Next Generation Steering Device

Designing for Emergency Situation

Master’s thesis in Industrial Design Engineering

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Abstract

As autonomous vehicles progress toward full automation, new challenges arise in ensuring safety during emergency scenarios where human intervention may still be necessary. This thesis, conducted in collaboration with Autoliv, investigates how Level 4 robotaxis can be designed to allow first responders to manually reposition stalled vehicles in critical situations. The project focuses on developing a fallback steering solution that addresses the absence of traditional controls in future vehicle interiors. Using a human-centered design process, including literature reviews, in-depth interviews with automotive experts and users, and iterative prototyping, the project identifies key user needs such as intuitive operation, mechanical reliability, and secure access.

The result is HALOGRIP, a visible, analog steering device embedded within the dashboard of the robotaxi. Activated via a two-step ID verification process, the device uses a tilt-based mechanism for speed control and traditional rotation for steering. The system enables low-speed maneuvers without requiring training and supports quick response in space-constrained environments. Physical buttons and a HUD provide clear operational feedback, while mechanical locking ensures fail-safe deployment. HALOGRIP offers a pragmatic and user-friendly solution that empowers emergency personnel without compromising the autonomy of the vehicle. Future work includes validating usability in real-world scenarios and refining integration across different vehicle platforms.

Keywords: Autonomous vehicles, Robotaxi, fallback control, emergency response, human-centered design, tilt-based interface, first responders.

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Last but not least, we would like to express our gratitude to all the individuals who participated in our user tests and interviews.

Thank you!

SYLVIA XIE & YUXIN LIN, Gothenburg, June 2025

Contents

1

INTRODUCTION

This chapter outlines the foundation of the project, including the background, aim and research question, an introduction to the thesis provider and their expectations, as well as the project's intended deliverables. It also presents an overview of the project's structure.

1.1 Project Background

In the 1980s, significant progress toward autonomous vehicles began through research at universities and military programs. Early projects like Carnegie Mellon University's Navlab and the German-led EUREKA Prometheus Project demonstrated the potential for vehicles to navigate and make decisions independently. The Navlab project, starting in 1984, showcased autonomous driving capabilities (Carnegie Mellon University, 2014), while the Prometheus project (1987–1995) focused on autonomous highway driving and vehicle communication (Autonomous Vehicle International, 2018). These efforts laid the foundation for modern autonomous driving technologies.

A major shift occurred in 2009 when Google, now operating under the name Waymo, launched its self-driving car initiative. The project drew widespread attention and marked the beginning of large-scale private investment in the field. Over the next decade, major automotive and technology companies—including Tesla, Uber, and General Motors—started developing their own autonomous systems. Their goal was to reduce or eliminate the need for human drivers.

As these systems evolved, there was a need for clearer definitions of their capabilities. In 2014, the Society of Automotive Engineers (SAE) published the J3016 standard. It introduced six levels of vehicle automation, ranging from fully manual (Level 0) to fully autonomous (Level 5). This framework has since become the global reference for describing and comparing automation systems.

Today, SAE Level 2 systems are common in commercial vehicles. These systems handle both lateral (steering) and longitudinal (acceleration and braking) control but require the driver to monitor the environment and stay ready to intervene. Level

3 automation is now emerging, allowing the system to manage all driving tasks under certain conditions, including detecting and responding to events. However, since drivers are allowed to shift their attention away, they may become "out of the loop," leading to delayed or inappropriate reactions when suddenly required to take back control. Due to these safety concerns and technical challenges, many companies are choosing to bypass Level 3 and instead focus on Level 4 systems. At this level, the vehicle can drive fully autonomously within defined areas, with no need for driver intervention (SAE International, 2021; Seppelt & Victor, 2016).

According to our literature review, robotaxi companies are likely to be the first major adopters of Level 4 technology. These services already exist, primarily in the United States and China, where fleets of autonomous vehicles provide taxi services without a human driver. Equipped with advanced technologies such as sensors, cameras, lidar, radar, and artificial intelligence, robotaxis are capable of navigating complex urban environments, picking up passengers, and completing trips independently.

