challenge. The interplay of these two concepts is critical in determining how users will take advantage of the opportunity to repurpose their time while commuting. How do we ensure that when someone is deeply immersed in a virtual world, they can safely transition back to reality when necessary, especially during critical moments in an autonomous journey?

From this reflection on phase one's key findings, several pivotal questions emerge, out of which three caught attention:

***1. How might interactions with Autonomous vehicles be designed to build trust amongst users?***

Trust extends beyond ensuring safety. It encompasses understanding, predictability, and collaboration. A design direction could center on transparent interactions, where users are constantly informed about a vehicle's decisions, the rationale behind those decisions, and options to influence those decisions.

***2. How might experiences be created that leverage the value of co-presence?***

Transcending the individual experience to venture into shared realities presents exciting possibilities. Designing spaces where individuals can share experiences, journeys, or even immersive environments can enrich the overall XR narrative. Picture a scenario where two individuals in separate autonomous vehicles can embark on a virtual journey together, even if physically miles apart.

***3. How might interventions be designed that resolve the tension of immersion vs. safety?***

The dichotomy between desiring deep immersion and ensuring safety is a challenging one. Designing interfaces allowing seamless transitions between immersion and reality, or multi-modal cues that help users maintain situational awareness during deep immersion, can be avenues to pursue.

## Choosing the third option: safety related tensions!

Following extensive consultations with the client, it was unanimously decided that resolving safety related tensions should be prioritized. The reasoning was simple: safety is the foundation of user decisions and subsequently, being the condition for all others tensions to exist. If users do not feel safe interacting with the XR ecosystem during their commute, adoption rates may fall, potentially putting the company's entry into this promising market on hold. Thus, resolving this tension is critical not only for the design of future interventions, but also for the company's immediate action and strategy planning.





## Design Approach

To navigate and resolve this tension, several strategies were considered, including developing multi-modal alerts, improving haptic feedback during transitions, and even developing adaptive XR content that seamlessly merges with real-world cues. The idea of designing an ideal journey, one that is both immersive and safe, and then validating its efficacy through expert evaluation, however, emerged as the most promising approach. Not every stage of a commute is fraught with the same level of anxiety. The design can achieve a sharper focus by narrowing the scope and focusing on moments when this tension is at its peak.

Consultations with experts in the field, combined with findings from previous research phases, revealed a critical point in the user journey: the transfer of control between the vehicle and the user. This is the point with (potentially) maximum intensity of the tension. While giving up control of the vehicle is a relatively simple process, reclaiming it introduces an abundance of complications that can jeopardise feeling of safety amongst users.

The dynamics of trust are a contributing factor to this tension. Users expressed concern about the abrupt need to exit their immersive state in order to regain control, emphasizing that this transition (control transfer situation) contributes significantly to heightened tension. Additionally, users revealed gaps in their understanding of the autonomous vehicle landscape, complicating their feelings of safety even further.

Given the current technological landscape, and with level 4 autonomy still on the horizon, the most pragmatic approach would be to plan for the transition from level 4 to level 3 to level 2. With the possibility of level 4 clearances in the near future, addressing this transition becomes even more important for the company. Users' feedback was clear: a planned Takeover (TO) would significantly alleviate their concerns. Unpredictability is eliminated in a planned TO; users are informed and prepared for the takeover even before embarking on the journey. This structured approach is consistent with legal requirements, which allow immersion exits in higher autonomy levels only when the infrastructure is deemed reliable.

### Setting the context for the design

With this, the design challenge's focal point became clear: address the moment of peak tension intensity for a first-time user — the planned takeover — transitioning from level 4 to level 2.

The evolution from phase one to phase two is about rediscovery, challenge, and refinement. Thus, the final problem statement concisely articulates the design challenge:

> ***"How might we design an ideal takeover scenario for a user exiting the state of immersion for a planned TO situation?"***

This encapsulates the need for design safety, trust, and predictability, ensuring users have an immersive and secure experience. However, takeover is a complex phenomena, which is limitedly explored in research. In order to understand the underlying complications and revalidate the rationale, experts consultation was needed. The results of the expert interviews are discussed in the next sub chapter.

# 10.1 EXPERT INTERVIEWS TO KICK OFF

## Interview setup and design

Expert interviews were the starting point to figure out the direction of development of the ideal TO journey and understand the touchpoints to explore. Expert interviews helped to understand the key challenges, important considerations, and the vision for *the ideal*.

Experts from TUdelft and Mercedes-Benz were recruited, with expertise in areas such as human-automation interactions, takeover-focused research, regulations, automotive interfaces, and user experience research, among others. Table 10.1. Internal referrals and personal connections were used in the recruitment process, allowing for time-sensitive action. The participants were contacted through the organization's official communication channels - emails and Microsoft Teams.

The interview followed a semi-structured format. Individuals were given pertinent questions tailored to their respective areas of expertise prior to the interview. In addition, they were given background information on the project and its scope. The interview was not recorded due to both the need for confidentiality and the lack of explicit consent. The primary sources of data for analysis were the notes taken during the interview and the resources suggested by the experts. Interview notes and questions can be seen in Meeting notes-Appendix B.

At start of the interview, It was made clear to experts that users will be engaging into NDRTs (mediated through immersive technologies) in higher levels of autonomy (namely 4 and 5). Later, Various touchpoints were discussed as part of the interviews. Such as phases of the transition experience, contexts for the transition situations, timeframe for each phase, type of Takeover , communication requirements, Interaction modalities and finally, influencing factors for the interactions and experiences.

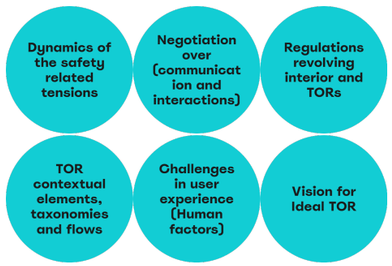



*Fig. 10.1 Topics discussed with experts*

| Expert code | Description | Expertise areas | Interview length |
|---|---|---|---|
| **T01** | Professor of Human-Centered Design for Smart Mobility, Head of Automated Mobility Labs, TUDelft | Using user-centered design principles to improve interaction with emerging technologies, the focus of this investigation is on ensuring the safe transition to autonomous vehicles. | 35 |
| **T02** | Associate Professor at Intelligent Vehicles / Cognitive Robotics, TUdelft | Specialises in human-automation interactions with preliminary focus on safety, comfort and acceptance. | 30 |
| **T03** | Assistant Professor at the Intelligent Vehicles group, TUdelft | Vehicle modelling and simulation, vehicle control, enhanced steering feel, driving comfort and driving simulator technologies | 35 |
| **T04** | Associate Professor Human Rights and Technology, TUdelft | Governance of socio-legal systems, in particular human rights in digital technologies, and designing more accountable decision-support systems. | 25 |
| **MB01** | Autonomous vehicles Researcher, R&D, Mercedes-Benz. | Main focus on transition situations, deployment of automation levels (testing and embodiment) | 30 |
| **MB02** | Automotive UI/UX researcher, R&D, Mercedes-Benz. | Human-Computer interactions, Design of displays (interaction modalities) | 30 |

Table 10.1 Overview of expert participants

The synthesis process was conducted using clustering and affinity mapping approaches. Ultimately, the questions were devised with the aim of diving deeper into the details encompassing the concept of an Ideal Takeover.

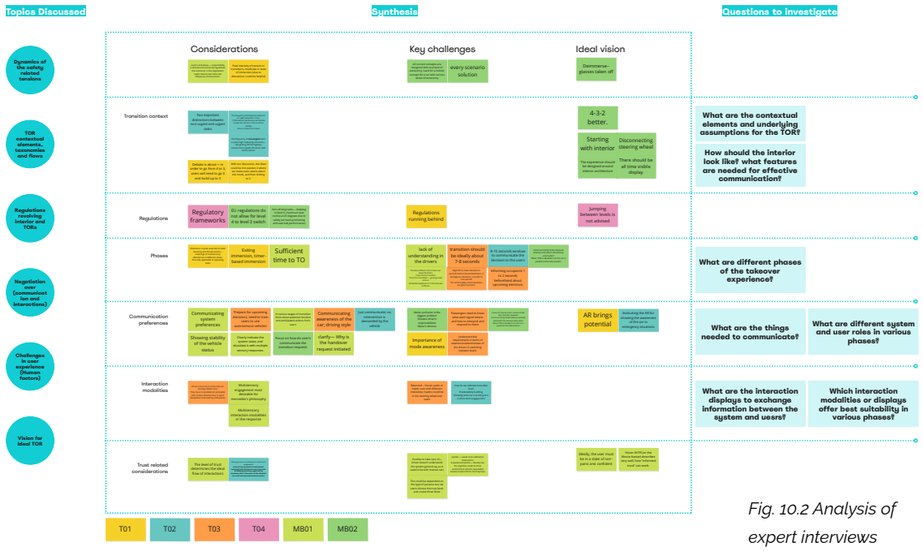



*Fig. 10.2 Analysis of expert interviews*

# Synthesis

Following are the takeaways from the synthesis process. Several important considerations and key challenges were brought into discussion, which are based on various view points (from actors) on technology development, regulations and user experience.

### Consensus on peak intensity of tension

According to the experts, safety related tensions are a pivotal aspect of any XR intervention. According to them, the peak intensity of tension could be encountered during transitions, where negation over control of the vehicle happens. Takeover (where user takes control from vehicle i.e disengaging automation) has greater tension than handover (where vehicle take control from the user i.e engaging automation). Furthermore, they believe that it has low-moderate intensity during immersion, which could be attributed to distraction from commuting, which can be beneficial (Miller et al, 2015). They emphasize the importance of reducing the felt tension during the takeovers for safety and sound user experience by designing the user journey in detailed.

### Key Consideration: Understanding and establishing the Takeover Context

Autonomy levels and the context in which a takeover is requested become critical. Responsibility at Level 3 and above is fluid—shared and constantly negotiated during information exchange. Friction in this negotiation may decrease over time with evolving mental models and with frequent interactions. In order to design the ideal takeover, it is important set the context.

Experts make a clear distinction between non-urgent and urgent takeovers. While emergency or urgent takeovers are believed to be uncommon, they do occur on a regular basis. Perhaps emergency takeovers may occur once a year for a regularly commuting user (according to T02). In emergency situations, there is a 1/100 chance that the user will safely take control. In such situations, it is speculated that, users preferences will not be considered due the design of the algorithm. Non-urgent takeovers i.e planned TOs, such as exiting a highway, occur more frequently and provide ample time to guide the driver using all sensory inputs.

### Key Consideration: A Critical Debate on Transition Flow

T02, T01 elucidated that there is a debate within the research community regarding the transition flow of the takeover. If we consider the TO happening from level 4 to level 2, some researchers advocate going from level 4 to level 2 by going all the way down to level 0 and working up to level 2. They believe that it will allow users to understand system's capacity better. However, others find this approach inefficient and cumbersome. Through our discussion (T01, T03), it was concluded (informed prediction) that it would be ideal to move from Level 4 to Level 2 through Level 3 progressively, alerting users about the mode before settling on each level. It's a beneficial approach for gradually acclimating users to the impending change in system capacity.

### Key consideration: Understanding the Regulatory Environment

Surprisingly, technology's relentless march forward frequently collides with the regulatory environment. While current regulations, such as those issued by SAE in 2021, warn against level-hopping in order to reduce driver confusion. This complies with the previous conclusion on transition flow. There are a few more guidelines established by the SAE (2021) for such transitions. They talk about Human Driver Availability, Operational Design domain (ODD), and Fallback considerations.

1. In Level 3 automation, the driver must be present and ready to intervene. Level 4 automation enables the vehicle to handle a variety of situations without the need for human intervention.
2. The term "ODD" refers to the autonomous operating conditions of L4 vehicles. Urban settings or weather patterns are examples of conditions. Outside of the specified domain, the vehicle may operate at L3 or lower levels of automation.
3. If the Level 4 autonomous vehicle encounters a scenario that is outside of its operational design domain (ODD), it must be able to safely maneuver, such as pulling over, without the need for human intervention. In Level 3 (L3) automation, the system would request human intervention.





The SAE J3016 standard will be modified or revised in response to technological advances or the emergence of novel understandings about vehicle automation. Although the EU is still fine-tuning its rules for AVs, it has foundational laws in place, such as Directive 2007/46/EC, that ensure vehicle safety, minimal environmental impact, and consumer protection. Various EU member states have responded by developing their own rules, which reflect the different approaches and interpretations of nations (Ardiyok, 2020). However, Directive 2007/46/EC has no concrete guidelines for TOs (Eur-lex, 2018). Given the current clearances for level 3, the TO interactions are different for different car manufactures.

Experts agree that "**policies are lagging behind technological advancements in AVs**". This disparity presents an opportunity to shape the regulations as well. Experts believe that the emerging design for Ideal TO could trigger a discussion between technologists and policymakers to bridge this gap through strategic collaborations.

### Key Consideration: Starting with the Interior of a Vehicle

The interior of the vehicle serves as the canvas for the AV experience. Experts (MB01, MB02) recommend that the interior architecture should be the starting point of design as it will concretize the user-car interactions and modalities. All current vehicle concepts are designed with one level of autonomy; need for a holistic concept for a car with various levels of autonomy. Continuing this line of thought, It was also found that current directives on AVs also falls short of providing precise guidelines for interior design in higher autonomy levels (Eur-lex, 2018).

Leading industry analysts, such as Deloitte Insights ("Forget the wheel," 2021), forecast a shift toward user-centricity. The importance of creating engaging interfaces and services grows. Southco, on the other hand, delves deeply into the challenge of balancing functionality and trust, emphasizing touchpoints within the vehicle to instill passenger confidence. AV interior design is currently oscillating between traditional and revolutionary. Traditional designs, with steering wheels and forward-facing seats, echo current vehicles, whereas revolutionary designs explore a world without the driver.

The demands on the vehicle's interior change as driving tasks change. With the possibility of non-driving activities, such as sleeping in Level 4, safety considerations like maximum seat recline or rotational angles come into play. *MB02* clarified that, as of now, maximum seat recline at 45 degrees is recommended for ensuring safety. This angle shows evidence of effective functioning of airbag and seat belts.

In summary, there are no strict guidelines for designing interiors in higher levels of autonomy. However, companies are working towards developing best practices that focus on user-centricity, building trust, and providing comfort. The design can be traditional or non-traditional, depending on the OEM's vision for the future of AVs.

Through client meetings it was seen that, Mercedes has inclination towards **non-traditional preferences** such as a tucked-away steering wheel, large digital interfaces, re-configurable comfortable seats. Experts (T01, T02) recommended that, a constant display across levels is crucial to communicate important system details and the current states to passengers.

### Key challenge: The Importance of Well-Defined Takeover Phases

Designing a seamless transition between machine and human operation, particularly in the realm of autonomous vehicles, is no simple feat. A primary challenge lies in *Creating Distinct Phases in Takeover*. This is important because it instills meaning and directs actions, especially during tasks that require repetition. Phases help dictate transitions, ensure safety, and provide clarity.

For instance, a user emerging from an immersive experience must be given the right tools to return to their baseline performance level. Here, timer-based immersions have been proposed, which accentuates the significance of a clear exit from one state to another. Just as one must be cautious when diving into water, so must they be when resurfacing. Too abrupt a change might be disorienting, thereby risking user performance and safety.

Furthermore, the challenge deepens when considering the timeframe for these transition phases. Ensuring users have sufficient time to comprehend and respond is vital. But, what constitutes "sufficient" varies, influenced by subjective and objective variables alike.

### Key challenge: Timing—From Understanding to Execution

The discussion further underscores a pertinent issue: *Decisions about the Timeframes for Each Phase*. A novice driver may grapple with unfamiliar system cues, hence, it's crucial to allocate ample time for them to take over. Moreover, this takeover time isn't just about length but also about clarity in communication. Different system timers can be used to prompt varied actions, ensuring drivers are adequately informed and prepared.

Yet, these timeframes are not static. The rapid decision-making capability of algorithms – especially in emergencies – necessitates swift human response. For instance, while a routine decision might allow a leisurely 8-10 second communication window, emergencies drastically cut this down (half to one second). Thus, the challenge amplifies: how do you ensure safety and clarity when time is compressed? This query naturally transitions into a related concern: communication.

### Key challenge: The Necessity of Clear Communication

Arguably one of the most formidable challenges is facilitating effective *Communication Between the Vehicle and Users Throughout the Experience*. From understanding the reason behind a takeover request to discerning the system's capacities, the user is constantly navigating a sea of information.

Understanding a user's mindset and anticipated actions becomes crucial here. Just as a pilot relies on a co-pilot for better judgment and assistance, drivers need clear, timely cues from their vehicle to act effectively. Ensuring that users can comprehend and respond timely is paramount for safety.

Further complicating matters is the specter of mode confusion. When there's ambiguity about who (or what) is in control, risks escalate. Overcoming *Mode Confusion* requires making system states palpably clear, necessitating training for users to seamlessly switch between autonomous and manual modes.





### Key challenge: Tailoring Communication Modalities

Even if the right message is crafted, the mode of its delivery matters immensely. The challenge is finding *Effective Ways to Communicate in Various Phases (Interaction Modalities)*. The human sensory system is a marvel, and leveraging it effectively can be the difference between comprehension and confusion.

Multisensory engagement, in line with Mercedes's philosophy, becomes an asset. A balanced combination of visual, auditory, and haptic cues can enhance user understanding and responsiveness. Imagine the steering wheel subtly vibrating as a takeover request, or a soft chime indicating a system state change. These modalities can act as ambassadors of trust, ensuring that the driver remains engaged, informed, and safe.

### Key challenge: Trust— A Fragile Bridge Between Man and Machine

Finally, at the heart of all these challenges lies a foundational concern: *Dealing with Various Levels of Trust*. Trust isn't binary but exists on a spectrum. A newbie might be hesitant, requiring frequent reassurances. An experienced driver might only need periodic confirmations. This dynamic nature of trust means systems must adapt accordingly.

For instance, showing a driver what the car "sees" can foster initial trust. Yet, this same information might become overwhelming later on. And as autonomous technology adoption increases, certain trust-building interactions might become redundant.

However, it's worth noting that designing for trust isn't just about information but also about empowerment. Providing users the autonomy to select their trust level ensures a personalized driving experience, ultimately leading to safer and more harmonious man-machine collaboration.

In Conclusion, the breakdown of expert interviews acts as a compass, guiding us towards questions that lie at the heart of designing the ideal takeover request. By addressing these questions, we move closer to a system where technology doesn't just serve, but collaborates harmoniously with its human counterpart. Each challenge underscores a facet of the takeover experience, and by seeking answers, we lay down the blueprint for a more intuitive, safe, and efficient future. Next chapter addresses these questions.

# formulating key questions

The synthesis of key challenges in designing an ideal takeover request serves as a rich foundation to propel us towards the next logical step: formulating key questions to guide the development of the concept. By critically examining each challenge, we can extrapolate pivotal inquiries that promise to shed light on the intricate mechanics of the takeover process.

## Delving into Phases and timeframes

Our first key challenge was the creation of **distinct phases with strategic timeframes in takeover**. This emphasized the necessity for clear transitions and demarcations between different states, ensuring users understand and effectively navigate the takeover process in a timely order.
This leads to:

> ***What are different phases and the timeframes of the takeover experience?***

Answering this provides a roadmap to the entire takeover journey, helping us identify key moments that require specific design interventions.

## Determining the roles of users and systems

An evolving dynamic between the **system and user roles** was evident from the synthesized challenges. The system must sometimes lead, sometimes follow, and at other times collaborate. The fluidity of these roles across different phases can dictate the success of the takeover process.
This leads to:

> ***What are different system and user roles in various phases?***

By defining these roles, we can set clear expectations, responsibilities, and actions for both the system and the user at each phase.

## Deciphering Communication Needs

Effective and clear **communication** stood out as a cornerstone challenge. Communication isn't just about delivering messages but ensuring they are understood and acted upon. The system must convey its intent, capabilities, and requests to the user, ensuring they are equipped to respond aptly.
This leads to:

> ***What are the things needed to communicate in various stages?***

Understanding this helps in tailoring information that is pertinent, timely, and easily digestible.

## Crafting Interaction Displays

The concern about **mode confusion** and the **necessity for clear communication** directly points to the interface between the system and the user. This interface, or interaction display, becomes the tangible medium of information exchange.
This leads to:

> ***What are the interaction displays (and interior elements) to exchange information between the system and users?***

Determining this ensures we design interfaces that are intuitive, clear, and conducive to effective decision-making.

## Selecting Suitable Interaction Modalities

Finally, the discussion on **interaction modalities** emphasized that not all communication channels are equally effective at all times. Depending on the phase and nature of the message, different modalities might prove more effective.
This leads to:

> ***Which interaction modalities or displays offer the best suitability in various phases?***

Answering this ensures we use the most effective means of communication, leveraging the strengths of each modality. Based on the synthesis, a vision for ide
Based on the synthesis, a vision  for ideal TO journey



# Important decision made

could be devised as follows.

> ***An ideal takeover request has an effective interaction flow that maintains the feeling of safety and control in a calm way for everyone in the car.***

The synthesis derived from the convergence of expert discussions and challenges has propelled us towards identifying the foundational elements for the design of the ideal takeover request. These elements are not just decisions; they are informed choices that integrate user needs, system capabilities, and realistic constraints to manifest an experience that is both innovative and intuitive. Let's unpack these decisions to understand the larger vision they construct.

## Accounting for the Newbie User

**Decision**: *The user will be considered a newbie, possessing an untrained cognitive model with uncalibrated trust. This necessitates trust-building communication and guidance from the system.*

Understanding the user is the cornerstone of any design. By considering the user as a newbie, the design takes on the responsibility of not just informing but also educating and guiding. This approach ensures that the system communicates not just functionally but also empathetically, helping to nurture trust and confidence, which are vital in autonomous vehicle interactions.

## Practical and Effective Interaction Modalities

**Decision:** *Interior elements are designed keeping in mind effective interaction modalities. A conservative approach is recommended for the interior, aiming for compatibility with vehicles set for a 2025 launch, such as the EQs.*

Rather than embarking on a revolutionary redesign, a pragmatic approach was chosen. The emphasis was on leveraging existing features to meet the communication and interaction requirements of the TO process. The design prioritized ergonomic efficiency and user familiarity by including visual displays embedded within the steering wheel and prioritizing comfort seating. This ensures that users benefit from advancements without being alienated by a new environment.

## Designing Distinct Phases

**Decision:** *Phases should be distinctly designed based on different user's and system's roles.*

This decision stems from the primary challenge of creating distinct phases in the takeover process. Recognizing the importance of clarity and differentiation, it's been decided that each phase will have a unique design, reflecting the specific roles and responsibilities of both the user and the system. This ensures a seamless transition between phases and a clear understanding of expectations, reducing potential errors and enhancing the user experience.

## Adopting the 4-3-2 Transition Flow

**Decision**: *The takeover will adopt a 4-3-2 transition flow, aligned with a planned takeover approach.*

This choice acknowledges the insight that people prefer immersion when the takeover is anticipated. By structuring the transition in a 4-3-2 flow, the design caters to this preference, ensuring that users are comfortably acclimated to the takeover process. This systematic and gradual transition aids in building trust and minimizing abrupt disruptions.

# Setting up the context for an ideal Takeover

The journey begins at level 2 (when the vehicle comes to a stop) and progresses to level 4 as the vehicle approaches the highway. Based on the insights from trends analysis and validations through expert interviews, highways will be most likely to fall under level 4 ODD. Users are informed about an upcoming TO at the start of their journey from **Munich to Stuttgart**. They select the path with the fewest TOs, allowing them to effectively repurpose their time.

## When and why?

This Takeover happens when "***Jane***" (user in the scenario) is **25 kms away from Stuttgart** and is **approaching a road construction site** (system in level 4 at 90km/hr. at the outermost lane on the 8 fold highway) in about 2 mins.

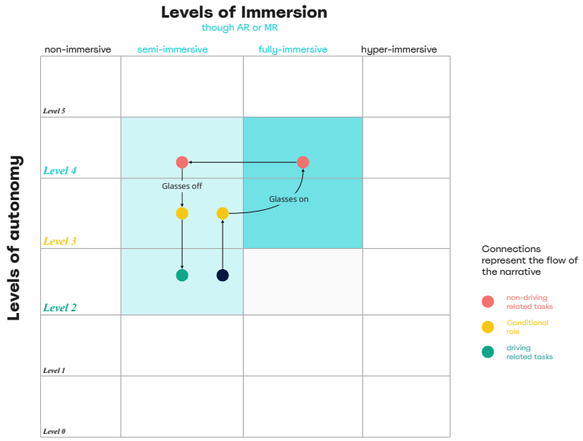
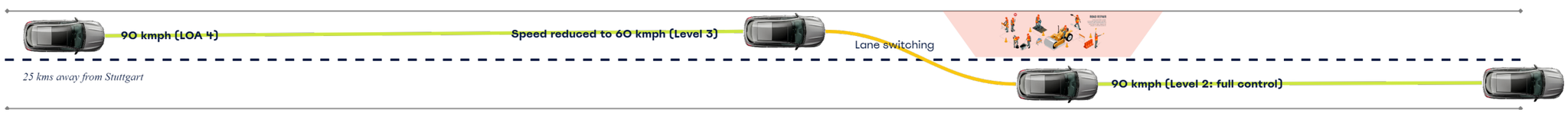



*Fig 10.3 The transition flow of the experience*

***"Jane is travelling from Munich to stuttgart for a meeting. She is travelling with her autonomous car and plans to work on the way. She chooses the route accordingly."***



# DESIGN OF IDEAL TAKEOVER JOURNEY

*In this chapter, we outline the design process used to depict an ideal takeover journey, which is displayed in video format. We present an overview of the design process, followed by a more in-depth investigation, culminating in a screenplay that captures the ideal experience. In addition, we address questions raised during expert interviews.*



11.0

# SUMMARY OF DESIGN PROCESS

## Crafting the Ideal Takeover Journey

In this chapter, an overview of the design process is presented using a flowchart. This flowchart shows how the decisions are connected with each other and ultimately inform the final narrative.

### The primary objective of the design

The ultimate goals of the design were to create an ideal TO journey for the established context. was to be used in the focus group session with experts from various fields to assess the true ideal for the experience. The vision was to develop a concept that would also serve as a baseline inspiration for developing an experiential prototype for future research. Because of these two reasons, the journey had to be mapped in detail. Moreover, everyone is familiar with driving tasks; therefore, a lack of detail will create a sense of non-realism and ultimately not contribute to the depth and quality of results.

### The true 'ideal': core principles.

The core objective of the ideal takeover (TO) journey is to foster an effective communication pathway between the user and the system. The essence of this effectiveness is captured as "delivering the right information, at the appropriate time, utilizing the most suitable interaction modalities, throughout distinct phases of the experience." The intricate nature of the TO journey arises from myriad parameters that influence these core aspects.

A salient aspect of the journey's ideal nature is the emotional state of the user. It is vital for the user to remain composed and confident. Emotions, shaped by interactions with the system and surrounding environment, can considerably influence TO performance. Intuitively presented information promotes emotional stability. For instance, clarity about the reason for the TO should be shared promptly after the alert, mitigating potential anxiety from ambiguity. Thus, the human-machine interface should dynamically resonate with the user's emotional range and focus, especially during critical phases.

Reflecting on the preceding chapter, the insights gleaned from interviews were invaluable. The questions that emerged provided directional cues to navigate this multifaceted space and underlined the overarching context of the TO scenario.

# The Design Process Explained

## An experience map

*An experience map was conceptualized to demarcate distinct phases with well-defined roles for both users and systems, and interaction modalities. This map subsequently informed a comprehensive narrative. The formulation of these parameters was a synergistic blend of empirical evidence and imaginative endeavors.*

### 1. Refining TO Phases:

Drawing from the foundational Society of Automotive Engineers (SAE) standard phases (referenced in chapter 2), we identified and addressed contextual gaps. This led to the inception of the 'deimmerse' phase and bifurcation of the disengagement phase into 'declutter' and 're-engagement'. These adjustments catered to specific contextual requirements, shaping user roles within each phase. In total, eight phases were outlined, orchestrating the user's journey from initiation, control transition, to subsequent assistance.

### 2. Role Definition and Effective Communication

**Emotional Resonance and User Role:** A user-centric approach was adamantly implemented, as evidenced by the granularity with which roles were defined. An empathy map for a first time user— "Jane"— was created to gain deeper insights. This map went beyond a literal representation to weave an intricate patterns of what users might think, feel, or do at various points along the TO. These interactions were disected to better understand how emotions, expectations, and behaviors interact with TO. Recognizing the importance of personalization, the empathy map was informed to cater to specific personas, particularly those probable for their first-time TO experience (as explained in sub chapter 4.1). Contextual variables influenced the emotional spectrum of users during the TO, providing crucial insights. Finally, users roles were defined.

**User role's impact on HMI:** Despite advancements in automation, the driver remains an important cog in the system and should be ready to take control at any (and all) time. Walch et al. (2017) emphasized the limitations of traditional handover mechanisms, particularly in a landscape that now offers a plethora of automation levels. They made a compelling case for transitioning from traditional handovers to scenario-specific cooperative (and adaptive) control interfaces. Evidence suggests that when users are placed in commanding positions, they feel a greater sense of control, which influenced our Human-Machine Interface (HMI) design. These interfaces enable the driver to seamlessly integrate into the control process without the need for a thorough reorientation to driving dynamics. Such an interface aspires to deliver an experience that resonates on hedonic dimensions in addition to practical functionality. As a result, the design should bridge the gap between the user and the system, encompassing both functional (pragmatic) and experiential (hedonic) quality.

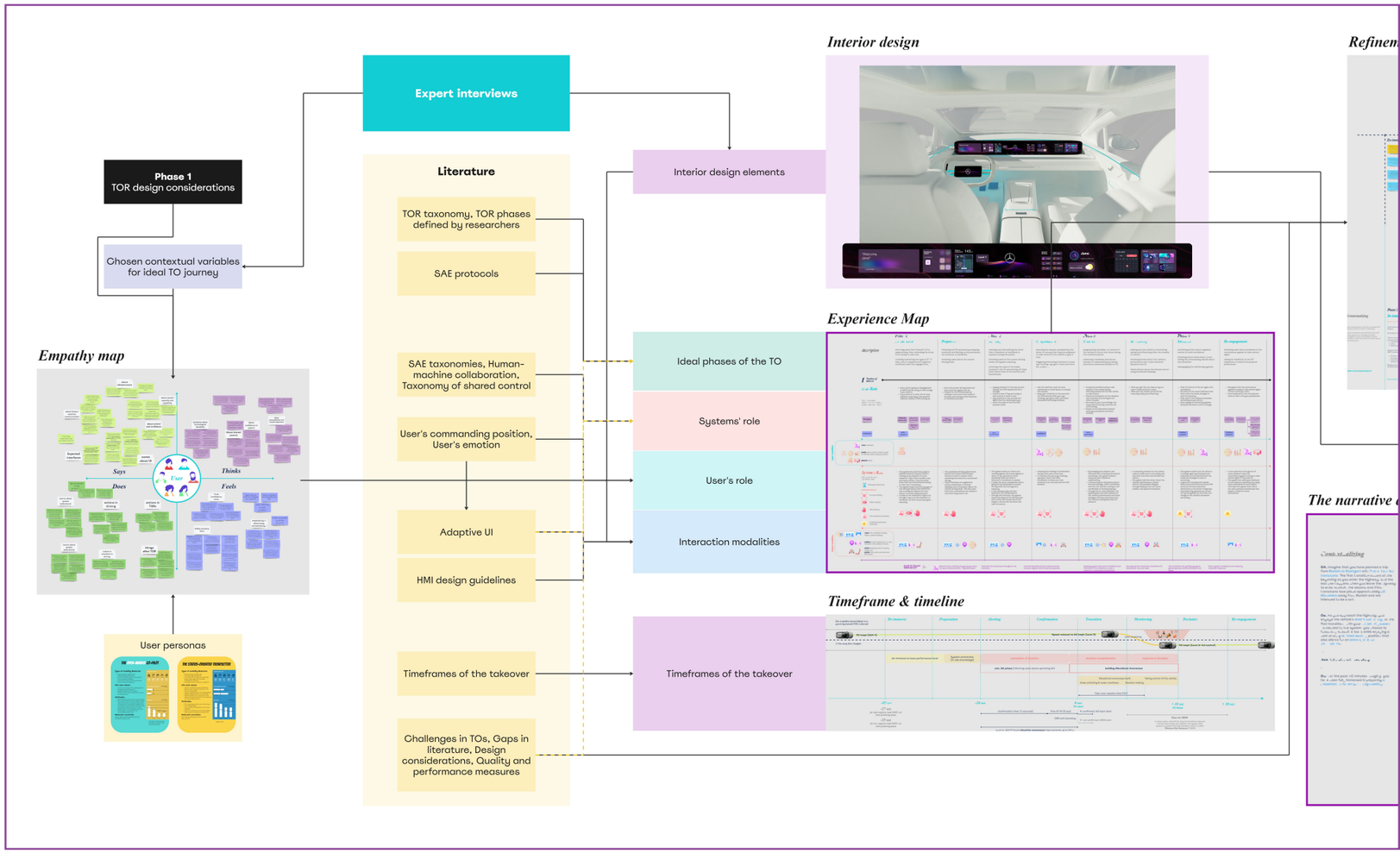
**System Role and Responsive Adaptation:** The system's role was not simply defined statically based on existing protocols. Instead, it evolved as a dynamic entity, responding to user expectations and needs. This responsiveness was founded on the conceptual protocols and empirical findings of the Society of Automotive Engineers (SAE). The role was shaped not only by what the system is designed to do, but also how it should respond to user anticipation. This comprehension informed our strategy for the system-user communication dynamics. This strategy included mapping interaction modalities to ensure a seamless and intuitive dialogue between the user and system.

*The entire role definition and communication dynamics were, in essence, an orchestration of empirical evidence, user insights, technological possibilities, and design principles. Every detail was taken into account to ensure that the journey remains intuitive, reassuring, and effective."*

### 3. Interaction Modes & Interior Design:

Every design element, from individual components to the overall layout, is influenced by the overarching goal of facilitating intuitive communication and interaction. Interior elements like the steering wheel and the Augmented Reality (AR) windshield are more than just physical entities; they help define the nature of user-system interaction.

According to the literature, interaction modalities are more than just vehicles for communication; they



The screenplay of ideal TO Journey (176)

can also be transformative in dictating user performance during TO. For example, the inclusion of a conversational auditory modality, particularly one with a distinct personality, can have a significant impact on user directive during critical moments of control transfer. With these insights, the interaction modalities were strategically matched to the negotiation scales. The goal was to provide clear, timely communication throughout each phase. This customized approach ensures that the interior elements not only serve functional purposes, but also contribute to the user's overall experience and emotional state.

### 4. Human-Machine Interface (HMI):

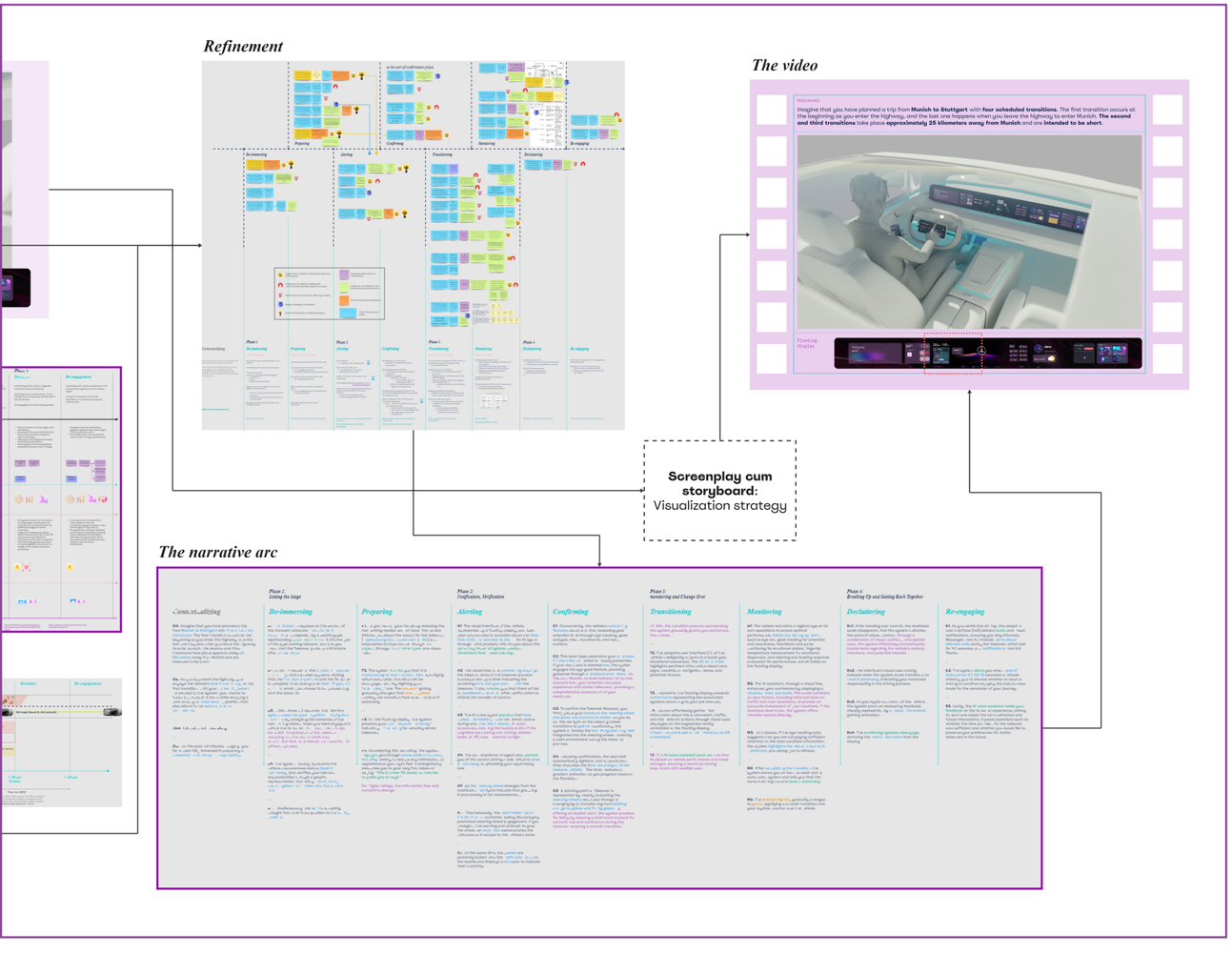
In essence, the HMI serves as a link between the user and the system. The interface must evolve in tandem with the scenarios to ensure seamless communication and interaction. The AR windshield, steering wheel, and floating display were all meticulously designed to be integral parts of this bridge.

The relationship between the interior layout and the interaction modalities heavily influences HMI development. Because of this interconnectedness, the design is not only visually appealing but also functionally efficient. Several HMI guidelines were derived from extensive literature reviews, ensuring that the interface's design incorporates both current best practices and forward-thinking insights. The addition of an adaptive UI system that spans the AR windshield, steering wheel screen, and floating display was a key feature. This adaptability ensures that the interface remains relevant to the needs of the user and the context of interaction.

### 5. The game of Timeframes:

Understanding the rhythm of the interaction is much more important than simply defining the appropriate timeframes. These timeframes were calculated using a variety of academic sources while carefully considering the various influencing factors.

Several dynamics are at work, including the user's cognitive states, the ebbs and flows of user performance, the detailed protocols of TO, the urgency inherent in specific phases, and the nature of interactions. Each factor contributes to the puzzle. Understanding cognitive states, for example, aids in determining the best time to introduce specific information, ensuring that the user processes and acts on it effectively. The timeframes were articulated in a way that ensures a fluid, intuitive, and effective TO experience by incorporating insights from all of these facets.




## Narrative development:

With a grasp on the aforementioned facets and their intertwined nature, we conceived an experience map through iterative refinement. This map underpinned the narrative, capturing interaction trajectories. It continually evolved, benefiting from robust peer input and academic insights. Speculative product features, inspired by literature-derived gaps, enriched the narrative, elevating the overall TO experience.

## The video representation:

Choosing a visual medium was rooted in design principles accentuating clarity and user engagement. The video's tempo/pace and graphic configurations were critically calibrated. This visual narrative distilled research discoveries, forming the storyboard for the ideal TO journey. The leap from storyboard to video hinged on highlighting essential visual elements, granting viewers a lucid grasp of each phase. A succinct one-minute TO was expansively elucidated across ten minutes.

In conclusion, the design process for the ideal TO journey epitomizes the synergy of rigorous research, empathetic design thinking, and deliberate implementation. It exemplifies the harmony achieved when user needs, technological strides, and design principles intertwine. This meticulously crafted journey sets a benchmark for a user-centric TO experience, ushering in avenues for novel explorations.

The process is explained in detail in the next chapter, and the final result is showcased in the chapter later. (Press jump to see the final storyboard).