As Level 4 automation becomes more prevalent in robotaxis, manufacturers are increasingly exploring the removal of traditional steering controls. Some argue that manual controls will become obsolete, and eliminating the steering wheel can increase cabin space and improve passenger comfort. Tesla, for instance, recently unveiled a robotaxi concept without a steering wheel, reinforcing this vision. While such designs reflect growing confidence in autonomous technology, recent real-world incidents have raised concerns about whether removing manual controls is always a safe choice. Since early 2023, the San Francisco Fire Department (SFFD) has reported numerous cases where robotaxis interfered with emergency operations—such as failing to yield to fire trucks with active sirens, entering closed roads, or blocking emergency scenes (Farivar, 2023). These events reveal that current autonomous systems can behave unpredictably in complex or abnormal situations, highlighting the need to reconsider the complete removal of human override capabilities.

The transition toward increased vehicle automation presents both challenges and opportunities. A balanced approach is essential—one that advances the industry's pursuit of greater comfort and interior space, while also ensuring that emergency responders can effectively interact with robotaxis in critical situations. In light of these developments, this thesis was conducted in collaboration with Autoliv, a global leader in automotive safety systems.

1.2 Starting Point of the Project

Autoliv gave this master's thesis considerable freedom to explore different directions, with two initial constraints: the outcome should relate to the design of a steering device influenced by emerging technologies or automotive trends, and the design should be set in the context of the year 2035. The specific focus on steering devices for robotaxis was defined later, based on insights gained during the initial literature review.

1.3 Aim

This project builds on identified challenges in emergency scenarios involving autonomous vehicles, exploring how a device could enable first responders to manually reposition stalled vehicles and reduce obstruction in critical situations. Simultaneously, it aims to align with expectations for spacious and futuristic interiors appropriate for that time.

1.4 Deliverables

The project's expected deliverables are presented below.

- Final presentation of findings, including key insights, design rationale, and concept evolution.
- Concept mock-up showcasing the proposed steering system design.
- Detailed test results from user testing sessions.
- Documentation of brainstorming sessions and idea generation, including concepts sketches an initial prototypes.

1.5 Report Outline

The summarized report outline will be presented below.

Chapter 1: Introduction

This section provides the background of the thesis project and situates it within a broader context. It outlines the aim and research questions, introduces the thesis provider Autoliv, describes their role and expectations, and summarizes the expected deliverables.

Chapter 2: Final Result

This chapter summarizes the final results, including the problem statements and a description of the final concept.

Chapter 3: Robotaxi

Chapter 3 outlines key aspects of the robotaxi landscape, including definitions of automation levels and projections that robotaxis will lead the Level 4 vehicle market by 2035. It highlights industry trends such as the removal of steering devices and analyzes past robotaxi incidents along with the strategies companies use to address them.

Chapter 4: Project Scope

Based on the research information presented in the previous chapters, the project scope was formulated and will be presented in this chapter. The section also defines the target user group for the project, outlines its limitations, and considers ethical aspects and GDPR compliance.

Chapter 5: Process and Method

This chapter provides an objective overview of the methods selected for the project, without detailing their practical application.

Chapter 6: Procedure

This chapter outlines how the selected methods were practically conducted during the project. It describes the step-by-step implementation, the context in which each method was used, and the expected outcomes from each method.

Chapter 7: Design Foundation

The results are presented in three main sections. First, the identified problems from the literature review, user studies, and expert interviews are outlined, along with how these issues informed the concept development. Second, the various design concepts are introduced, and their evaluation process is described. Finally, the developed final concept is presented.

Chapter 8: Concept Development

This chapter presents the various design alternatives explored throughout the process, along with the proposed concept suggestions.

Chapter 9: Final Concept Refinement

This chapter outlines the refinement process of the final concept, covering key stages from early sketch iterations to digital modeling. It includes feedback gathered from stakeholders, the development of the final design sketch, and the translation of the concept into a 3D model and rendered visuals to communicate form and function.

Chapter 10: Final Concept HALOGRIP

This chapter presents the final concept developed through the design process. It outlines the key features of the HALOGRIP solution, its intended functionality, and the rationale behind design decisions based on the insights gathered throughout the project.

Chapter 11: Discussion

This chapter discusses the project's results, how well the defined aim has been fulfilled, and other aspects that may be relevant to reflect upon regarding the final outcome and the project's approach.