11.1

# DETAIL DESIGN PROCESS

## A brief overview of Takeover phases

As seen in chapter 2.2, SAE has provided phases of a TO. It is important to note that SAE's handover taxonomy talks about abovementioned phases consdering a transition 3 to level 2. However, there is a limited evidence in literature or in guidelines that talks about level 4 to 3 to 2 transition.
One of such guideline on stages of TO is provided by Gold et al., 2013; Kim et al., 2018; Morales-Alvarez et al., 2020. The TOR process and the transition from higher automation to manual driving follow different stages and have been the subject of ongoing research. The following is the recommended order for a smooth transition of control.

1. There should be a state of perception in which drivers gather information (through, for example, eyes-on-road or mirror glances) i.e the mental processing of the situation leading to situational awareness.
2. There should be enough settling time in which drivers initiate to regain control (through, for example, hands-on-wheel)
3. There should be the state in which drivers take over the automated driving (through, for example, throttle, brake, or steering wheel actions).

With these insights and SAE's guidelines from 2021 issues follwing phases were drafted, that build on basic phases *preparation, suspension and handover*. The descriptions of the phases are as follows,

**1. Prepararion**
Setting up the procedure for handover is done during this stage. The automated driving system must provide the human driver precise advice on what to expect while switching from manual to automated driving. Also, the driver must be ready to take over or give up control of the vehicle.

**2. Alerting**
The automated driving system warns the driver that a TO is required during this phase. The warning should be unmistakable and obvious, giving the driver adequate time to get ready to take over or give up control of the car. Among many factors, warning, and alert systems in automotive interfaces play an important role in take-over requests (TOR). It ensures a timely and smooth transition from autonomous to manual driving. (Mukhopadhyay et al, 2023)

**3. Confirmation**
After sending out the alarm, the autonomous driving system should ask the driver to affirm whether they are prepared to take control of the vehicle or give it over. This assurance can support ensuring that the driver is alert and ready for the change in control. Based on the response, TRM (taking vehicle to a safe location autonomously, when driver doesn't reponse) protocol is intiated.

**4. Transition**
The autonomous driving system progressively hands over control of the vehicle to the human driver during the transition period. In order to achieve a seamless and secure transfer of responsibility, this phase has to be properly handled through system cues.

**5. Monitoring**
To make sure the user is functioning safely and effectively after the transfer of control, both the automated driving system and the human driver should keep an eye on the vehicle's performance. Also, the autonomous driving system must be ready to restart if necessary.

**6. Disengagement**
Under rare circumstances, it can be essential to totally disconnect the automatic driving system. This could happen if the system is malfunctioning or if the driver has to take over steering for a long time.

### Adaptation for ideal TO context

Some adaptation to the phases were needed in order to bring the contextual variables into play for designing the ideal TO such as intiatial state of immersion and use of multimodal interfaces (like AR).

**0. Introducing the de-immerse phase**
In the envisioned context, user is exiting the state of immersion and is wearing glasses to be invested in Non-driving related task (NDRT). This has significant effect on user's cognitive state and base performance level. Therefore, a phase ''de-immersing'' was added at the begining — before preparation. In this phase, user is informed about the approaching TO. Parrallely, user is monitored and guided by the system to exit the state of immersion effectively.

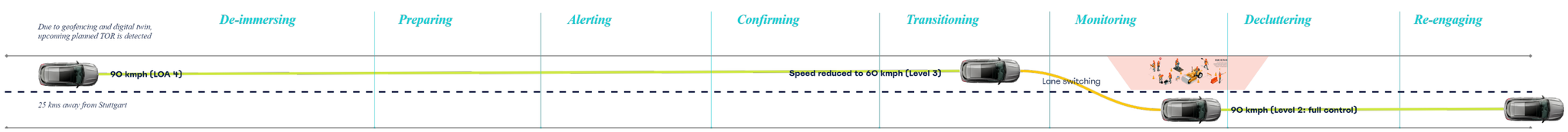
### Redefining the Disengagment phase into segments

The disengagement phase was deemde to have less relevance to the chosen context. To make it relevant, it was replaced by two distinct phases — *declutter* and *re-engagement*. The multimodal interactions through various interaction displays (such as AR windshield, Floating screen) were also considered in design of these phases. *(Interaction displays and interior features are explained in this section later.)*

**7. declutter**
*This phase comes after the monitoring phase where full control is achieved by the users. The information and functions that become irrelavant, once the full control is achieved, are removed i.e de-clutter.*

**8. Re-engagement**
*Here, system's autonomous functions become available again for engagement. Also, user is asked to offer a feedback on the TO experience, so that the performance data is used for improving the experience.*

*Fig 11.1 Eight distinct phases — De-immersing, Preparing, Alerting, Confirming, Transitioning, Monitoring, Decluttering, Re-engaging — were decided.*



# User and system roles

Understanding the roles of the user and the system in each Takeover Request (TOR) phase is critical for a great autonomous driving experience. Understanding the roles of the user and the system was deemed critical for understanding the dynamics of each phase. The roles available to a human within a system can be dramatically different and can hold very different implications for driver-vehicle system performance as well as for HMI design (Angell & Elm, 2019).

In this journey, feeling of safety is of the utmost importance. The system protects users and its operations by assigning clear roles and responsibilities (Hancock, 2019a). This clarity increases user trust in the system. When roles are consistent and well-defined, users can anticipate system behaviors and the system can accurately predict and rely on user inputs.

Usability can be improved by understanding these roles. A seamless, user-centric experience is created by user expectations and an intuitive system. Mode confusion persists despite this harmonious interface, but defined responsibilities may help to avoid misunderstandings and ensure a smooth transition from user control to autonomy.

The TOR system's efficiency during these transitions demonstrates its comprehension. To provide a safe and personalized driving experience, the system adapts and learns from its interactions. Recognizing and integrating roles within each phase aids in the development of a more sophisticated, communicative, and responsive HMI.

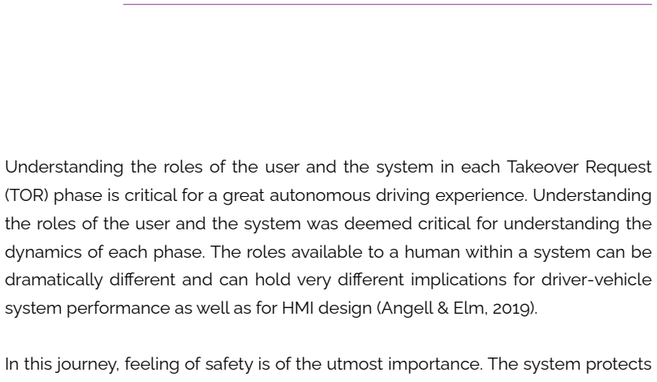



*Fig 11.2 Selected personas for design*

## About the users' role

The SAE regulations specify what the user should do in response to the system's nudge. However, there are a number of other factors that can influence the user's role, mental state, and performance. Prior knowledge of the system and protocols (Casner & Hutchins, 2019), in-situ knowledge/expectations/thoughts, natural instincts (driven by driver behavior and mental model — Michon's model 1985), and emotional states in various stages could all be factors. Driver's emotion also significantly contribute to feeling of safety and control. According to Sanghavi et al (2020), among all the induced emotions (as a result of automation), drivers had the best take-over performance when they felt calm and the lowest take-over readiness when they were angry.

In consultation with the client, the personas in fig 11.2 were considered in order to concretize the user's mindset and expectations (for our narrative). As seen in subchapter 4.2, personas (in fig 4.4) play as power personas in levels 3 and 4, with the highest proclivity to engage in NDRTs, which corresponds to the choice of first time user.

**Building An empathy map**

The process of consolidating and organizing user data is referred to as empathy mapping. The purpose of the empathy maps is to empathise with users. It's a clear and straightforward graphical representation of the feelings and activities of a user. In this particular example, the empathy map was used to map desirable user behaviors and anticipate the role in various stages.

Using information from selected personas (namely user's attitudes, mobility behaviours), TOR design considerations drawn from the phase 1 and contextual considerations empathy map was created. See fig 11.3.

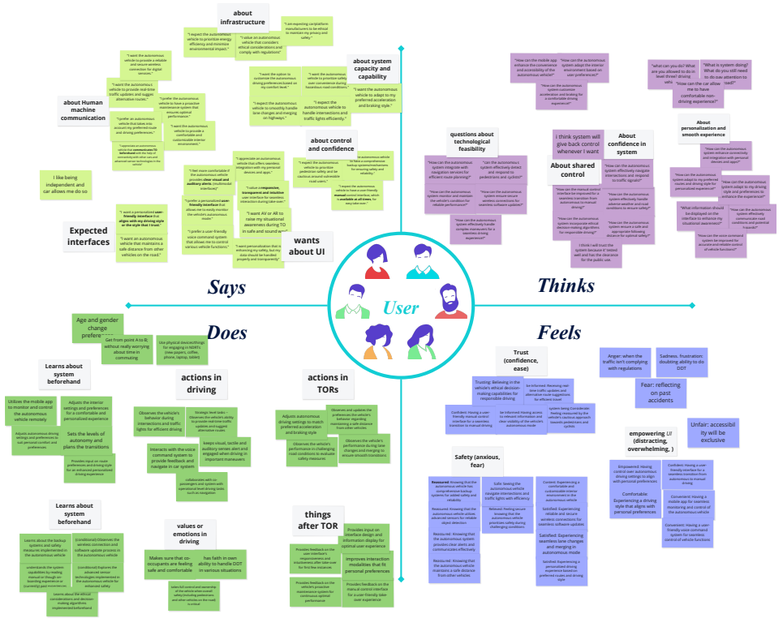



*Fig 11.3 Empathy map*

**Choice to keep user's in commanding position**

The driver's role in the vehicle system, such as a fall-back-ready user or a commander or a quarterback with a playbook for managing different sections of the trip, can significantly affect the driver's experience of navigating these transitions.

According to the manual, SAE considers drivers to be fall-back-ready users. Drivers provide a "safety net" for the automation system in the limited context of supervision (primarily monitoring and fallback support). However, contrary to popular belief (due to the simplicity of the low-level supervisory role), not all drivers can provide a "fallback" capability in highly reliable automation (Victor et al., 2018). Moreover, role can affect the experience in terms of interactions and ownership of the feeling of safety. Therefore, it was decided to keep user's in commanding role while designing.

This may appeal to first time users, due to two main reasons

1. The commander role retains the ownership over control and safety of drivers or occupants (Cohen et al., 2020)
2. Commander role puts users in a state of authority which also bolsters the trust in automation and caters to the value of competence (in driving scenarios) (Hildebrand & Sheller, 2018)

To learn about commander responsibilities, cognitive models, knowldege and skill requirements refer to Appendix E.

**Impact of commanding role on HMI**

Driver-vehicle system performance and HMI design can be significantly impacted by human roles within the system (Angell & Elm, 2019).

- A commander's HMI should convey risk factors and allow for in-interface strategy changes, while a lower-level supervisor's HMI should make it simpler for the human operator to detect the deviation from normal.
- Augmented and mixed reality display concepts, decision-support systems, cognitive dashboards, and efficient ways to represent situation information over time—particularly in time-critical situations—might be useful in this situation.
- HMIs could be designed in more gamified way to keep the users engaged in something, in order to maintain the readiness for takeover (by maintaining attention, situational awareness and skills) in all situations. (see, for example, Schroeter et al., 2014; Schroeter & Steinberger, 2016; Sureephong et al., 2016; Steinberger et al., 2017)

*More about application of these guidelines is explained later, in the Floating display UI design and AR windshield.*

**Role of user's emotions in TOR**

Even in autonomous cars, emotions will affect driving performance. The driver must take over in level 3 automated vehicles. Take-over actions must be precise to protect drivers and passengers. Takeover actions are influenced by the same factors as in lower automated vehicle studies. This includes emotions. Although drivers in highly automated vehicles (level 3) have changed, **emotions should not be ignored in take-over scenarios.** Among all the induced emotions, drivers had the **best take-over performance when they felt calm** and the lowest take-over readiness when they were angry. (Sanghavi et al, 2020)— a key requirement for an ideal situation.

Emotionally intelligent in-cabin assistants can learn from their users' feedback and tailor their interactions to each individual's needs thanks to continuous learning and personalization.

**Detecting emotions in driving**

With automated driving, detecting emotional differences between vehicle occupants and in-cabin social dynamics will become more important. Alvarez (2019) created automated driving scenarios to frustrate and startle drivers and compared emotional expressions between single drivers and driver-passenger pairs. Their findings suggest that emotional states may differ between driver roles under the same driving conditions (driver vs. co-driver) and that emotion recognition and handling strategies may need to adapt to





the number of vehicle occupants and interpersonal dynamics and that in-cabin driving assistants may use similar social dynamics. which is also in line with the tension between immersion vs safety.

Emerging technologies provide open-source and commercial emotional state classifiers using camera, voice, and biometrics. Most of the interaction community uses simple machine learning tools to combine these for robust emotional state estimation. Interactive assistants make it easy to integrate emotional state cues into dialogue interfaces for natural language processing or visual cues (i.e., ambient lighting, music selection, etc.) making UIs more adaptive to user preferences.

**Measuring emotions is hard**

Quantifyin emotions is hard due to lack of theoretical framework to distinguish emotions from other cognitive constructs and lack of sufficient evidence with real life testing in terms of emotion strength & duration.

## Defining the Systems role

In order to understand the role of the system, several sources from literature were considered. Some of the notable resources are — DeGuzman et al, 2022; SAE, 2021; Abbink et al, 2018; Wintersberger et al, 2017. System's role mainly encopasses monitoring users and in response adapting and managing thier attention and in-situ knowledge. Furthermore, system role was also hypothised following HMI design guidelines (in terms of monitoring functions, feedback loops, etc.- explained later in this section) and using what guidance or cues user's might be needing in each phase.

# Interior concept: availing interaction modalities

## Defining key Interior elements

As seen previously, some of the key features of the interior were devised through the expert interviews — A large digital display, A tucked steering wheel, re-configurable comfortable seats. AR windshield was added to the concept as a speculative feature.

A moodboard for interior elements was created (see appendix G). The primary inspiration frame was EQS 2024.

**1. Floating Display:**

A large visual display spanning across the dashboard was designed — A floating screen. This display remains primary throughtout the transition. It presents key safety and transision information to driver and passangers. It has adaptive UI that re-priorotises information by adjusting the visual hierarchy. The design of this adaptive UI is explained in the next sub-section. The inspiration for this display also came from concept cars — Kia EV9, Mercedes EQXX.

**2. Steering wheel with two buttons:**

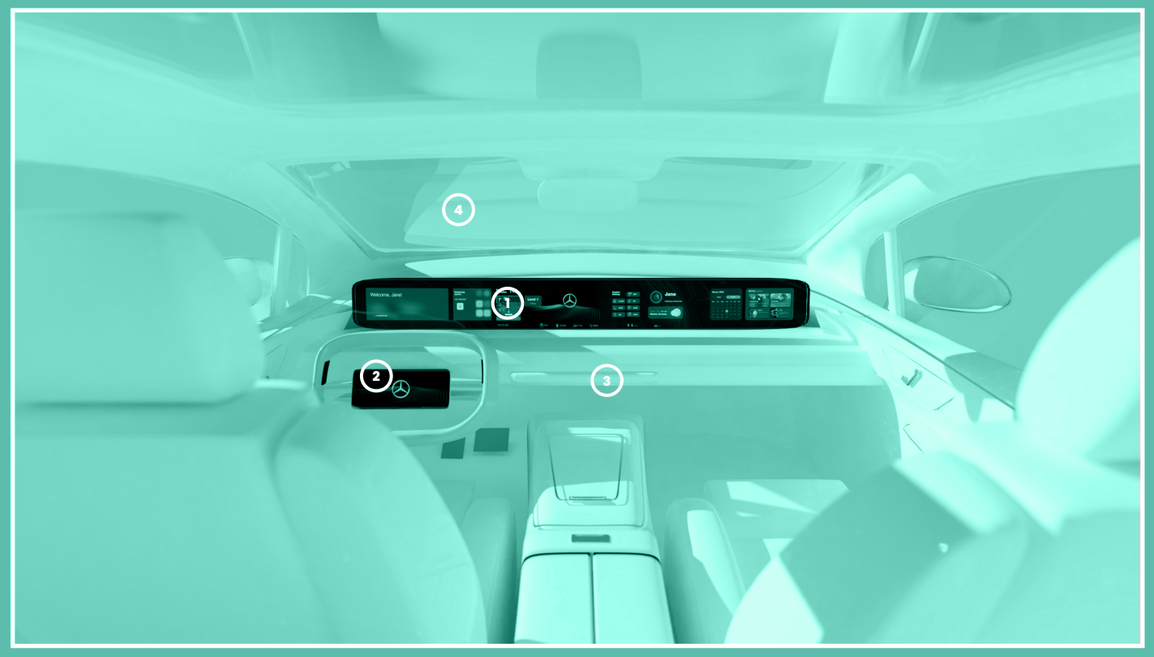
Steering wheel is a primary tactile modality user's have. Threfore, a touchscreen display to interact and two buttons (laterally placed) for confirming the takeover were designed. It was strategically shaped and placed, so that it doesn't cloud any information on the floating display. It has embedded multicoloured LED lights to communicate with users. A feature of integrated breathing assist was added to regulate and measure emotions (Paredes et al., 2018).

**3. Ambient Lights**

Ambient lights are one of the primary ways to communicate information with users, given that they know what the colours signify. Current embodiment of level 3 autonomy in Mercedes EQS uses LED lights to show the level of autonomy. The use of ambient lights was also informed by studying How European and North American OEMs have implemented the TORs namely Audi A8, Volvo XC90, Tesla model S (details could be found in appendix F). Ambient lights were placed on dashoard (under the floating screen), foot area (on the pedal) and through LED strips on the side of the interior.

**4. AR windshield**

Need to raise situational awareness has been substantiated by various researcher. As seen in chapter about situational awareness, Out-of-the-loop performance degradation happens when a driver is not in control of a vehicle and is not paying attention to the road environment. This can make the system vulnerable when a control transition is needed (De Winter et al., 2014; Stanton et al., 2006, 2017).
Environmental complexity is introduced as one of the factors that influences safe transfer of control (Wiehr et al, 2021). AR displays can address this issue. AR windshield allows for point of interest visualisation, which can improve 'directability', which refers to guidance towards future actions or relevant pieces of information (such as road hazards) (Clark et al, 2019). It also avails attention directing features in SA building (Langlois and Soualmi, 2016). It is important to note that technical feasibility of this visual display is very challenging, however, it was not considered in this non-conservative design appraoch. UI system for AR windshield is displayed in Appendix H.




# Interaction modalities

Creating the ideal interaction during a vehicle's takeover journey requires striking a balance between ensuring driver readiness and reducing potential distractions. These modalities must be designed to deliver timely, effective information that is appropriate for the nature and urgency of the takeover (Frison et al., 2019; Forster et al., 2019; Wintersberger et al., 2017). Exploring the reasoning behind our design's chosen interaction modalities can help us understand our decisions.

## Visual Displays: Direct and Informative

Because of its simplicity, the visual modality is a natural choice. However, when driving, which requires a high level of visual attention, there is a genuine risk of either overwhelming or ignoring these displays (Yang et al., 2022). This delicate balance guided our design decisions. Our emphasis on user experience and safety led to the positioning of automotive HUDs below the driver's line of sight. Furthermore, we prioritized the use of clear icons in conjunction with textual indications to improve processing fluency and user intuitiveness (McKeown and Isherwood, 2007). AR is being used to ensure that, while providing a richer visual experience, we also improve situational awareness without causing undue distraction (Langlois and Soualmi, 2016; Pltis and Pollick, 2015).

## Auditory Displays: The Subtle Prompters

Auditory modalities have a distinct advantage in that they do not necessitate visual attention. They can detect vehicle states, changes in the road, and even potential collisions (Nees and Walker, 2011). Speech-based displays, in particular, have consistently been shown to improve the takeover experience (McKeown and Isherwood, 2007). Our decision to implement conversational interfaces stems from our belief in an emotionally intelligent system capable of effective communication, particularly in high-stress situations (Wiseman, T., 1996; Nass et al, 2005; Lee et al, 2019).

### Haptic Feedback: The Touch of Assurance

The importance of touch, especially in critical situations, cannot be overstated. Vibrotactile alerts delivered via the seat, steering wheel, or seat belt ensure the message's immediacy without overburdening other senses (Telpaz et al., 2015). Safety is still a top priority, which led to the inclusion of haptic displays, which have been shown to provide a safer takeover experience (Petermeijer et al., 2017).

### Multimodal Displays: Symbiotic Synergy

Multimodal displays, which combine two or more modalities, are deemed to be at the forefront of modern vehicular design, promising a seamless transition from automation to human control.