Chapter 12: Future Work

This chapter outlines potential directions for further development, including technical refinement, long-term evaluation, and broader implementation considerations that go beyond the current project scope.

Chapter 13: Conclusion

The thesis concludes by summarizing the project's main findings, design contributions, and societal relevance.

2

FINAL RESULT

This chapter presents the final outcome of the project in the form of a summary of the defined problem statement and a description of the developed final concept.

2.1 Problem Statement

This section presents a summary of the problem statement.

2.1.1 Overall Concern about Robotaxi in Emergency Situation

Both first responders and public participants expressed uncertainty about how to interact with robotaxis during emergencies, especially when traditional controls like a steering wheel are removed. Several firefighters pointed out that in high-stress situations, the absence of familiar interfaces may delay appropriate actions. Similar concerns appeared among public, where some appreciated the futuristic interior but saw the lack of clear manual controls as a safety risk, potentially lowering trust and willingness to ride.

2.1.2 Insufficient Strategies

The user study highlighted that current strategies for handling stalled robotaxis during emergencies are unreliable and can delay response times. Firefighters stressed the need for immediate, local manual control—independent of the robotaxi company—where they hold full authority. Existing methods like pushing or winching are limited, reinforcing the need for a compact steering device that enables precise control in tight spaces and can be operated by a single responder.

2.1.3 Standardization

First responders were worried that emergency steering devices are not standardized. They pointed out that if every robotaxi has a different location or method for activating manual control, it could cause confusion and mistakes in emergencies. Just like with electric vehicles—where each brand places high-voltage parts differently—this lack of consistency increases stress and slows down response.

2.1.4 Control Over Vehicle Behavior During Ground Operations

A major concern among first responders was the lack of control over robotaxi behavior during emergencies. When asked whether the vehicle should remain stationary or move away when stuck, responses varied based on role—floor-level firefighters preferred it to move away, while commanding officers preferred it stay. Despite these differences, all interviewees emphasized the need for control over the vehicle's movement. This led to a key design requirement: the system must include both a freeze function and an option for the vehicle to autonomously leave the scene when appropriate.

2.2 Final Concept

HALOGRIP is an analog fallback system embedded into the dashboard of a 2035 robotaxi, specifically designed for first responders.(see Figure 2.1) It provides manual vehicle repositioning during emergencies when autonomous or remote control is not viable.

- Tilt-Based Interation Model

HALOGRIP maintains a familiar steering experience by using conventional rotational input for directional control—users simply turn the device left or right as they would with a traditional steering wheel. However, instead of relying on foot pedals for speed control, the system introduces a tilt-based mechanism. Tilting the device forward results in acceleration, while tilting it backward initiates deceleration or reverse motion. When held in a neutral, upright position, the vehicle remains stationary.

- Form Language

HALOGRIP features a non-traditional U-shaped steering design with outward-angled grips. The open geometry enables the driver to position their hands quickly and naturally, minimizing the need for adjustment or visual confirmation. The grip's cross-section is contoured to fit the area between the thumb and index finger, enhancing physical comfort and control during operation. These structural choices reduce both the physical and cognitive effort typically associated with engaging a steering interface, making the act of control feel immediate and instinctive. Rather than simply reimagining form, HALOGRIP redefines interaction—offering a steering solution optimized for clarity, precision, and seamless integration within the next generation of intelligent vehicle interiors.

- Secure Activation Workflow

HALOGRIP uses a two-step ID verification process to ensure secure access. First, authorized users scan their ID on the B-pillar to unlock the vehicle. Once inside, a second scan on the steering unit activates and deploys the system for manual control.

- Human Factor and Safety Prioritization

HALOGRIP is designed with a strong focus on safety, usability, and clarity during high-stress emergency scenarios. The system limits speed to 15 kilometers per hour to reduce the risk of injury. Large physical buttons, designed for use with gloves, provide straightforward access to parking and emergency contact functions. A clear head-up display communicates mode status and guidance to support situational awareness. (see Figure 2.3) Automatic deployment of the steering unit eliminates the risk of unintentional input during activation. Mechanical locking with redundant engagement points ensures the device remains securely in place throughout use.

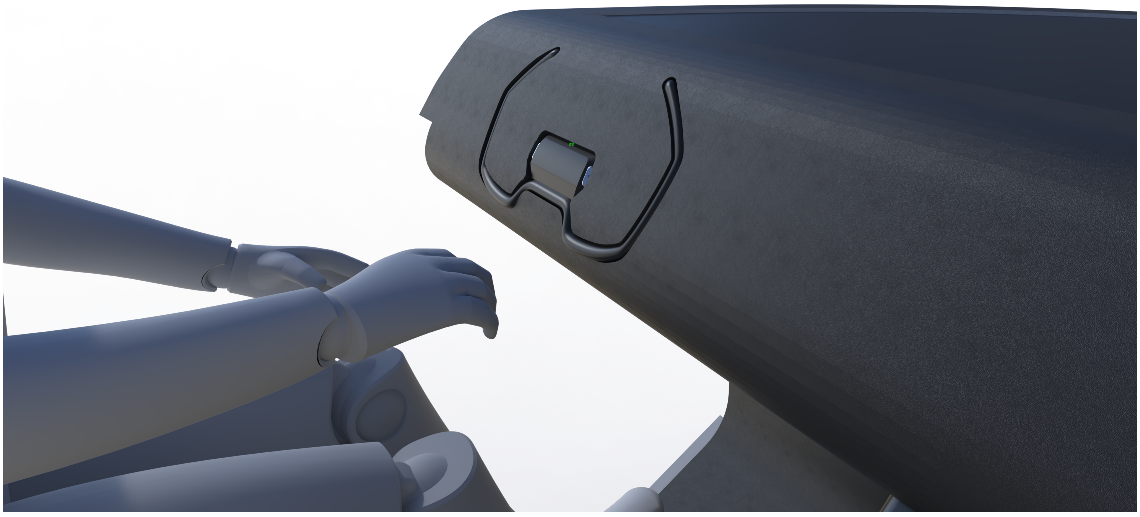


Figure 2.1: HALOGRIP embedded in the dashboard

Figure 2.2: Form of HALOGRIP

`figure/2.3.png`

Figure 2.3: HUD interface while driving with manual mode

3

ROBOTAXI

This chapter presents the theories and studies that define the robotaxi as the scope of this thesis. It includes findings from literature reviews in the following areas: automation levels and the role of robotaxis as a steppingstone for Level 4 vehicle adoption, as well as market size forecasts for the robotaxi industry. Furthermore, it addresses trends in robotaxi development, selected incidents involving robotaxis relevant to this project, their underlying causes, and the response strategies implemented by robotaxi companies.

3.1 Automatic Level

In this section, the definitions of the different automation levels according to the SAE standard will be presented.

The progression toward autonomous vehicles is formally categorized by the SAE J3016 standard, which defines six levels of driving automation, ranging from fully manual (Level 0) to fully autonomous (Level 5). These levels are based on the vehicle's ability to perform the Dynamic Driving Task (DDT).

The DDT refers to the real-time operational and tactical actions required to control a vehicle in traffic.

Key functions of the DDT include:

- Lateral control (steering)
- Longitudinal control (acceleration and braking)
- Monitoring the driving environment (object and event detection, recognition, and classification)
- Object and event response execution
- Maneuver planning (e.g., lane changes, merging)

- Enhancing conspicuity (e.g., signaling intentions through lights or sound)

Based on how much of the DDT is automated, SAE defines the levels as follows (SAE International, 2021):

Level 0 – No Automation: The human driver performs the entire dynamic driving task (DDT), although the system may provide warnings or momentary assistance (e.g., emergency braking or lane departure warnings). There is no sustained vehicle control from the system.

Level 1 – Driver Assistance: The system supports either steering or acceleration/braking, but the driver is responsible for the rest of the DDT and full environmental monitoring.

Level 2 – Partial Automation: The system performs both lateral and longitudinal control but requires the driver to supervise and remain fully engaged at all times.

Level 3 – Conditional Automation: The system handles the entire DDT under certain conditions, including full object and event detection and response (OEDR), but the driver must be ready to take over when requested.

Level 4 – High Automation: The system performs the complete DDT within specific operational design domains (ODDs), such as predefined urban areas. No driver intervention is required as long as the vehicle remains within these conditions.