***The Advantages of Multimodality:***

By combining visual, auditory, and haptic signals, we cast a wider net of driver engagement, ensuring that at least one, if not all, modality receives the driver's attention. If one mode of alerting the driver fails, another can compensate. In critical situations, this redundancy can be life-saving. According to Politis et al. (2013), multimodal displays frequently elicit faster responses than unimodal ones. This could mean the difference between a successful takeover and a disaster. The modal combination can be determined by the nature of the takeover request (TOR). Unplanned TORs, for example, which have a natural sense of urgency, may benefit more from the immediate sensation of a haptic alert combined with auditory cues for clarity. Planned TORs, on the other hand, may be better suited to a combination of visual and auditory signals, giving the driver enough time to comprehend and act (Yun & Yang, 2018). Multimodal displays can be customized to convey various levels of urgency. Auditory and vibrotactile displays may be preferred in situations of intermediate urgency. In high-urgency situations, however, utilizing all three modalities may be required.

***Preventing Overcomplication:***

While the power of multimodal displays cannot be denied, there is a fine line between informing and overwhelming. To avoid sensory overload, the selection and intensity of modalities must be balanced. As drivers progress from passive to active roles, their emotional state becomes increasingly important. Multimodal displays can address this by incorporating calming auditory cues, such as self-selected music or guided breathing rhythms, particularly in situations where the driver may be anxious (FakhrHossein & Jeon, 2015).

While multimodality has many advantages, it is critical to avoid complicating the driver's experience. A cluttered display or a cacophony of sounds can be detrimental. The effectiveness of certain modalities may differ depending on cultural or individual preferences. For example, as Bazilinskyy et al. (2017) discovered, the acceptability of haptic feedback varies significantly across populations.

## Creating an experience Map for the ideal journey

By integrating all above aspects— various phases of the experience, appropriate interaction modalities for each phase, and considering the roles of both the user and the system in each stage — a comprehensive visual experience map was developed.

**See fig.11.5.**





## Design of HMI

Conceptual framework of TOR defines the way information flows through the system and users. A TOR system sends information to the driver through an HMI depending on whether the ODD limits have been reached or an emergency situation has been detected. TOR starts when either the driver or the system (based on ODD) makes the first contact. A TOR can be thought of as a control switch between two systems that sets the security level based on how the systems are built and what parts they have (Venkita et al., 2020).

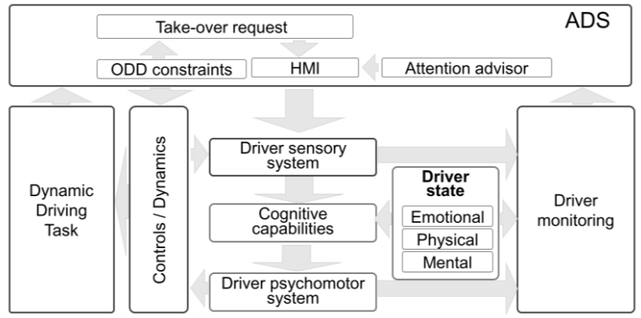



*Fig 11.4 Overview of conceptual framework for TOR*

The work in (Li et al., 2019) suggests a TOR system that works as a shared control model that constantly checks the driver's awareness of the situation before giving the driver full control. In order to do this, a DMS looks at the driver's physical responses and how they perceive their surroundings (Allamehzadeh et al., 2017).

This framework prominently points to the fact that Human-Machine Interfaces (HMI) are a very important part of TOR communication. As seen before, TOR systems should use multimodal communication interfaces that send clear messages and put information in order of importance. Here, the use of Adaptive UIs was deemed the most appropriate.

## Use of Adaptive User Interfaces (AUIs)

AUIs that can monitor and adjust driver attention will become more important as driving automation increases underload and driver distraction. AUIs can support driver takeover in critical situations and improve user experience by easing transitions between non-driving tasks and driving.

Driver state monitoring systems can track driver attention or attentional demands in real-time (Aghaei et al, 2016; Dong et al, 2011; MacDonald et al, 2020) and manage attention. Therefore, in our context, floating display and AR windshield come under AUI primarily. In AUI, the system takes care of the driver's attention and en

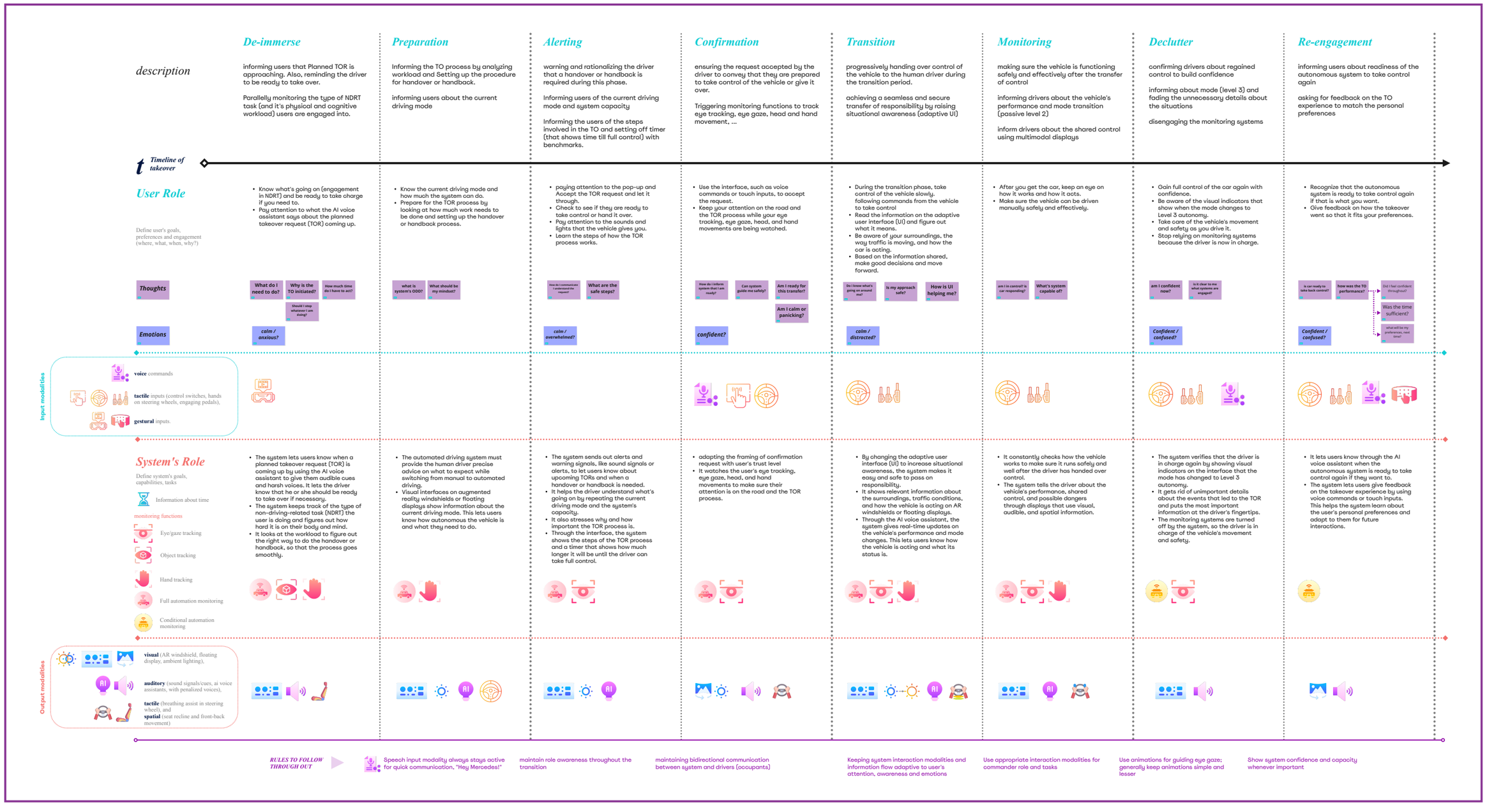



*Fig 11.5 The experience map of an ideal TO*

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Driver state monitoring systems can track driver attention or attentional demands in real-time (Aghaei et al, 2016; Dong et al, 2011; MacDonald et al, 2020) and manage attention. Therefore, in our context, floating display and AR windshield come under AUI primarily. In AUI, the system takes care of the driver's attention and engagement areas through multiple modalities.

Maglio et al. (2000) and Vertegaal et al. (2006) define three main components of AUIs —

1. The system *monitors and measures the user's attention*, either directly (eye-tracking) or indirectly (task complexity; more complex tasks require more attention).
2. The system *changes the interface based on the user's state*.
3. This adaptation manages user attention. Thus, the interface will *match the user's attentional capacity, enhance it,* or direct it to important areas.

## Monitoring the user is essential for AUI

AUIs estimate the driver's state and attentional demands for a given situation and adjust built-in or carried-in device displays. An AUI's effectiveness depends on its algorithm for monitoring driver attention and environmental attentional demands. AUI performance can suffer from algorithms with low hit rates or high false alarm rates. Research on automated driving has highlighted various methods to monitor and determine a driver's attention and potential distractions —

- **Eye Gaze Patterns**: Studies, like the one by Louw and Merat (De Waard and Brookhuis et al., 1996), have shown that a person's wandering gaze can indicate distracted driving. Specific eye contact patterns can be especially telling of distraction.
- **Brain Oxygenation Levels**: The use of functional near-infrared spectroscopy (fNIRS) measures brain oxygenation. Drivers engaged in non-driving tasks show increased brain oxygenation levels, as observed by Sibi et al. (2016). This suggests the potential of fNIRS to track distracted driving.
- **Eye Tracking Measures**: Automation in driving has revealed metrics like blink duration, blink frequency, and pupil diameter as markers of driver underload. Research (Körber et al., 2015) suggests these measures can illustrate the outcomes of such underload.
- **Drowsiness Indicators**: Metrics such as blink duration and frequency can hint at drowsiness. Though differentiating its cause – whether from underload or other sleep-inducing factors – can be challenging, specific signs like eyelid closures over 1 second or head-nodding help identify higher drowsiness levels (Vogelpohl et al., 2019).
- **Specific Activity Detection**: Recent research has explored the potential of using drivers' eye and head movements to discern particular activities like reading or texting, pinpointing where attention is focused (Braunagel et al., 2017). Additionally, measures of driver state and environmental demand can help gauge takeover readiness, considering factors like driving task complexity and non-driving tasks.

**The screenplay of ideal TO Journey (176)**





# Design of the Floating display UI

Spanning across the pillars of the car's interior, the floating display presents a panoramic user interface with a 1:10 aspect ratio. The layout is partitioned into modular "information blocks," designed to provide key details in an easily digestible format.

## Layout and Design

*Left Section*

1. **AI User Interaction (AUI) Block**: Positioned at the left, this block handles AUI communications. It displays keywords extracted from AI voice commands, TO progression timers, TO progress information and extra NDRT notifications like calls. This serves as a supplementary visual cue to the AI's auditory responses, thereby enriching the conversational experience.
2. **Monitoring Systems Block**: Adjacent to the AUI block, this area indicates the engagement status of various in-vehicle monitoring systems.

*Central Section*

1. **Navigation and Automation Block**: Situated centrally for maximum visibility, this block provides vital information on navigation routes, the system's current automation state, the level of vehicle autonomy, and the driver's role in the driving process. It was deliberately placed there so that every person in the car is aware of the car's autonomous state.
2. **Constant Information Bar**: Located at the bottom, this region continuously displays essential data such as battery life, distance until the end of the charge, connectivity settings, and paired devices.

*Right Section*

1. **User and Environment Block**: On the far right, this block presents details about the logged-in user, current weather conditions, and options for entertainment or media.
2. **Safety Cues**: Safety-related signals are strategically positioned at both ends of the display. Accompanied by alarming beeps, these cues alert the driver to potential hazards or required actions.

*Background Animation: System Confidence Indicator*

The background's dynamic particle animation shows the system's confidence in real time. Slow, soothing particle movement indicates system peak performance and confidence. Faster, more chaotic particle motion indicates lower confidence, subtly alerting the driver to intervene. (This feature was not visualized in the concept video, as animations were not the primary focus of research).

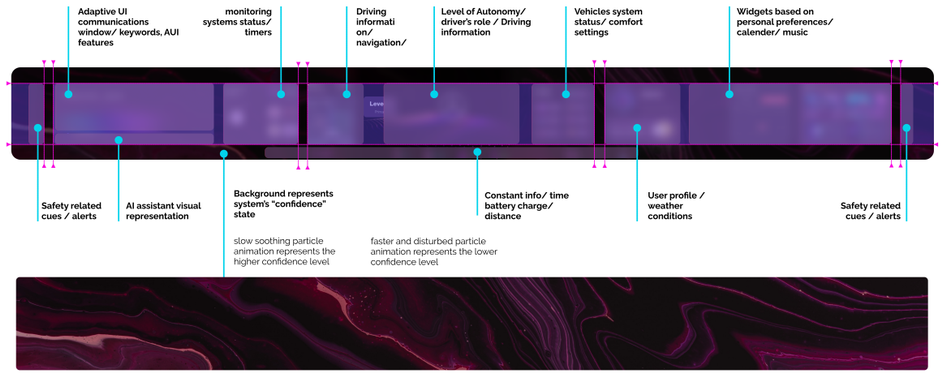



*Fig 11.6 The UI system of floating screen*

### Adaptive Layout

During various stages of Takeover (TO), the blocks may rearrange themselves to emphasize different types of information, thus adapting to real-time situational requirements. The adaptiveness of this UI is primarily driven by changes in automation state (i.e system capacity) and Communicating alternations with changes in driver's roles. By understanding the needs of adaptiveness and automation modes, this UI system has been meticulously designed to provide a cohesive, intuitive, and adaptive driving experience, harmoniously integrating technology with human intuition.

Following the establishment of the basic narrative arc of the experience (refer fig 11.8), communication requirements (What information needs to be communicated and how+when it changes) at various points along the journey were identified. These requirements were then translated into wireframes, which were then converted into keyframes (in Figma) which were used in the final video.

A mood board for iconography, and UI elements (like ASAS visualizations) is in Appendix H.

## Design guidelines for HMI

Various design guidelines for HMI were compiled from the literature.

### Integration of Multiple Sensory Modalities:

- Think about using a multimodal interface that alerts and informs the driver through a combination of sounds, touches, and displays. According to a number of studies (Ho et al., 2007; Ho and Spence, 2005; Liu, 2001; Ferris et al., 2006; Oskarsson et al., 2012; Petermeijer et al., 2017; Zhang et al., 2019; Borojeni et al., 2017; Wan and Wu, 2018; Melcher et al., 2017; Borojeni et al.
- Multimodal TORs were found to be the preferred option over unimodal TORs (Bazilinskyy et al., 2018), so they should be implemented for extremely time-sensitive takeover situations.

### Interfaces that Use Sound and Touch:

- Use auditory and tactile interfaces instead of visual ones because they encourage quicker response times and more precise actions. To wit: (Petermeijer et al., 2017; Zhang et al., 2019)
- Drivers have a positive attitude toward auditory warnings from TOR, so it's a good idea to implement them in the TOR UI (Bazilinskyy and de Winter, 2015).

### TOR's Touchscreen User Interface:

- Takeover requests (TORs) could be communicated through a tactile user interface by means of alternating vibrations in the driver's back support and seat, which would relieve stress on the driver's visual and auditory channels. (2018, Wan, & Wu)

### User Interaction in the Environment: Ambient lights

- Takeover times can be reduced by investigating the use of ambient interfaces, such as cues by changing ambient light. (Borojeni et al., 2016)





### Spatial information:

- Incorporate spatially-aware tactile interfaces to better direct takeovers in the anticipated direction. (Lv et al., 2021; Petermeijer et al., 2017)

### Language-based Warnings:

- Warnings that make use of languages, such as visual text information, speech, and speech actions, are just as effective as abstract warnings but are less annoying in less urgent contexts. (Politis et al., 2015; Brewster and Brown, 2004).

### Personality and Preferences of Drivers:

- User interfaces for TOR should be developed while taking driver feedback into account. In extreme time-sensitive takeover situations, drivers prefer multimodal TORs and are generally receptive to auditory warnings. There has been some research on this topic (Bazilinskyy and de Winter, 2015; Bazilinskyy et al., 2018)

### Experience Requirements and Degree of Automation:

- Increasing the level of automation may make driving safer, especially for drivers who are unfamiliar with the system (Weaver et al., 2020), so keep that in mind.

### Real-time adaptation:

- Create a model or system that can gauge the driver's readiness to hand off based on external indicators and adjust the UI in real-time. According to research (Deo & Trivedi, 2020; Perello-March et al., 2021)
- To determine when a driver is ready to be taken over, it is necessary to create a mechanism that dynamically adjusts the user interface in real-time using observable cues (Deo & Trivedi, 2020).
- To determine whether or not the driver is prepared to take control, a driver-state monitoring system should be implemented (Perello-March et al., 2021).

### Keeping the driver informed:

- Especially at level 4 of automated driving, it is important that the vehicle keeps the driver apprised of its capabilities and operational status. That's according to a recent study (Kyriakidis et al., 2019).
- Up to SAE level 4 (Kyriakidis et al., 2019), provide the driver with information about the vehicle's features and current status.

## Design Rationale of Various UI Features:

### 1. Driver's Readiness Assessment:

***Phase: De-immersing***

**Rationale**: When transitioning from a high cognitive activity to driving, a driver's mental model must be realigned to anticipate and respond to real-time driving scenarios.

- **Description**: During the De-immersing phase, the vehicle's system gauges the driver's cognitive and physical workload, reflecting on non-driving related tasks they were previously engaged in. Such an assessment is pivotal in orchestrating the takeover protocol – setting timeframes, determining information cascades, and shaping interaction modalities. By leveraging sensors for eye-gaze and glance analysis, the TOR system can non-intrusively ascertain a driver's readiness, ensuring that their privacy remains uncompromised.

### 2. Prior Experience Rating:

*Phase: Preparating*

**Rationale**: Prior experience influences drivers' reactions during crucial moments, and this knowledge can be harnessed to calibrate the takeover protocol.

- **Description**: Research indicates a discernible difference in takeover response times between novice and experienced drivers. In acknowledging this variability, the system presents the user's *prior experience rating*. This allows the system to transparently communicate with drivers about the takeover process and anticipated system guidance.

### 3. TO Readiness Indicator:

*Phase: Confirming*

**Rationale**: As drivers confirm the takeover, it's important that they know everything there is to know about the system and the environment.

- **Description**: Acting as a combination scale of attention and prior experience, the TO Readiness Indicator provides a holistic appraisal of a driver's readiness. This feature not only gauges attention but also retroactively considers past interactions, enhancing its predictive accuracy. The visibility of this information can nudge drivers to recalibrate their attention, reinforcing safety measures.

### 4. Situation Awareness Readiness Scale:

*Phase: Monitoring*

**Rationale**: Once drivers assume control, their situational awareness is paramount to safety.

- **Description**: The SA readiness scale shows how alert a driver is right after the takeover. If a problem is found, like if drivers miss important safety instructions, the system uses conversational AI to get their attention back on track.

### 5. System's State Stability:

*Phase: Alerting*

**Rationale**: Existing mental models from traditional driving experiences might not align with the novel systems of autonomous vehicles. These preconceived notions can lead to instinctual actions that might conflict with the vehicle's current state.

- **Description**: As the steering wheel emerges, innate driving instincts might propel users to grab it prematurely, potentially jeopardizing safety. This potential hazard necessitates strategic intervention. The system's intelligent Human-Machine Interaction plays a pivotal role here: if users attempt to grasp the wheel, sensors detect this motion, triggering a disturbed animation on the entire dashboard (so that everyone in the car knows). This visual cue, embodied through projection mapping, subtly suggests system instability, urging drivers to refrain. As drivers comply, the animation morphs into a more serene depiction, signaling system stability.

### 6. Eye Gaze Guiding Features:

*Phases: Confirming, Monitoring*

**Rationale**: Assisting drivers in building situational awareness is critical, yet continuous visual prompts might be counterproductive.

- **Description**: Driving, inherently dynamic, requires drivers to perpetually assimilate environmental information. The combined prowess of the AR windshield and the floating screen can accentuate this awareness, especially in ambiguous situations. However, incessant displays might be disregarded or prove distracting. Hence, intermittent guidance through animations can be more effective (findings from Cohen-Lazry et al., 2017 and Yang et al., 2017).





### 7. System Timers:

**Rationale**: Timing is pivotal, especially when drivers' actions need synchronicity with system demands.

- **Description**: Recognizing the salience of timely user responses, the floating UI features timers. These serve dual purposes: to prompt user action and to clearly delineate the time window available for said action.