Level 5 – Full Automation: The system can perform the entire DDT under all conditions without any human input, including scenarios beyond those a human driver might reasonably handle.

Currently, most vehicles on the market operate at Level 1 or Level 2 automation. Notably, BMW has received approval in Germany for Level 3 autonomous driving in its 7 Series models. This system, known as BMW Personal Pilot L3, allows the vehicle to take over driving tasks at speeds up to 60 km/h (37 mph) on motorways, enabling drivers to engage in secondary activities like reading or watching videos during traffic jams. However, drivers must remain ready to retake control when prompted (BMW Group, 2023).

Looking ahead to 2035, the presence of Level 3 vehicles on the market is expected to increase, although projections vary depending on regulatory, technical, and user acceptance factors. Nevertheless, Level 3 presents significant challenges: despite not actively monitoring the environment, drivers are still required to take over in unexpected situations, which can lead to delayed or inappropriate reactions.

For this reason, some researchers suggest it may be more effective to move directly to Level 4 automation by 2035. This would eliminate the problematic handover phase associated with Level 3 and support a safer, more consistent automated driving experience (Seppelt & Victor, 2016).

3.2 Bridge to Level 4 Adoption

In this section, the rationale for why robotaxis are expected to serve as a stepping-stone toward the widespread adoption of Level 4 vehicles by 2035 will be presented. In addition, the growing potential of robotaxi services will be discussed, along with the emerging trend among robotaxi companies to remove on-board steering wheels.

3.2.1 Economic Barriers to Private Level 4 Ownership

When examining market projections for Level 4 (L4) vehicles, the biggest challenge to wider adoption in the passenger car market is the high cost of development and deployment. Advanced AI systems, LiDAR sensors, radar, high-resolution cameras, and powerful computing units are all expensive. Additionally, research and development (R&D) costs remain significant, covering self-driving algorithm improvements, safety measures, and regulatory compliance (Metatech Insights,2025). These financial barriers are expected to keep L4 vehicle prices high, making them impractical for most individual buyers. However, taxi and ride-sharing services could be an exception, as their business models rely on maximizing vehicle utilization—often operating over 20 hours per day with minimal downtime for refueling or charging (S&P Global, 2023).

3.2.2 Legal and Liability Challenges

Another challenge is the unclear allocation of responsibility in the event of an accident, whether it falls on the automaker, the remote safety operator, or the vehicle owner. If the vehicle operates entirely under an autonomous system, the manufacturer may be held accountable for system defects or errors. If an accident occurs due to a failure to intervene by the safety operator, liability becomes ambiguous. Furthermore, if an L4 vehicle is registered under an individual's name, legal questions arise regarding whether the owner is responsible for issues such as maintenance failures or delayed software updates.

In contrast, robotaxi services are operated by companies that employ the remote operator, and handle regular maintenance and software updates, ensuring optimal performance. As a result, legal responsibility typically falls on the service provider.

Experts predict that robotaxis will serve as a bridge to wider L4 adoption in the privately owned vehicles market. According to KPMG (2022), this transition is expected to create a new market,potentially disrupting the industry as traditional taxis and ride-sharing fleets are replaced byrobotaxis.

3.2.3 Robotaxi Market Size

Today, approximately 2,000 robotaxis are operating globally, with the majority concentrated in China and the United States (Counterpoint Research, 2025). In China, around 1,000 robotaxis are active across at least 19 cities. The largest operator is Baidu's Apollo Go, with over 400 fully driverless vehicles in Wuhan. In the U.S., Waymo operates over 1,000 robotaxis in cities like Phoenix, San Francisco, and Los Angeles, having completed more than 5 million rides—4 million of which occurred in 2024 (Counterpoint Research, 2025).

According to expert interviews, robotaxis could capture 50% or more of China's taxi market by2035—but only if serious accidents are avoided. Public tolerance for autonomous vehicle crashes is low. For example, the Cruise incident in the U.S. led to a full suspension of services after a single crash (Roy, 2024). Similar events could significantly delay or derail industry growth.

While China and the U.S. are expected to remain the leading robotaxi markets, market growth forecasts vary widely. Frost & Sullivan (2024) estimate the global robotaxi market will grow from USD 84 million in 2023 to USD 68.75 billion by 2035. In contrast, IHS Markit projects that China alone could reach RMB 1.3 trillion (USD 178 billion) by 2030 (KPMG, 2022).