## Game of timeframes in the TO

The transition between automated systems and human control has proven complex. A myriad of factors come into play, from cognitive load to timing nuances, all contributing to the effectiveness and safety of these handovers. Here's a structured exploration of the key insights into the take-over dynamics in automated driving.

### Overview of TO Process timeline

When a TOR is issued, drivers need to stop whatever they are doing on the road and pay attention to it. To do this, they must process the information they get from the environment and respond by turning on the vehicle's actuators to do the dynamic driving task based on what they know about the situation at the moment (Goncalves et al, 2015; Morales-Alvarez et al, 2020). Figure 11.7 shows how the process works by showing the parts of a take over request.

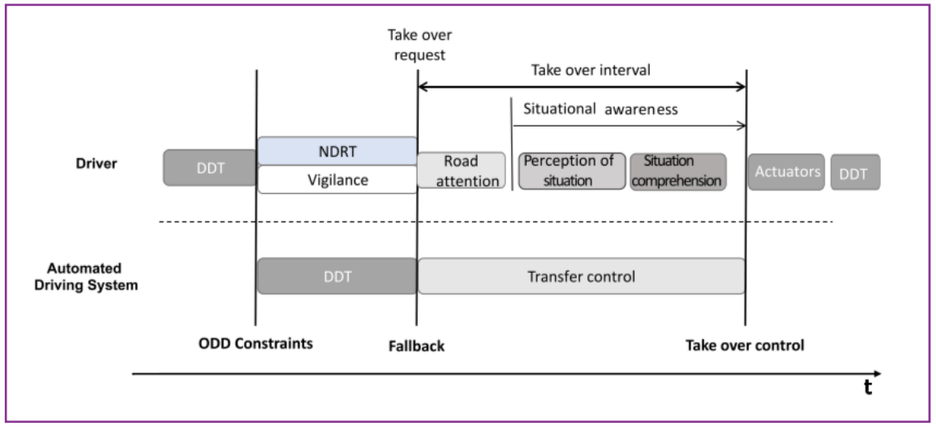



*Fig 11.7 Parts of the Takeover process*

## Visual-Cognitive Load and Take-Over Performance:

Wintersberger et al. (2021) have highlighted the role of visual-cognitive load in determining takeover performance. The design of interfaces and notifications can have a profound impact, underscoring the need for optimization in these areas.

## Factors Influencing Takever Times (TOT)

Various factors mold the timeframes in which drivers take over controls. Zang et al. (2019) enumerate parameters such as the urgency of the situation, non-driving tasks, the level of automation, experience, anticipation, driver age, and the nature of surrounding traffic. Each can considerably shift the TOT, adding layers of complexity.

- **Urgency of the Situation:** The more urgent a situation is, the quicker drivers tend to respond. However, paradoxically, when given more time, drivers tend to delay their takeover, suggesting that they might be using the extra time to better assess the situation.
- **Non-Driving Tasks:** Engaging in tasks using handheld devices notably increases TOT. Yet, the nature of the non-driving task (visual, auditory, or cognitive) doesn't seem to have a significant influence.
- **Level of Automation:** Interestingly, higher levels of automation, such as SAE L3 and above, result in longer TOTs than partial automation. This could be due to various reasons such as longer time budgets, decreased urgency, or an increase in the usage of handheld devices.
- **Experience and Anticipation:** Prior experience with takeovers can enhance response times. Additionally, the ability to anticipate a TOR from environmental cues significantly reduces reaction times.
- **Driver Age and Surrounding Traffic:** While age would typically be considered a factor for slower reaction times, the study surprisingly found no significant effect of age on TOTs. Meanwhile, dense traffic scenarios increased TOTs due to the increased complexity of the situation.

Furthermore, multimodal displays can also affect the reaction times Petermeijer & Bazilinskyy, 2017). One study (Ericksson & Stanton, 2017) suggested setting TOR timings based on the situation. Many stakeholders need time-margin information, but determining one magicnumber is impossible.

## Key insights from the Literature

Here are some of the most important insights from the literature that informed the design of timeframes in the given context.

**Drowsiness, Distraction, and Performance Quality:**
Merlhiot and Bueno (2022) brought to the forefront the impact of drowsiness and distraction on the reaction time during TORs and the overall quality of the takeover. Understanding and addressing these factors are paramount to ensuring seamless handovers.

**Exiting Immersion and Distraction Dynamics:**
Upon disengaging from a NDRT, a driver's distraction lingers. Findings suggest that this post-engagement distraction can persist up to 27 seconds after highly distracting tasks (NDRTs) and up to 15 seconds after moderate distractions. In contexts with moderate levels of activity, this distraction duration is estimated at 20 seconds. (Morales-Alvarez et al, 2020)

**The Intricacies of Timing in TORs and MRs:**
Monitoring requests are crucial to consider while designing — One might choose to just monitor the road in order to raise SA, without necessarily taking control over it. Triggering an MR before the actual transition helps to develop the SA before the actual transfer of control initiates. The idea of "soft-TOR" or "two-step TOR" is used in a number of studies to get the driver's attention before taking control (Lapoehn et al., 2016; Naujoks, Purucker, Neukum, Wolter, & Steiger, 2015; Van den Beukel, Van der Voort, & Eger, 2016; Willemsen, Stuiver, & Hogema, 2015).

**Situational Awareness in Level 3 Automation:**
In the realm of Level 3 conditional automation, maintaining situational awareness is crucial. While Lu et al. (2017) noted that situational awareness could improve over a span of 20 seconds. This also substantiates that MR request could be triggered ~10 seconds. It it titled as sub-SA phase as shown in Fig. 11.8.

Understanding the pivotal role of timing, TORs and MRs help orchestrate smooth transitions. Alert timings for TORs can vary, with an 8-second window often deemed suitable for most scenarios. However, in contexts demanding a gradual transition, this can be extended to 15 seconds (Merlhiot and Bueno, 2020). The sequence of alerts generally has the MR preceding the Time to Collision (TOC) by 12 seconds, followed by a TOR 7 seconds later, lasting approximately 5 seconds.

**Real-time Dynamics and Varied Control Takeover:**
While there are general timelines established for TORs, real-time control takeover durations can fluctuate between 5 to 7 seconds (Zhang, De Winter et al., 2019). These depend on both the driver's state and the unfolding situation. The role of sensors like radars or cameras, which detect collisions, can also drastically shorten the time between TOR and an imminent collision, necessitating instantaneous responses.

**Post Take-Over Adjustments/considerations:**
After a take-over, drivers often require significant time, up to 27 seconds, to stabilize and gauge their surroundings. This involves actions like braking to maintain a safe distance from the vehicle ahead. Additionally, the time budget—the interval between the TOR and potential obstacles—is a critical factor. Despite some general estimates, it's clear that the required time for safe takeover varies based on the specific driving context and task. This suggests the need for dynamic TOR systems that adapt to the situation at hand.

## Gaps and Limitations in Current Research

While the presented insights are valuable, it's essential to acknowledge the limitations. A predominant reliance on simulator studies, varied methodologies in measuring TOR-RT, lack of control conditions, and mild reported drowsiness due to the simulation constraints are some of the noted gaps. These limitations underscore the need for more diverse and holistic research. Real-world implications can differ vastly from simulations. Wintersberger et al. (2021) drew attention to the stark differences between simulator outcomes and on-road tests, emphasizing the importance of real-world evaluations.

## Linking timeframe with the context and phases

The illustration (fig 11.8., next page) was created by combining the fundamental dynamics of the phases, contextual elements, and time frame insights. This describes the time-driven phases of building situational awareness (SA) and highlights the key decisions related to timeframes. It also gives us more information about certain aspects of the proposed TO protocol.

# The narrative Arc

The narrative of the ideal TO journey is thoughful blend of insights from literature and creative appoach. The literature encompasses several key considerations that went to design of this narrative in 8 distinct phases of the TO. The narrative starts with context of the expereince stating how user starts her journey. Later, goes into details of the 8 phases. The frames of the sentences were carefully designed. This arc went into several iterations, with peer reviews, to improve the comprehension and delivery.

*Fig 11.8 The narrative arc in combination with timings*

### *Contextualizing*

**OA.** Imagine that you have planned a trip from Munich to Stuttgart with four scheduled transitions. The first transition occurs at the beginning as you enter the highway, and the last one happens when you leave the highway to enter Munich. The second and third transitions take place approximately 25 kilometers away from Munich and are intended to be short.

--

**OB.** As you approach the highway, you engage the vehicle's level 4 autonomy for the first transition. With your AR smart glasses connected to the system, you choose to focus on productive tasks while enjoying a comfortably reclined seating position that also allows for an extra space for interactions.

--

**Now, let's dive into the story.**

--

**OC.** For the past 90 minutes, roughly, you have been fully immersed in preparing a presentation for an upcoming meeting.

### *De-immersing*

**D1.** A notification appears at the bottom of the transient windows, one minute in advance, accompanied by a soothing yet reprimanding audio notification. It informs you of the approaching takeover and lets you know that the Takeover protocol will initiate after 20 seconds.

-

**D2.** After 20 seconds, the transient windows fade away, and a prompt appears, stating that the function is silenced until the Takeover is complete. It advises you to take off your AR glasses, which you choose to do, proceeding with the takeover.

--

**D3.** Within those 20 seconds, the vehicle's system assesses your cognitive and physical workload by analyzing the demands of the non-driving related tasks you were engaged in before the takeover. This assessment helps establish the protocol for the takeover, including timeframes for each step, information flow, and interaction modalities in different phases.

--

**D4.** The system visually represents the vehicle's autonomous status (level 4 autonomy) and clarifies your role and responsibilities through a graphic representation, indicating active driving mode, system awareness, and the driver's role.

--

**D5.** Simultaneously, the seat is smoothly brought from a reclined position to the driving position.

### *Preparing*

**P1.** As you free up your hands by releasing the non-driving related task at hand, the vehicle informs you about the reason for the takeover (approaching road maintenance site) and emphasizes its importance, though not urgent, through an AI voice agent and visual cues.

-

**P2.** The system informs you that it is transitioning to level 3 automation, specifying which automated functions will be disengaged and highlighting your "supervisory" role. The ambient lighting gradually changes from blue to yellow, marking the transition from level 4 to level 3 autonomy.

--

**P3.** On the floating display, the system presents your "prior experience rating," indicating a low rating for handling similar takeovers.

-

**P4.** Considering this low rating, the system engages you through conversational auditory modality, aiming to reduce any intimidation or apprehension you might feel. It energetically welcomes you to your very first takeover, saying, "This is a new TO scenario; I am here to guide you through."

For Higher ratings, the information flow and modalities change.

### *Alerting*

**A1.** The visual interface of the vehicle, represented by a floating display, provides clear and concise information about the Take-Over (TO) process and its steps. An AI agent, through voice prompts, informs you about the upcoming phase of system-assisted Situational Awareness building.

--

**A2.** The visual interface prominently displays the steps involved in the takeover process, accompanied by a timer indicating the remaining time until you can confirm the takeover. It also informs you that there will be an additional 3 seconds after confirmation to initiate the transfer of control.

--

**A3.** The AI voice agent explains that lane, speed, and braking assist will remain active during and after the takeover. System recommend keeping the assists active if the cognitive load during non-driving-related tasks (NDRT) was moderate to high.

-

**A4.** The conversational AI agent also reminds you of the current driving mode, which is Level 3 autonomy, emphasizing your supervisory role.

--

**A5.** As the steering wheel emerges from the dashboard, red lights indicate that grabbing it prematurely is not recommended.

-

**A6.** Simultaneously, the visual interface on the dashboard activates, subtly discouraging premature steering wheel engagement. If you disregard this warning and attempt to grab the wheel, an animation demonstrates the disturbance it causes to the vehicle's state.

-

**A7.** At the same time, the pedals are passively locked, and the notification icon on the dashboard displays a red color to indicate their inactivity.

### *Confirming*

**C1.** Concurrently, the vehicle's monitoring features become active, assessing your attention level through eye tracking, gaze analysis, head movements, and hand motions.

**C2.** This data helps determine your readiness for the takeover, which is visually presented. If your readiness is deemed low, the system engages the eye gaze feature, providing guidance through directional animations. The Takeover Readiness level indicator takes into account both your attention and past experience with similar takeovers, providing a comprehensive assessment of your readiness.

**C3.** To confirm the Takeover Request, you firmly place your hands on the steering wheel and press two buttons on wheel. As you do so, the red light on the steering wheel transitions to yellow. Additionally, the system activates the breathing assist system integrated into the steering wheel, fostering a calm environment during the takeover process.

**C4.** Following confirmation, the seat belt automatically tightens, and a countdown timer indicates the time remaining until the takeover initiates. The timer features a gradient animation as you progress towards the Transition.

**C5.** A starting point of Takeover is represented by visually indicating the steering wheel's readiness through a changing light, transitioning from blinking orange to yellow and finally green. By offering an implicit start, the system provides flexibility by allowing a brief extra moment for convenience and confidence during the takeover, ensuring a smooth transition.

### *Transitioning*

**T1.** With the transition process commencing, the system gradually grants you control over the vehicle.

--

**T2.** The adaptive user interface (UI) of the vehicle intelligently adjusts to elevate your situational awareness. The AR windshield highlights pertinent information about road signs, conditions, navigation, lanes, and potential threats.

-

**T3.** Meanwhile, the floating display presents active icons representing the automated systems according to your preferences.

**T4.** You can effortlessly gather vital information about the environment, traffic, and the vehicle's actions through visual cues displayed on the augmented reality windshield or the floating display. (show lane and brake assist animation on AR windshield)

--

**T5.** The AI voice assistant provides real-time feedback on vehicle performance and mode changes, ensuring a seamless driving experience with audible cues.

### *Monitoring*

**M1.** The vehicle maintains a vigilant eye on its own operations to ensure optimal performance. Active monitoring systems, such as eye and gaze tracking for attention and awareness, heartbeat and pulse monitoring for emotional states, fingertip temperature measurement for emotional responses, and steering and braking response evaluation for performance, are all visible on the floating display.

-

**M2.** The AI assistant, through a visual feed, enhances your confidence by displaying a situation readiness scale. This scale considers various factors, including historical data on traffic and road conditions, to provide an accurate assessment of your readiness. If the readiness level is low, the system offers remedial actions directly.

-

**M3.** For instance, if the eye tracking data suggests that you are not paying sufficient attention to the road condition information, the system highlights the relevant text with animations, prompting you to refocus.

--

**M5.** After completing the transition, the system shows you an icon for each active automated system and tells you that the current driving mode is Level 2 autonomy.

-

**M6.** The ambient lighting gradually changes to green, signifying a smooth transition and your regained control over the vehicle.

### *Decluttering*

**Do1.** After handing over control, the readiness scale disappears, And the system indicates the state of shared control. Through a combination of visual, auditory, and spatial cues, the system effectively communicates crucial data regarding the vehicle's actions, intentions, and potential hazards.

--

**Do2.** The interface's visual cues clearly indicate when the system mode transitions to Level 2 autonomy, indicating your increased responsibility in the driving process.

-

**Do3.** As you regain command of the vehicle, the system provides reassuring feedback, visually represented by a successful control gaining animation.

-

**Do4.** The monitoring systems disengage, removing the notification icons from the display.

### *Re-engaging*

**R1.** As you settle into driving, the adaptive user interface (AUI) delivers audio and visual notifications, ensuring you stay informed. Messages from AUI include alerts about silenced calls during the takeover, which last for 45 seconds, and notifications from MS Teams.

--

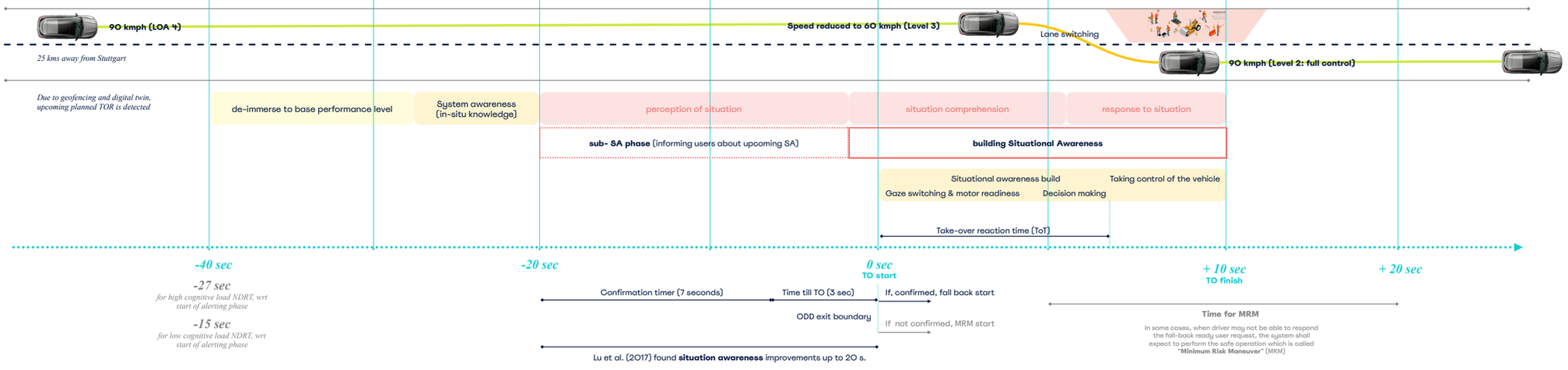
**R2.** The system alerts you when Level of Automation 3 (LOA 3) becomes available, allowing you to choose whether to resume driving or continue enjoying the autonomous mode for the remainder of your journey.

--

**R3.** Lastly, the AI voice assistant seeks your feedback on the takeover experience, aiming to learn and adapt the car's behaviors and future interactions. It poses questions such as whether the time provided for the takeover was sufficient and whether you would like to preserve your preferences for similar takeovers in the future.

*Legend*

**Voice over**
**Visuals**
**Extra contextual elements that viewers needs to know**
**Audio notifications; AI conversational commands**
**Ambient light**



## Screenplay for the video

The goal was to create a video representation of the ideal TO journey. As a result, the narrative was converted into storyboards. A storyboard template was created that clearly shows the voiceover, visuals (with visual hierarchy guidelines), and audio (AI agent frames, notifications). Figure 11.9.




*Fig 11.9 Template to read/build screenplay*

**Render settings:** The interior model was created with *blender* and included all of the desired interior elements. Keyshot was used for the rendering. The scene's camera settings, lighting, and colors were chosen to emphasize the interior elements.

**Video pacing:** Video pacing refers to the rate of movement and flow of events that occur as a film's story progresses. Pacing is critical for engaging the audience properly. In our context, the camera angles are the most important factor influencing pacing. The pacing was changed so that frames became more consistent as TO progressed, allowing the viewer to track the changes in focus.

**AR windshield components:** Digital sketches were used to visualize the AR windshield elements.

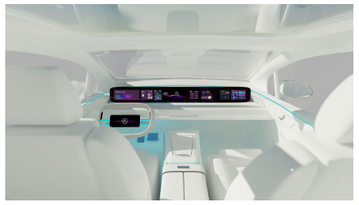
**Keyframes for floating UI:** The focus window was added in the video frames to bring the focus to the changing/changed information, as shown below. The Keyframes are frames are presented in Appendix P.

**Timeline:** Because the video shows details of what is happening in various locations, viewers do not have an exact perception of when this is happening and how quickly it is happening. In other words, the experience of 1 minute of TO was explained in detailed in 10 minutes. As a result, a progressbar-like animation at the bottom was created to track the real-life timeframe of various phases.



# THE STORYBOARD OF THE VIDEO

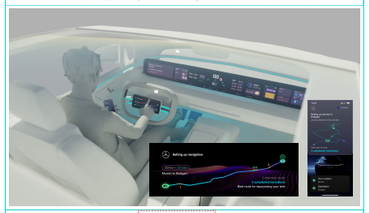
## CONTEXTUALISNG





Voiceover

Imagine that you have planned a trip from **Munich to Stuttgart** with **four scheduled transitions.** The first transition occurs at the beginning as you enter the highway, and the last one happens when you leave the highway to enter Munich. **The second and third transitions** take place **approximately 25 kilometers away from Munich** and are **intended to be short.**



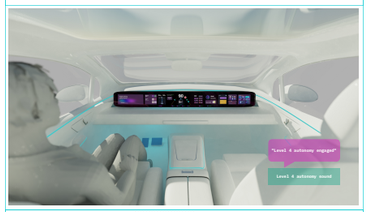



Floating display

**oA**

Voiceover

As you approach the highway, you engage the vehicle's **level 4 autonomy** for the first transition.






Floating display

**oB**

With your **AR smart glasses** connected to the system, you choose to focus on productive tasks while enjoying **a comfortably reclined seating position** that also allows for **extra space for interactions.**



Voiceover

Now let's dive into the story.
For **the past 90 minutes**, you have been **fully immersed** in preparing a presentation for an upcoming meeting.