3.2.4 Removal of Steering Device for Robotaxi

The following section presents the trend of removing on-board steering devices in robotaxis, along with the identified advantages of this approach.

Robotaxi companies such as Zoox, Tesla, and Cruise are actively developing vehicles without steering wheels or pedals, aiming to fully realize the potential of autonomous driving technology. While technically feasible, large-scale deployment is currently limited by regulatory constraints.Nonetheless, there are robotaxis without traditional controls that have already been legislatively approved and put into limited use, though only within highly controlled and restricted environments. The motivation behind this design direction is driven by several factors, including interior space optimization, cost reduction, and differentiation in the market.

Optimizing for Full Autonomy Companies like Tesla and Zoox are building vehicles that rely entirely on advanced self-driving systems, eliminating the need for human intervention. Elon Musk has described Tesla's robotaxi as"highly optimized for autonomy," with the absence of manual controls intended to reduce manufacturing complexity and costs. This simplification is expected to lower production and maintenance expenses, enabling Tesla to target a price point below $30,000 and make autonomous mobility more accessible (Business Insider, 2024).

Reimagining Interior Design and Market Positioning Removing traditional driving controls offers greater flexibility in interior layout, enabling manufacturers to focus on passenger comfort and interaction. Zoox, for example, has designed a bidirectional vehicle with inward-facing seats, maximizing space and usability (Hawkins, 2020). As noted by CTO Jesse Levinson, this sets Zoox apart from competitors like Cruise and Waymo, who primarily adapt existing vehicle architectures (Levinson, 2025)

3.3 Robotaxi Incident

In this section, the targeted robotaxi incidents for this project will be presented.

The San Francisco Fire Department's official report (2023) documents 74 individual incidents involving AVs interfering with emergency response operations between November 2022 and August 2023. Each entry provides a timestamp, location, company involved, and a description of the issue, offering a comprehensive overview of recurring failure patterns.

These incidents include:

- AVs blocked narrow roads, forcing fire trucks to take detour routes to fires.
- AVs got stuck near firefighting operations, forcing firefighters to work around them as they positioned hoses and ladders.
- A few AVs were parked in front of fire stations, trapping fire trucks inside.
- A couple of Cruise vehicles drove over firefighters' hoses.

Although the majority of the incidents did not result in human injuries or other serious consequences according to the report, they nonetheless posed significant obstacles to the work of first responders. Firefighters were frequently forced to reroute, reposition their equipment, or even pause rescue operations due to the presence of autonomous vehicles.

Additionally, the unpredictable behavior of AVs at emergency scenes introduced new cognitive and logistical burdens, requiring first responders to divide their attention between managing the core emergency and addressing the unintended interference caused by the vehicles. These issues do not stem from catastrophic system failures, but rather from a consistent lack of situational awareness and adaptability in dynamic, high-pressure environments. It is precisely this category of incidents that serves as the focus of this project, which aims to identify where AVs fall short in supporting emergency operations.

Example Case: Response Delay at Emergency Scene

While many of the incidents listed above are documented in the SFFD report, the following example is the most detailed one available. It has also been widely used within this project as a basis for various materials, such as scenarios in user interviews.

On August 14, 2023, a tragic accident occurred when a human-driven bus struck a pedestrian named Sammy Davis. Although the collision was not caused by an autonomous vehicle, three Cruise AVs became entangled in the resulting traffic congestion.

Following the crash, a fire truck arrived and positioned itself across the left lanes of the one-way street to secure the scene. The Figure 3.1 depicts the situation (by this point a third Cruise vehicle had already departed).

An ambulance arrived shortly after, stopping behind one of the Cruise vehicles. While the Cruise AV in the front was able to depart before the patient was loaded into the ambulance, the rear Cruise vehicles remained stationary for over six minutes after the ambulance was ready to depart.

According to a San Francisco Fire Department memo, Cruise vehicles were reported to have blocked two lanes; however, Cruise later presented footage showing that the AVs were aligned one behind the other in the same lane, with the right lane remaining passable to other vehicles. Cruise also contended that the ambulance could have navigated around the stalled AV using that lane, although it remains unclear whether the clearance was sufficient.