Floating display

**oC**

## DE-IMMERSING

-40sec

Voiceover

A **notification** appears **at the bottom of the transient windows one minute in advance**, informing you of the **approaching takeover**, accompanied by a soothing yet reprimanding audio notification.





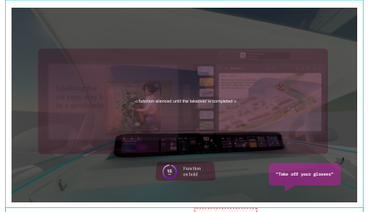

Floating display

**D1-D2**




Voiceover

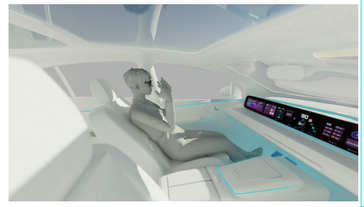
After a few seconds, **the transient windows fade away**, and a prompt appears stating that the function is silenced until the Takeover is complete. It **advises you to take off your AR glasses**, which you choose to do before proceeding with the takeover.





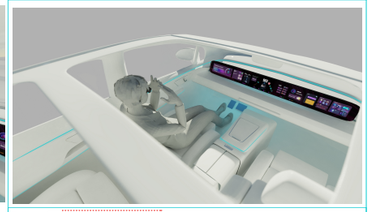

Floating display

**D1-D2**



Voiceover

Within those few seconds, the **system assesses your cognitive and physical workload** by analyzing the demands of the non-driving-related tasks you were engaged in, before the takeover.

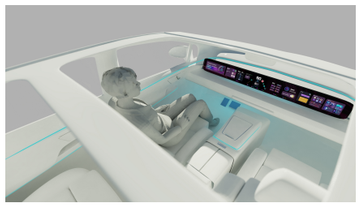


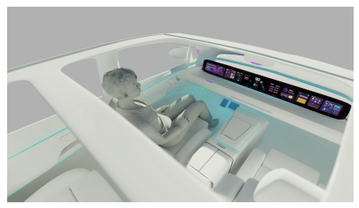


Floating display

**D3-D5**

This assessment helps establish the protocol for the takeover, including timeframes for each step, information flow, and interaction modalities in different phases.





Voiceover

Next, the system visually represents or **reminds the vehicle's autonomous status** and **clarifies your role and responsibilities** through a graphic representation, indicating active driving mode, system awareness, and the driver's role.



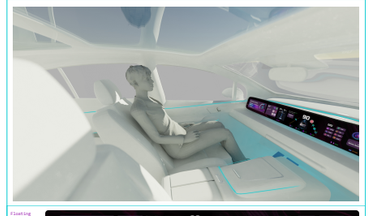


Floating display

**D3-D5**

Voiceover

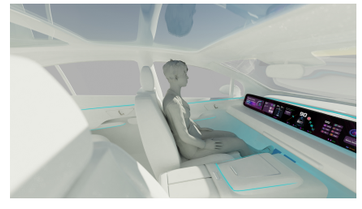
Simultaneously, the seat is **smoothly brought** from a reclined position **to the driving position.**





Floating display

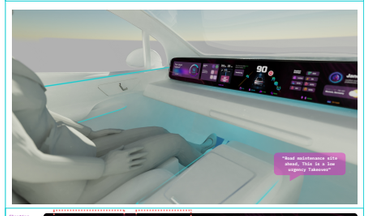
**D3-D5**



## PREPARING

Voiceover

In order to prepare you, **the vehicle informs you** about the **reason for the takeover** through audio-visual cues and **emphasizes its urgency, ~~in this case it is not urgent~~.**






Floating display

**P1**

Voiceover

The system informs you that it is **transitioning to level 3** automation, specifying which automated functions will be disengaged and highlighting your **"supervisory" role.**






Floating display

**P2-P3**

The ambient lighting gradually changes from blue to yellow, marking the transition from level 4 to level 3 autonomy.




Voiceover

**Using past data**, the system **analyzes your "prior experience rating,"** which **accounts for** your **experience** with handling **similar takeovers.**





Floating display

**P2-P3**

Voiceover

Considering **this low rating,** the system opts to engage with you **through a conversational auditory modality**, aiming to reduce any intimidation or apprehension you might feel. It energetically welcomes you to your very first takeover, saying, ~~"Hello! Great to be your co-pilot!"~~ For Higher ratings, the information flow and modalities change.





Floating display

**P4**

# ALERTING

-20sec

Voiceover
The visual interface of the vehicle provides **clear and concise information about the Take-Over (TO) process and its steps.**




Floating display
**A1**



Floating display
**A2**

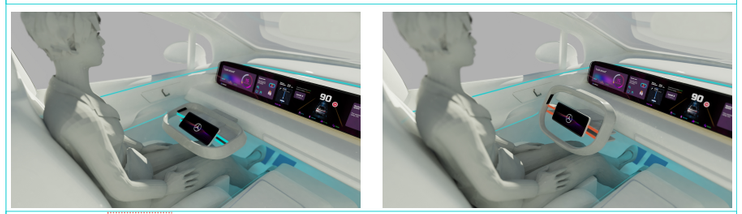
Voiceover
An AI assistive agent, informs you about **the upcoming phase of system-assisted Situational Awareness building.**

Voiceover
It also explains that the lane, speed, and braking assist **will remain active during and after the takeover.** The system recommends keeping the assists active if the cognitive load during non-driving-related tasks (NDRT) is moderate to high or if you are new to the Takeover.



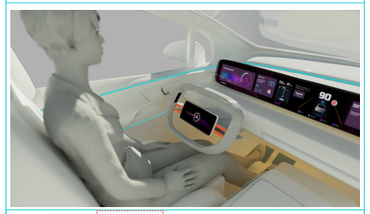
Floating display
**A3-A7**

Voiceover
As the steering wheel **emerges from the dashboard**, **red lights indicate** that grabbing it prematurely is not desired.



Floating display
**A3-A7**

Voiceover
Simultaneously, the visual interface on the dashboard activates, **subtly discouraging premature steering wheel engagement.**

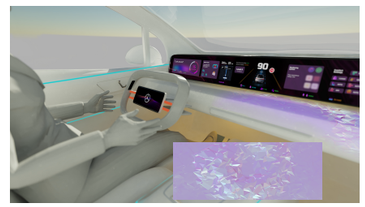


Floating display
**A3-A7**



If you disregard this warning and attempt to grab the wheel, an animation demonstrates the disturbance it causes to the vehicle's state.





Voiceover
At the same time, **the pedals are passively locked**, and the notification icon on the floating display indicates their state.

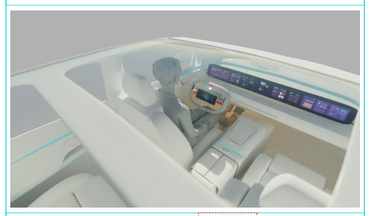


Floating display
**A3-A7**

# CONFIRMING

-10sec

Voiceover
Concurrently, the **vehicle's monitoring features fully engage**, assessing your attention level and emotional state through eye tracking, gaze analysis, and hand tracking.



Floating display
**C1**



Floating display
**C2**

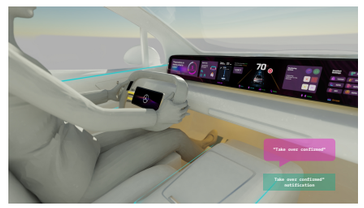
Voiceover
This data helps **determine your readiness for the takeover** and is visually presented. If your readiness is deemed low, the system engages the eye-gaze feature, providing guidance through directional animations.

Voiceover
To confirm the Takeover Request, **you firmly place your hands on the steering wheel and press two buttons on the wheel**




Floating display
**C3**

As you do so, **the red light on the steering wheel transitions to yellow.**




Additionally, the system activates the breathing assist system integrated into the steering wheel, fostering a calm state during the takeover process.




Voiceover
Following the confirmation, **a countdown timer** indicates the time remaining until the takeover initiates. The timer also features a gradient animation as you progress towards the transition.

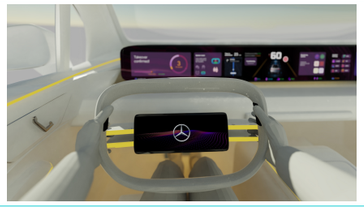


Floating display
**C4-C5**

Voiceover
The **starting point of Takeover** is represented by visually **indicating the steering wheel's readiness through a changing light,** transitioning from blinking yellow to blue and finally green.



Floating display
**C4-C5**







-0sec

## TRANSITIONING

+0sec

Voiceover

With the transition process commencing, the system gradually grants you control over the vehicle. The **adaptive user interface (AUI)** of the vehicle intelligently **adjusts to elevate your situational awareness.** The AR windshield highlights pertinent information **about road signs, conditions, navigation, lanes, and potential threats.**



Floating display

**T1-T2**

Voiceover

Meanwhile, the floating display presents **active icons representing the automated systems** according to your preferences.



Floating display

**T3-T5**

Voiceover

You can **effortlessly gather** vital **information about the environment**, traffic, and the vehicle's actions through visual cues displayed **on the augmented reality windshield and the floating display.** The AI voice assistant provides real-time feedback on vehicle performance and mode changes, ensuring a seamless driving experience with audible cues.




Floating display

**T3-T5**

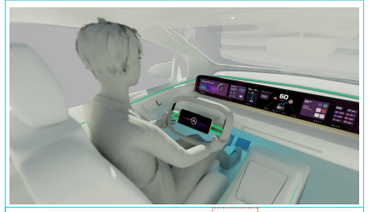


## MONITORING

+5sec

Voiceover

The vehicle maintains **a vigilant eye on its own operations** to ensure optimal performance. **Active monitoring systems,** such as are all visible on the floating display.



Floating display

**M1-M2**

Voiceover

The AI assistant, through a visual feed, enhances your confidence by displaying **a situation readiness scale.**



Floating display

**M1-M2**

Voiceover

For instance, if the **eye tracking data suggests** that **you are not paying sufficient attention** to the road condition information, the system highlights the relevant text with **animations, prompting you to refocus.**



Floating display

**M3-M6**

Voiceover

After completing the transition, the system shows you an icon for each active automated system and **tells you that the current driving mode is Level 2 autonomy.**




Floating display

**M3-M6**

The ambient lighting **gradually changes to green,** signifying a smooth transition and your regained control over the vehicle.



## DE-CLUTTERING

Voiceover

After handing over control, the readiness scale disappears. And the system indicates the state of shared control. The system **effectively keeps communicating crucial data** regarding the vehicle's actions, intentions, and potential hazards.



Floating display

**Dc1**

Voiceover

The interface's **visual cues clearly indicate when the system mode transitions to Level 2 autonomy,** indicating your increased responsibility in the driving process.



Floating display

**Dc2-Dc4**

Voiceover

As you regain command of the vehicle, the system provides reassuring feedback, visually represented by a successful control-gaining animation. Parallelly, the monitoring systems disengage, and the silenced functions resume.



Floating display

**Dc2-Dc4**

## RE-ENGAGING

+10sec

Voiceover

As you settle into driving, **the adaptive user interface (AUI) delivers silenced notifications.** AUI informs you about the **silenced call from Teams** during the takeover, which was indeed the last minute.




Floating display

**R1**



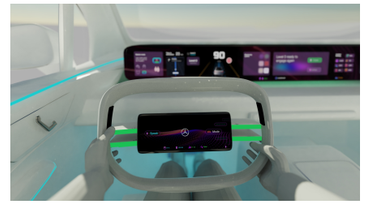
Voiceover

The system alerts you when **Level of Automation 3 (LOA 3) becomes available,** allowing you to choose whether to resume driving or continue enjoying the autonomous mode for the remainder of your journey.



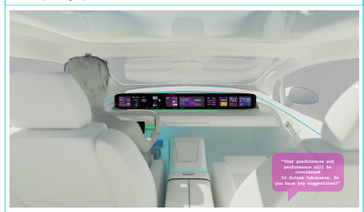
Floating display

**R2-R3**



Voiceover

Lastly, the AI voice assistant **seeks your feedback on the takeover experience,** aiming to learn and adapt the car's behaviors and future interactions. It poses questions such as whether the time provided for the takeover was sufficient and whether you would like to preserve your preferences for similar takeovers in the future.




Floating display

**R2-R3**

# DESIGN OF FOCUS GROUP SESSIONS

*The video depicting the ideal TO scenario was used during focus group sessions involving subject matter experts. This chapter presents a setup of a design evaluation study conducted to investigate the perceived effectiveness of the TO request from the perspective of experts. The chapter commences by elucidating the research strategy and objectives, followed by a comprehensive exposition of the methodology and research setup.*



12.0

# RESEARCH DESIGN

## Research strategy

After developing the ideal Takeover scenario, in the form of a video, it was time to investigate what is really ideal and what could be made better. The goal was to assess the initial perception of the envisioned user journey from expert's point of view by bringing multiple perspectives in play. These perspectives are valuable to get a better understanding of the dynamics of the experience in terms of complexity, experience, emotional state, interactions and stakeholder visions. In order to so a focus group session was deemed the most effective way (Lawson, 2015).

## Research Objective

The focus of the concept was on interaction flow and overall experience maps (which involves the designed phases of the TO). Following this focus following questions were prioritised, with client consultation.

1. *What are the perceptions of proposed Ideal TO scenario? (of product features, phases, overall experience)*
2. *Which emotions might emerge in various phases of TO potentially hampering the ideal emotional state?*
3. *Which elements of Journey are repeatable in unplanned TO scenarios? How might they differ?*
4. *What will change once users get familiar with the process?*

The first question aims to learn what people think about the proposed Takeover journey and if they have any early ideas or assumptions. The second goal is to identify the instances in the journey that can hamper the calm and confident state of mind in users. This is important because it helps improve the design for the user experience. The third question examines the TO design's flexibility or adaptiveness, considering whether it can be used consistently in unexpected situations and whether any parts need to be changed. The fourth and final question

examines user experience evolution. Familiarity with a process can affect how people think, feel, and act over time. This research aims to learn as much as possible about the TO user's experience using specific questions.

## Methodology

A product evaluation tool called PrEmo (Laurans and Desmet, 2017) has been used to vocalize and visualize emotions in an intuitive way. This tool has been designed for non-verbal self-reporting of emotions, but here it has been repurposed to act as a probe for conversation. It captures fourteen emotions (6 positive, 6 negative). However, we added six emotions that were relevant to the concept: feeling of safety, feeling of trust, feeling of control, confusion, disappointment, and overwhelm (which are also associated with the empathy map discussed in the previous section). The visual representation of emotions also helps to engage participants. Furthermore, for effective facilitation, techniques such as purging and rules for converging—affirmative judgment (Prince, 1970), protecting originality (Byttebier et al., 2007), trusting hedonic responses (Dijksterhuis and Nordgren, 2006), and having action in mind (Tassual, 2009)—were used.

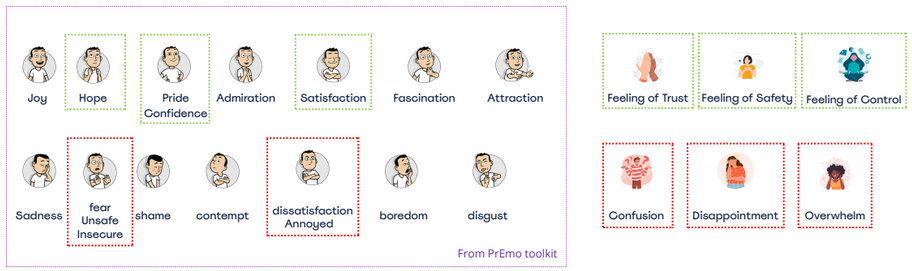



*Fig 12.1 Selected emotions (positive and negative) from PrEmo toolkit*

## Use of video as a speculation

Choosing a concept video as a speculative artifact for a focus group session in a corporate setting is a well-informed and foresighted decision. Corporations such as Microsoft, Google, and Amazon have long used concept videos as a powerful rhetorical tool, not only to forecast technological landscapes but also to strategically align teams, stakeholders, and customers around a unified vision. As Tognazzini suggests, their narrative strength allows audiences to not only anticipate potential user interactions and futures, but also offer a critique, ensuring a comprehensive understanding of the prospective terrain. Scenario planning challenges existing paradigms in the domain of Human-Computer Interaction (HCI), inspiring reflection and driving informed decisions. This also fits with the research objectives. According to Pargman et al. (2017), such scenario-based concept videos provide depth that goes beyond mere gadgetry in HCI. Furthermore, aligning concept videos with Speculative Design, particularly in the third wave of HCI, increases their credibility. Speculative Design emerges as a cornerstone for envisioning corporate futures by combining established methodologies such as scenarios, concept videos, and prototypes.





## Sampling participants

The decision to exclude end users at this early stage was made on purpose. The design is still in the conceptual stage at the moment (focusing on phasing), making it premature to inculcate end-user perspectives that may primarily focus on features that are still being developed. The decision to rely solely on expert input was made with the intention of improving the fundamental aspects of the design before engaging a broader range of users.

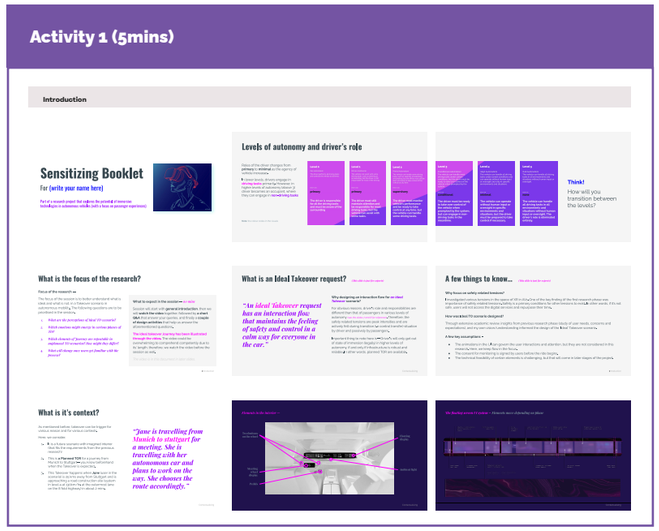
A meticulous and exclusive selection process was used to identify experts from within the organization. The selection also included supplementary factors such as the inclusion of diverse experiences with theoretical and applied backgrounds. Every expert had at least five years of experience in the relevant field. The experts were members of various internal research and development (R&D) teams such as Human-Computer Interaction, Human-Automation Interaction, Immersive automotive experiences, and level 4 automation (design, embodiment and regulations). The strategic emphasis on internal expertise was intended not only to capitalize on their deep understanding of the company's values and design principles, but also to protect intellectual property. The recommendations from internal teams were undertaken to ensure the involvement of people with recognized expertise in the focus group composition, which in turn added to relevancy and actionability.

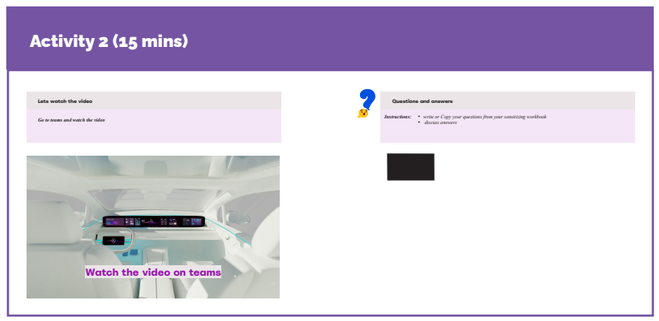
The study recognises and take into account potential biases while formulating the insights, such as the presence of loyalty bias (Sim and Waterfield, 2019) due to the internal composition of the focus group. Efforts were made to encourage open and honest feedback, assuring experts that expressing critical opinions would not have any negative consequences. Confirmation bias (Sim and Waterfield, 2019) was also raised to the forefront of people's minds, particularly among experts who had previously participated in the design process. To address this issue, a facilitator's (researcher's) stance was kept neutral while guiding the sessions and ensure that the discussions remained fair and impartial.

Internal channels and email were used to communicate with the experts. Through emails, experts were briefed on the research objectives, setup and the focus of the upcoming session.

# Research Setup

A total of two online sessions were carried out with groups of experts (2 experts in second session and 3 in the third one). During each session, the duration was approximately 60 minutes. The session commenced with a brief introductory segment lasting approximately 3-5 minutes. Next, the participants were presented with a video lasting approximately 10-12 minutes. Following the video, a short question and answer session was conducted to address any inquiries raised by the participants. The inquiries influenced the trajectory of the session, leading to intriguing discussions. Ultimately, they were engaged in a series of design activities aimed at addressing the research questions.



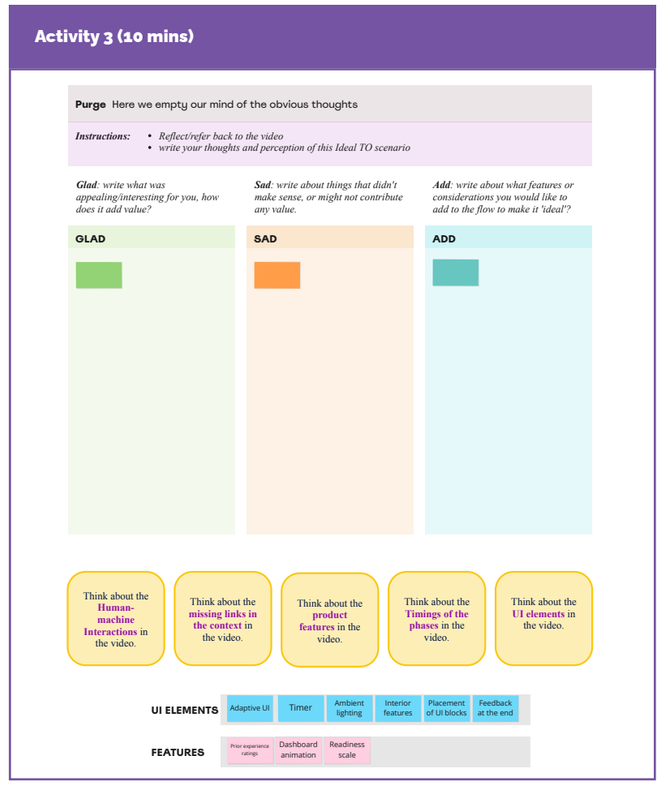
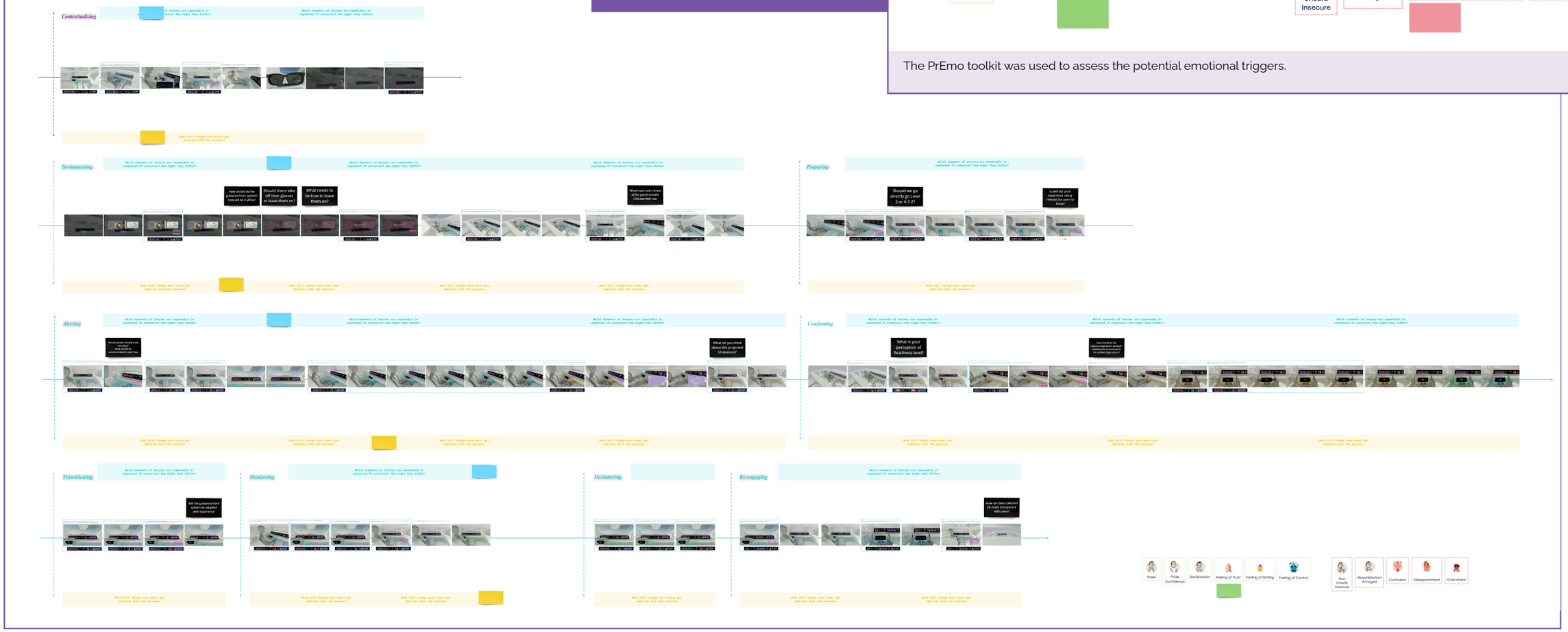



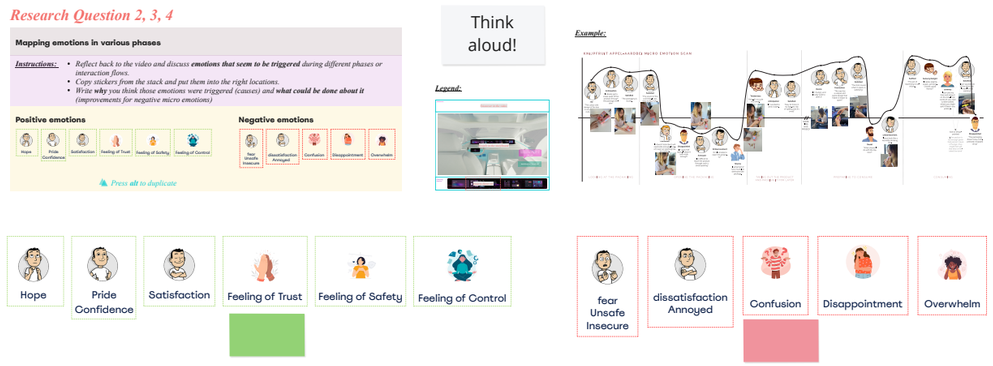

*Fig 12.2 Activites 1 to 3 in focus group sessions*

Activity 3 (Glad, Sad, Add) was structured to facilitate participants' contemplation on the positive aspects, negative aspects, and potential additions to the TO journey. This approach aimed to elicit reflections on the elements that were well-received, those that failed to resonate or lacked persuasiveness, and ultimately, the aspects that participants desired to incorporate. In order to trigger reflection cards (in yellow) were used as shown in figure 11.2.

During activity 4 — which addressed research questions 2, 3, and 4— participants were directed to walk through the storyboards (made using the same visuals as those shown in the video). In addition, participants were given specific questions to guide their analysis and discussion, which were indicated by black post-it notes in figure 12.3. The use of visualized storyboards made it easier to provide contextual information for the questions.

Participants were also asked to share their thoughts on product features, user interface elements, and interactions that may change as users gain experience and familiarity (bottom yellow line with yellow post-its, Figure 12.3). They were also asked to identify any unplanned instances of repeatable user actions (Top blue line with blue post-its, Figure 12.3).




The PrEmo toolkit was used to assess the potential emotional triggers.

A pilot session was held with team members to evaluate the activities' efficacy in terms of time management and facilitation, as well as the quality of the subsequent discussions. Following the pilot session, minor changes were made to improve the coherence and structure of the instructions.

### Sensitizing

The ideal takeover journey was illustrated in the video. In the pilot session, it was observed that the video was overwhelming to comprehend competently due to its' length and depth. This resulted in more surface-level assessment. Based on the questions from the participants, it was also observed that it's necessary for participants to understand the contextual elements and decisions made to fully comprehend and critique the journey. To address this, a 'sensitizing booklet' was created with the goal of providing contextual information that supplements the video.

The goal of the sensitizing booklet was to improve participants' understanding of key elements and decisions important to the TO journey. By sending the booklet to participants two days before the session, they had ample time to watch the video multiple times and make thoughtful observations. The booklet addressed important questions such as, Why is designing an interaction flow for an Ideal TO scenario important What exactly is an Ideal TO request? What context should be grasped? What key aspects of the video should be noted? What are the fundamental assumptions?.

## Data Collection and Ethics

Due to legal reasons, the session was not recorded, hence no transcripts were generated. Therefore, the notes were taken by facilitator (in the form of post-its) as the session progressed.
The session was conducted with experts from the company on secure channels provided by the company Microsoft teams). The video was shared through these channels with specified access. Overall, ''work integrity'' protocols were categorically followed.

## Data Analysis

For synthesising insights, affinity mapping (Northcutt & McCoy, 2004) was used. Affinity mapping involves sorting and clustering language-based information into relationships, which allows for discovering patterns. This was done on Miro. It involved iterative clustering around the identified topics (Iordanidis, 2021). The potential clusters were identified through notes taken during the session and focused research questions.

# 13 FOCUS GROUP EVALUATIONS

*This chapter delves into the findings of expert evaluation sessions. We begin by assessing perceptions of takeovers and then investigate the emotions that may be elicited by the proposed takeover journey. Following that, we identify elements that are applicable in unpredictable takeover scenarios before concluding with an investigation of how familiarity may alter user experiences during various takeovers.*

## 13.0

# RESULTS OF FOCUS GROUP SESSION

### Results Structure

The focus group session results are organized into insight themes based on the research objectives and activities. The initial discussion pertains to the perception of an ideal Take Over (TO), which is then followed by an evaluation of emotions. Finally, expert opinions on the changes that may occur as users become more acquainted with the TO are presented.

# Perception of ideal TO

Expert focus group insights on the ideal TO are presented in this comprehensive text. It discusses design features, modalities, and the potential of Augmented Reality (AR) to improve user experience, covering HMI and AUI. Standardized colours, the user journey's complexity, and proposed improvements for a seamless and safe transition in automated vehicles are discussed. Learn about driving automation's future from experts.

## Things appreciated

Experts agreed that the context of the future scenario had been convincingly established. They expressed a strong desire to comprehend the implications of such a scenario, particularly how navigation systems would adapt to the various level transitions. The experts believed that the distinct phases had been clearly and precisely delineated. The dynamics associated with these phases were generally agreed upon to guide users and foster collaboration.

Experts conducted a critical evaluation of the Human-Machine Interface (HMI). Nonetheless, the majority praised the HMI for its clarity in presenting information. This sentiment was captured in one notable comment:

> ***"UI clearly states the driving automation and user's role, it is placed in the centre — this is quite good."*** */ Expert on Human-Computer Interaction, Expert on level 4 automation*

Furthermore, the use of multiple modes of communication to convey information was well received. AI-generated commands, for example, not only exist in the system but are also displayed in the AUI information block via a floating display. Experts believe that such AI-driven conversational interactions are in sync with current advancements and have enormous future potential.

Another highlight was the Adaptive UI's design, which was described as neat with its intuitive and straightforward interactions. Furthermore, users appreciated the consistent activation of the voice-input modality, which ensured continuous communication.

## Takes of transion flow: 4-3-2 or 4-2?

There was initial hesitation about the 4-3-2 flow in the TO, stemming from the belief in the urgency of TO. However, by the end of the session, a shared sentiment emerged that the 4-3-2 sequence ensures a more robust learning effect and mode awareness. The fact that regulations discourage skipping levels further affirmed that the 4-3-2 progression is currently more appropriate.

## Critical debate on timeframes

Experts had mixed feelings about the proposed timeframe for the various phases of the Takeover (TO) scenario. While some thought the proposed timeframes were reasonable and that TO should be completed quickly, others thought the opposite, implying that the TO journey was perceived as too hurried. These experts expressed concerns about the complexities that could result from such rapidity. However, there was unanimous agreement on the significance of each second during the TO process. Experts emphasized that multiple events can occur at any given time. As a result, they advised further investigation into the timeframes to achieve greater clarity. An experiential prototype is deemed useful in for this. Plus, It's also important to understand how user knowledge, preferences, and regulations can affect these timeframes.





## Takes of Design features

**Visuals in UI**

Focus group sessions revealed that, while the HMI is generally well-liked, there are some areas of the UI that could be improved. Feedback specifically stated that certain UI elements, such as the timer, may not fully align with the design language. While they serve their purpose, they lack the desired visual appeal and coherence. Similarly, the readiness scale UI appeared to fall short of its primary goal. Participants saw the potential for a synergistic relationship between this progress bar and the Timer elements, implying that such nuances could be refined further in collaboration with the design team. Furthermore, the current UI is strewn with jargon, such as '*geofencing stability*' While it is true that familiarity with these terms will increase with usage, as it did with monitoring icons, the safety aspect of this learning curve cannot be overlooked. Instead of relying solely on manuals, there is a need for experiential design that helps users understand these elements organically.

**Product Features**

According to feedback from the sessions, the prior experience rating feature is useful, particularly in guiding the flow of information. However, there is some debate about its necessity in the eyes of the users. The projected state stability animation was another source of contention. While it is an appealing feature, experts agree that its placement on the entire dashboard may be distracting to drivers. One compelling idea was to limit this animation to a display on the steering wheel, ensuring a more driver-centric interaction. Another suggestion was to use haptic feedback or change the temperature of the steering wheel grip as more intuitive cues instead of animation. Concerns were also raised about users' comprehension of this novel animation and the possibility of inadvertent interactions, such as moving too close to the steering wheel. Experts emphasized the importance of distinguishing between intent and mere actions. Furthermore, the animation's intensity and aggressivity must be carefully considered to avoid any undue emotional impact.

> ***"How does the user get the context of this? what if they come close to the steering wheel accidently?"*** */Expert on Immersive automotive experiences*

**Auditory modality**

Among experts, the adaptive user interface (AUI) has emerged as a favorite. They recognized the enormous potential for redefining interactions by combining auditory modality with AI conversational agents. The tonality and framing of audio commands, on the other hand, are critical. Because of their negative connotations, phrases like ' *be alert*' looked intimidating.

> ***"Here (at the end of phase— preparing), it says 'this is a new TO for you, be alert'. 'Be alert' can be a bit intimidating for users, as it has negative connotations"*** */Expert on Human-Automation Interaction*

Furthermore, there was an intriguing discussion about the AI voice agent's persona. Maintaining a consistent character for both driving and non-driving tasks was hypothesized to foster user trust in the car and aid in personalizing experiences based on user learning.

## Call for standardisation in colours

A recurring theme in discussion aboout UI was the need for more standardization in the color schemes used in the floating UI. A significant number of experts have stated that the current interface is "*too colorful*" at times. They also emphasized the significance of maintaining design consistency.

A significant insight was how ambient colors were used in an unconventional way during the design process. This innovative use of color raised eyebrows, especially given that different colors have different meanings within Mercedes' fleet of vehicles. For example, while the cyan and green colors correctly denote automation levels 4 and 2, respectively, the use of the yellow color is inconsistent with Mercedes' standards. Yellow represents level 3 automation in the proposed concept, but in Mercedes' system, it represents a different attribute.

The potential benefits of industry-wide standardization are widely acknowledged by experts. Through interactions, such a consistent approach would not only streamline the information that needs to be conveyed, but it would also foster a shared understanding of meanings. To achieve this standardization, however, regulatory bodies and HMI designers must work together.

> ***"We need to check — How do regulations come into the picture when it comes to designing the colour scheme?"*** */Expert on Human-Computer Interaction*

## Concerns and Ambiguities

Participants first mentioned that the complexity of the user journey may initially deter users due to its intimidating nature. To allay these fears, incorporating dry or mock runs using Augmented Reality (AR) displays could be a viable solution. Such simulations not only allow users to become acquainted with the process, but also allow them to form a clearer mental model, resulting in a higher user experience rating. However, it is critical that these simulations ensure that information exchange remains as concise and straightforward as possible to avoid potential overload.

The current phases, as well as the overall interaction flow, were deemed promising by the group. However, the introduction of UI animations will dictate integration vs distraction tension.

> ***"The idea of directional animations is interesting but needs to be done right, as it is not fully envisioned yet."*** */Expert on level 4 automation, Expert on Human-computer interactions*

There were also some reservations about the Adaptive User Interface (AUI), particularly its monitoring features. Some experts speculate that in order for users to feel comfortable with such intrusive monitoring, they should provide consent that is specific to TO situations. However, questions remain about how transparent this system will be.

The de-immersion phase was a source of contention. According to some experts, the TO notification could be a "*slam in the face.*" Some experts suggest adding a notification in the transient window that looks like the steering wheel display to help with this. This will work in all situations where the driver is immersed. Experts stressed the importance of clearly communicating time to users while de-immersing. Ideally, each interaction in this space should be geared toward fostering trust.

Finally, the topic of third-party Extended Reality (XR) hardware accessibility raised safety concerns. Some experts expressed concern about allowing restricted access to such devices, particularly during critical TO moments. The majority of experts thought that the car's Operating System (OS) should have complete control over XR devices. To that end, experts advised allowing only government or Mercedes-certified glasses in their vehicles to ensure optimal safety standards.

An exciting insight that can have strategic implications emerged here. Any digital (immersion) device that is paired with the car's operating system must allow permission to change the settings inside the transient windows for safety reasons. This can also provide a competitive advantage in the digital space.

## Critical take on the use of AR glasses

The AR windshield's potential for point-of-interest visualization is undeniable. It does, however, pose technical challenges that may limit the user experience. The decision of whether to remove or keep the glasses on during use was a hot topic among experts. The prevailing sentiment was skepticism about leaving the glasses on, which was primarily attributed to the technology's current limitations. Current models, in particular, such as MR/AR headsets from Microsoft and Nreal, have a limited field of view and poor visibility. This means that the decision to wear glasses is heavily influenced by their design and construction.

Nonetheless, there is growing excitement in the tech community about the future of AR glasses. Experts predict that these devices have transformative potential, implying that they could pave the way for newer and, arguably, safer user experiences, particularly in transition situations. One example of this potential is the ability for users to quickly comprehend the function of active icons and how to interact with them by simply glancing at them.

> ***"It's a big opportunity for innovation and novelty: If we get it right, people will definitely buy into it"*** */Expert on Human-Automation Interaction, Expert on Immersive automotive experiences*

## Suggested improvements

The insights from our focus group sessions have been both revealing and instructive in determining the ideal Takeover (TO) scenario. Experts agree that the ability to provide a superior TO experience could be a powerful differentiator for the company. One noteworthy suggestion is the inclusion of multimodal alert systems. The experience can be elevated to feel luxurious by incorporating seat haptics, musical transitions, and ambient sounds. Seat haptics, in particular, is an intriguing possibility. Experts believe it can be used creatively not only as an alert but also during the confirmation phase. A novel suggestion was to have the seat belt tighten and then relax in response to the user's action. It is critical to note that the manifestation of such haptics may differ between planned and unplanned scenarios.

Furthermore, it is critical that the vehicle's automation status is not limited to the occupants. There is an urgent need to communicate this information to third parties such as other vehicles and pedestrians. Given the universal standardization of colors, it could be a viable method of effectively communicating the vehicle's state.

## Emotions in ideal TO

Experts felt a little conservative about talking about emotions, as it is premature to make a judgment due to the dynamic nature of emotions. They believe that an experiential prototype will be more suitable to cater to this research objective.

In general, experts were appreciative of the journey's idealness, as it seemed to maintain a state of calm and confidence through various phases. However, there were some notable discussions that implicitly and explicitly talked about improvements. The insights from those are as follows:

- Notification about the TO (in the de-immersing phase) might intimidate users as they are being told to take control. The guidance from the system is critical at this stage. There should not be too many things happening.
- As seen before, the framing of commands in the conversational modality could have a heavy impact on the user's state of mind. Hence, they should be thoughtfully designed. It is essential to note the cultural variations in such modalities.
- Sudden changes in the environment, like changing seat position and recline or the steering wheel coming out of the dashboard, could build feelings of overwhelm or insecurity. The visual hints should inform the driver before such changes so that they are aware of the physical change in the environment. These notifications should be well-timed as well.

## Elements repeatable in the unplanned TOs

The starting discussion differentiated between planned, unplanned, and emergency TOs in order to build a common mental image. In summary, planned TOs are the ones where users know about the TO before starting the journey; in unplanned TOs, users are informed about the TO while they are already on the journey; and in emergency TOs, the car becomes the primary owner of the control with less or no time to ask for human intervention.

This leads to the understanding that there are different emotional starting points in planned and unplanned TOs. In unplanned TOs, users are more vulnerable to being intimidated by the request. Hence, HMI should create a soothing effect and build confidence. Experts believe that the rest of the interaction could remain the same, with one notable adaptation. In the proposed solution, the users were in a commanding position. However, in unplanned TO, it would be better if initial interactions were more suggestive, i.e., the system would suggest actions. This should change radically in emergency TOs; the system should take an instructive stance to facilitate quicker action. Here, explaining why the TO is necessary to users may not be a priority. Experts believe that every TO situation is treated differently, so further research is definitely needed.





There was another discussion on balancing user preferences and safety margins. Users would expect some personal ways to handle such situations, but standardization (which builds the mental model) may conflict with such expectations. A critical question emerges from this discussion:

> ***How will there be a negotiation between regulations and protocols (safety margins) and user preferences (convenience)?***

It is also important to understand the changes in timeframes of the phases. How they will change is hard to predict, as there are too many objective and subjective complexities in the TOs (Morales-Alvarez et al., 2020). These changes will have a big impact on interactions, especially in building situational and automation awareness. Some experts speculate that timeframes in planned and unplanned TOs will not change significantly, but again, this needs to be tested through real-life tests.

> ***"Everything depends on how much time one has"*** */Expert on level 4 automation*

## Takes on changes once users get familiar

Experience builds judgment, knowledge, and eventually preferences. This has a significant impact on the mental state and reaction times of users. Therefore, it is essential to understand how experience affects the interaction flow in TOs.

Experts believe that experience will not affect the interaction flow, mainly due to safety protocols. Even if the user has gone through several TOs, they must follow the protocols. This could be frustrating, but it could be mitigated through clever and minimal effort and time-consuming design. Experts also believe that experience will not affect the timeframes, as they will be primarily driven by regulations and safety protocols. Experts also speculate that eventually, TOs will not be even necessary due to robust automation and infrastructure.

**To summarize,** the insights gained from our focus group sessions were both illuminating and instructive in determining the ideal Takeover (TO) scenario. Experts agree that the company's ability to provide a superior TO experience could be a powerful differentiator. One notable suggestion is to include multimodal alert systems. Seat haptics, musical transitions, and ambient sounds can be used to make the experience feel more luxurious. Seat haptics, in particular, are a fascinating prospect. According to experts, it can be used creatively not only as an alert but also during the confirmation phase.The seat belt tightening and then relaxing in response to the user's movement was a novel idea. It should be noted that the appearance of such haptics may vary between planned and unplanned scenarios. Furthermore, the automation status of the vehicle must not be limited to the occupants. This information must be communicated to third parties, including other vehicles and pedestrians, as soon as possible. Given the universal standardization of colors, it may be a viable method of effectively communicating the vehicle's state.

# CONCLUDING

# CONCLUSIONS
# LIMITATIONS AND RECOMMENDATION

*As the thesis's final chapter, we revisit insights from both the research and design phases, reflecting on the breadth and consistency of our findings. The limitations of the study are then addressed, followed by recommendations for future research and practices. The chapter concludes with a personal reflection on our experience.*



## 14.0
# CONCLUSIONS

Autonomous vehicles will change the way users interact with cars. The time gained at higher levels of automation can bring several benefits to users. The rapid pace of development of autonomous vehicles is changing the way car makers think about how they can build new value propositions to allow users to repurpose their commute time. In order to do so, they want to integrate immersive technologies into autonomous vehicles. This also has huge projected economic prospects that companies can leverage. Their technological expertise, research capabilities, and design capabilities allow them to build those experiences. However, it is essential to understand how users perceive these interventions or novel experiences in the space of XRinAVs to build a strong why and inform their long-term vision.

## Research phase 1

*How might we design safe and meaningful A(X)R interventions for users (in in-journey experiences) with different levels of immersion and autonomy?*

We conducted strictly qualitative research to examine the perceptions of users towards the near-future technological interventions in commuting, the design of which was extrapolated from the trends observed in the technological, regulatory, value-driven, social, and economical landscape in the space of XRinAVs. The process of building speculations through speculative design and using those speculations in context mapping sessions proved to be an effective approach to exploring plausible future narratives and their implications on users' lives and beyond. This strategic blend of methodologies resulted in surfacing the user's perceptions, expectations, and concerns by allowing them to empathize with their future selves.

The process of building speculations and initial stakeholder analysis also resulted in an understanding of underlying tensions that show the complexity of this space. The crafted speculations also voiced citical (immersion vs. safety, immersion vs. privacy, privacy vs. invasion, integration vs. distraction, accessibility vs. exclusivity, isolation vs. social interaction) tensions implicitly and explicitly to provoke users and understand their tendencies or biases towards one or many conflicting values. Ultimately, this resulted in conditions that need to be true for adoption and user acceptance of such novel interventions.

***Some key findings***

Users do believe that the introduction of autonomous mobility will change the way they commute. Their main drivers of knowledge about AVs are their curiosity and interest in novel technologies. But this comes with a lot of skepticism about the successful implementation of such technology. The criteria for success here are the preservation and potentially enhancement of safety and efficiency in commuting.

Users are willing to adopt and accept novel value propositions and experiences to change, repurpose, or rethink commuting. They are willing to negotiate values like autonomy, privacy, accessibility for technological development, and immersive experiences in driving and non-driving-related activities. Users want their cars to know them and provide personalized values in commuting. For users, personalization is an alignment of the machine or system with their intuition and preferences. Users also find commuting a social paradigm, where shared engagement is immersive. The value of co-presence also came to light through shared experiences. However, they do want to preserve the ability to isolate for high-concentration tasks. Trust and safety in technology are two underlying threads that are pivotal for XRinAV's future to be fully accepted.

Finally, a key conclusion is that several critical tensions need to be solved in collaborative settings for speculated futures to become reality.

## Research Phase 2

*How might we design interventions to resolve the tension between immersion and safety?*

The second phase takes a more specific direction of design that is informed by the synthesis of phase 1. One of the key conditions for immersion is the assurance of safety and security while commuting. This creates the condition of being immersed while on the journey. The second phase of research attempts to resolve this tension. The peak intensity of this tension, in terms of impact, exists in situations where there is a transfer of control between vehicles and users. The design focuses on this very instance.

The design approach was to design an ideal experience (a speculative future scenario) that mitigates the tension and maintains a feeling of calm and confidence. The ideality of the experience comes from the effectiveness of the communication between users and systems. In order to map this communication, user roles and system roles were defined.

The user's role was understood through the empathy map, which clarifies what users might be anticipating, feeling, and doing in various instances of the journey. The entries in the empathy map were informed through TOR considerations (design wishes and requirements) drawn from the previous phase, contextual variables drawn from expert consultations, and mobility behaviors and life values from selected personas. System roles were defined through understanding the SAE's regulations and shared control frameworks.

The roles of system and user are dynamic in nature, as driving is a complex activity where situations change every second, bringing several factors into play. One way to deal with such complexity is to define the phases of the experience in detail and also account for the changing roles of users and systems. The design's focus was on building a plausible interaction flow by mapping the experience. Another important thing is the way information is being communicated, i.e., interaction modalities. Emperical evidence, insights from expert consultations, and non-conservative yet practical interior design (propped for 2026 models) solidified the types of interaction modalities. The idea of a floating display and a speculated AR windshield (with other interaction modalities such as in-vehicle haptics and AI conversation modality) was introduced as an integrated part of HMI.

The experience was designed through an effective integration of deep empirical evidence and a non-conservative design approach. The decisions on the timeframes of the phases, adaptive elements of the UI, and novel product features were meticulously designed. The experience was visualized through a video. It was used in the focus group sessions with carefully selected experts to evaluate the perception of the design of the ideal TO. Focus group sessions brought multiple expert perspectives from various backgrounds (such as HMI design, automation embodiments, and automotive immersive experiences) in search of true idealness. It resulted in several key insights and future design and research directions.

**Some key findings**

The expert analysis of the Ideal TO design highlighted its future plausibility and effectiveness in balancing immersion and safety. Its contextual setting, distinct phases, and clear human-machine interface (HMI) were appreciated, especially the adaptive UI and its AI-driven conversational interfaces. However, concerns arose over the 4-3-2 transition flow's rapidity, indicating a need for further experiential research. Certain UI elements, like the timer, were critiqued for not fitting the design language. Terms like 'geofencing stability' suggest a need for a more user-centric design.

The novel features, such as the projected state stability animation, while innovative, might pose distractions, impacting safety. Experts also stressed the importance of refining auditory command tones and the potential standardization of colors. Emotional management during TOs was emphasized, particularly for ensuring calm during varying TO scenarios like planned, unplanned, and emergencies. Suggestions included a minimalist approach to avoid overwhelming users and the significance of the interplay between standardization and user preference during unexpected TOs.

The influence of user experience on TOs was deemed significant, but not to the extent of altering fundamental TO interaction flows. Conclusively, while the ideal TO design seems robust, it requires refinement and real-life testing to ensure utmost efficacy. The design serves as inspiration for the design team to design TOs for future fleets of vehicles. It highlights important elements of HMI that can build trust in users, elevating adoption and acceptance. It also opens up new directions to investigate to prepare for the future in a sound way. The speculated TO scenario also has the potential to be used as a speculative artifact to shape future socio-ethical and socio-economic aspects in collaboration with regulatory bodies.

Finally, the thesis builds a strong case for adopting speculative design as a way of investigation in collaborative contexts to explore several futures. It also demonstrates its ability to build tangible and actionable solutions in the field of HCI.

## Reflection on validity and reliability

In terms of validity, the research focuses solely on qualitatively investigating the space in order to comprehend the dynamics of the desirability of future technological interventions. Although the feasibility is not fully considered when crafting speculations, the speculations are heavily based on technological trends. Given the company's technological orientation, proposed HMI and XR interventions are feasible; however, strong industry collaboration will be required to make XR interventions feasible. The interventions must also be financially viable and profitable for the company. The preliminary research and trends show promising economic projections from reliable sources. The thesis demonstrates that people are willing to invest in such offerings (once the value proposition resonates with their preferences), but this does not imply that people will invest. As a result, a more quantitative approach is required to comprehend viability. Finally, it is critical to make future interventions adoptable, sustainable, and inclusive.

In terms of reliability, the thesis employs a methodical approach to ensure the replicability and consistency of the research and design activities. Peers and supervisors, for example, reviewed all materials such as sensitization booklets and interview scripts. Furthermore, consistency is maintained by not changing interview and session guides and materials between participants. Data analysis has some limitations due to time constraints, which are discussed further below. Finally, keeping detailed records of the thought processes and decisions made throughout this thesis ensures the thesis's replicability, transparency, and consistency.





# 14.1 LIMITATION

Both phases of the study exhibit certain limitations that impede the validity and reliability of the findings. These limitations are outlined below.

## Limitations of phase 1

There were several challenges and limitations to the research that deserve to be addressed. For starters, the scenarios presented were not co-created. This was because of logistical and legal issues. Collaborations could have influenced the speculative outcomes differently and possibly more comprehensively. Another source of potential bias emerged from the trend data, which was drawn from the "Notion: trends library." Based on my personal interpretation, there is room for biases and subtle misalignments despite the establishment of criteria for assigning 3Ps and impact horizons. The struggle to do horizon scanning with pace, volume and reach remains a tension point for effective futuring. In the future, a more collaborative approach that includes diverse team perspectives could result in a richer dataset.

It's worth noting how our interviews were organized. Because they were semi-structured, they relied heavily on the researchers' storytelling abilities, affecting the study's replicability. This, combined with the meticulous yet constrained participant selection process - limited by sample size and varied background knowledge - raises concerns about the reliability of the results. It's worth exploring different hypotheses highlighting similar value tensions, or even narrowing focus to one persona in subsequent iterations, for a more solid validation.

The TOR design wishes derived from user interviews were critical. These could have biases or knowledge gaps. It is especially important to highlight the difficulties associated with users' unfamiliarity with the concept of "levels of autonomies." Despite the best efforts, supported by expert consultations, to create clear visual aids, some participants lacked prior exposure and, as a result, a complete understanding.

The solo coding process imposed constraints on analysis. Determining the subcategory boundaries, particularly around inclusion and exclusion criteria, was difficult and was heavily influenced by the researchers' personal perspectives. Anoth-

er limitation was the lack of a peer review phase due to time constraints, which is usually helpful in refining the coding process. Nonetheless, future research is promising. Engaging in qualitative analysis in collaborative settings and using grounded theory methods could provide more in-depth insights *(similar to research conducted by Kaur and Rampersad (2018) on investigating adoption factors of AVs)*. With their suitability for creating co-occurrence matrices and code networks, the codes generated in this study highlight the potential for revealing the nuanced relationships between subcategories and codes.

## Limitations of phase 2

### Design-related Limitations:

The complexity of Human-Machine Interface (HMI) design is a significant limitation. This complexity is best navigated with a diverse range of perspectives sourced from collaborative settings. The implication is that a single approach or limited perspectives may result in designs that aren't universally effective, potentially making research findings less applicable across different contexts.
Furthermore, the scope of the design process is vast, and adequately communicating its comprehensive scope through visuals alone is difficult. This limitation may cause users to struggle with comprehending the full scope of the research, influencing how they use and interpret the findings.

Each scenario requires a unique approach to designing Takeover Requests (TOR). This distinction emphasizes the significance of a design approach that is universally adaptable. The limitation of focusing on a specific context may limit the scalability of the research findings, implying the need for more adaptable designs or additional research for broader application scenarios.

Another design challenge arises when projects are based on assumed future conditions. While these assumptions are forward-looking, they may be overly idealistic. If these conditions do not exist, the research may face unexpected challenges, resulting in designs that are not feasible in the near future.

### Focus Group-related Limitations:

Expert bias is a significant constraint. Even with anti-bias measures in place, the influence of inherent perspectives from internal experts cannot be completely eliminated. This means that the research findings may inadvertently lean heavily toward company-centric perspectives, limiting their broader acceptance and applicability outside of the firm.

Another limitation is that the interaction flow is primarily assessed by system-familiar experts. It may cause users who are unfamiliar with the system to overlook challenges or requirements. The practical implication is that the design may not be as effective in real-world scenarios, particularly for users who are unfamiliar with the system.

Another limitation is the length of focus group sessions. Given their short length, it is difficult to thoroughly investigate every topic, potentially jeopardizing the research's depth and richness. Essential insights or opposing viewpoints may be overlooked, reducing the overall comprehensiveness of the findings.

Finally, the study's data collection method, which involved taking notes rather than verbatim transcription, is a limitation. Such an approach may overlook nuanced details or subtle perspectives, affecting the completeness and accuracy of the research findings.



# 14.2 RECOMMENDATION

Several directions for future study are proposed in light of the thesis's limitations and findings.

### Phase 1

Given the recurring insights on the importance of trust within the XRinAV space, it is recommended that subsequent research prioritizes this element. Exploring trust-building interactions emerges as an essential foundation. Subsequent design directions can be structured around design directions already delineated on page X. However, trust-building is just one component of this intricate puzzle.

To supplement this, it is advised to diversify research methods. The realm of speculative design, particularly when it incorporates experiential aspects, holds significant promise, in other words, conducting stakeholder interviews with different speculations for similar critical tensions. These engagements, by either validating or challenging existing insights, can broaden the research spectrum.

The adoption of speculative design could be implemented throughout the entirety of the research and development department. The automation of the trends library and the crafting of speculations could be facilitated through collaborative efforts across teams. The resulting configuration may resemble the one depicted in Figure 14.1.

Broadening the scope further, there's an undeniable need for cross-industry collaborations. The synergy between XR and AVs introduces myriad opportunities that hinge on robust partnerships across various sectors. Proactively investigating the suitability of XR

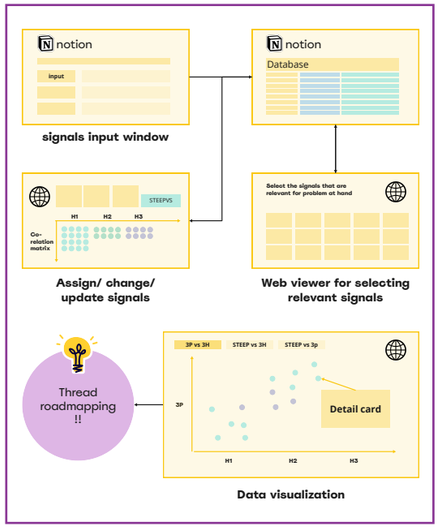



*Fig 14.1 The architecture for futuring platform*

platforms tailored for AVs becomes paramount. But beyond technical considerations, it is vital to encompass a more holistic view. This calls for assimilating perspectives from diverse stakeholders, especially those like XR content developers; this could be done the interview guide presented in appendix O. Their unique insights can significantly shape the trajectory of the research and development process, ensuring a design approach that's both innovative and holistic.

### Phase 2

Transitioning to the second phase, feasibility takes center stage. Several HMI features need to be investigated from feasibility point of view. It is crucial for researchers and designers to discern the feasibility of these features, harmonizing visionary aspirations with practical realities.

Beyond feasibility, refinement takes precedence. The existing TOR design, while foundational, beckons further enhancements. Acting upon expert recommendations in domains like color standardization, minimal information flow and consistent UI design necessitates a design reiteration. This iterative approach, besides refining the design, serves as a potential speculation for impending regulations. It also aids in charting the broader socio-economic, socio-ethical, and socio-political implications. To achieve this refined vision, it's advocated to initiate focus group sessions with varied stakeholders, thereby obtaining a comprehensive outlook.

Further, the refined designs, while theoretically robust, call for empirical validation. Collaborating closely with design teams can catalyze the creation of experiential prototypes. These prototypes can be virtual or tangible. On the virtual front, refer to Schroeter and Gerber (2018) who proposed a methodological tool combining VR and real-world videos for the rapid prototyping of automotive interfaces. Additionally, Riegler et al. (2019) proposed a VR-based automated driving simulator, merging software and hardware solutions. Conversely, for tangible prototypes, a projection-mapped UI on a rudimentary prototype is recommended. The embodiment of such a tangible approach is illustrated in Figure 14.2. Conducted user tests can then unravel various nuances – from mapping emotional landscapes to discerning effective information channels in dynamic contexts.

Lastly, engaging with external experts (distinct from Mercedes), even those outside the immediate paradigm, will introduce fresh perspectives. It is recommended that workshops be organized, drawing upon this external expertise, ensuring HMI designs that cater to a universal audience. Moreover, this can usher in unconventional insights. Such engagements can potentially blend traditional knowledge with creative innovations.

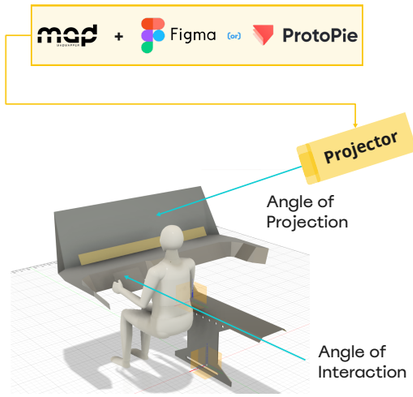



*Fig 14.2 Proposed system architecture to build experiential prototype*



# 14.2
# REFLECTION

"I've always wanted to master the design process, seeing it as a powerful tool, suitable for several lenses of problems, for shaping the future. This project served as my crucible, testing and honing my skills.

I found myself in unfamiliar territory at first, eagerly exploring new methodologies and tools. While I had previously thrived in team collaborations, this was my first foray into autonomy. Independence brought its own set of challenges, from navigating complex contracts to managing collaborations under tight deadlines. Even writing this report presented its own set of challenges, as I juggled the complexities of catering to various reader profiles while aiming for clarity and brevity. This journey, however, was about more than just overcoming obstacles; it was about evolution. It marked my transformation from a passive dreamer to a proactive doer.

My ambition, while largely serving as a catalyst, occasionally proved to be a hindrance. This pursuit of perfection resulted in adapted deadlines and unexpected roadblocks. Every blunder, on the other hand, was an invaluable lesson, meticulously documented in my "failure resume." I filled 3 pages in my failure resume, small and big fails.

Exploring interaction design exposed me to a world of narratives and their nuanced presentations. The complexities of this realm threatened to engulf me at times, urging me to strike a delicate balance between depth and distraction.

This journey taught me the importance of clear thinking over endless analysis. While I used to prefer thorough decision-making, I've come to appreciate the benefits of decisive action, even if it occasionally results in mistakes. After all, rapid failures frequently hasten the learning curve.

This project highlighted my core strengths: independence, a keen eye for detail, an unwavering commitment to quality, and a proclivity for reflection and adaptability. The relationships I formed and the creative energy I channeled throughout this journey emphasized a profound realization: "I am the only limit I have."

I look forward with renewed insights and convictions, knowing that this experience has brought me closer to my dream of becoming a design virtuoso.

Finally, a big thank you to my frineds, family and mentors."

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# Appendices

A separate report contains all of the appendices. They are only shared with the supervisory group. Please get in touch with me either in person or via e-mail if you'd like to see them.


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