Regardless of technical interpretations, the stalled Cruise vehicle's extended presence at the emergency scene created unnecessary complexity for first responders and risked delaying critical care. The incident underscores the challenges AVs face in responding appropriately to unpredictable, high-stakes situations. (Lee, 2023)

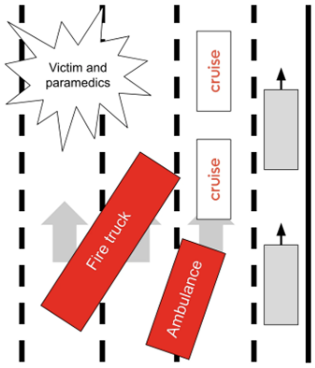


Figure 3.1: Illustration of the accident scene. Adapted from Lee(2023)

3.3.1 The Reasons Behind

The following section outlines some of the factors that led to the robotaxi becoming immobilized in the aforementioned incidents, as documented in the San Francisco Fire Department's official report (2023)

- Algorithmic Uncertainty in ODD Recognition

Autonomous Vehicles (AVs) must continuously assess whether they are operating within their Operational Design Domain (ODD) to determine if intervention is needed. Before escalating to human assistance, AVs attempt multiple self-recovery strategies, which may lead to hesitation or suboptimal decision-making. (Ceccarelli et al., 2024)

When an AV determines that it has exceeded its ODD, it must transition to a Minimal Risk Condition (MRC), which refers to a predefined safe state, typically involving slowing down and coming to a stop, in a safe and controlled manner. However, executing this transition is complex — stopping in certain locations, such as blocking emergency responders, can introduce new risks. Ensuring AVs can make context-aware decisions about when and where to halt remains a critical challenge. (Ceccarelli et al., 2024)

- Remote Assistance Decision Delay

If human intervention is required, it cannot assume an immediate or flawless response. A human driver, whether inside the vehicle or operating remotely, must first shift attention from their prior task, regain situational awareness, assess potential hazards, and formulate an appropriate reaction. While a commonly cited 10-second response time may suffice under normal circumstances, it is unlikely to be adequate when AVs request assistance due to critical system failures or unexpected hazards. In high-stress scenarios, response times could extend to 45 seconds or even a full minute, significantly impacting the ability to prevent mishaps. (Koopman, 2024)

- Network Failure and Power Outages

There have been multiple instances of AV mass strandings under various conditions, including one case where cellular network congestion caused by a nearby concert event led to AVs being unable to operate—despite the event not occurring on the affected street. This raises concerns about the potential consequences of broader communication disruptions or power outages affecting traffic control systems, particularly in the wake of natural disasters such as earthquakes. Ensuring AVs can maintain operational stability during infrastructure failures remains an open challenge. (Ceccarelli et al., 2024)

3.4 Current Strategy

Below is the coping strategies provided by robotaxi companies to manage interactions between autonomous vehicles and first responders.

- Waymo

The robotaxi found online to offer a more comprehensive coping guide for first responders is Waymo. They claimed to have conducted in-person training for 18,000+ first responders at 75+ agencies, and a 32-page guidance handbook was found that includes instructions on how first responders can manually steer the vehicle (Waymo, n.d.). This aligns with the SFFD Deputy Chief of Operations' Darius Luttropp request in the interview with journalist Timothy B. Lee for improved interaction with AVs— the ability to take manual control of a stalled vehicle (Lee, 2024). The image below presents a simplified overview of Waymo's manual driving procedure:

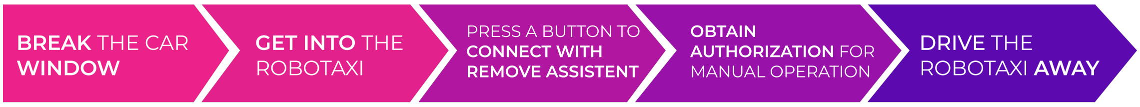


Figure 3.2: Waymo's current manual emergency strategy

- Apollo Go

Another strategy, described in an interview with a former employee of a Chinese robotaxi company, involves assigning a local assistant responsible for each service area. In the event of an emergency, this assistant is expected to arrive on-site within five to ten minutes to provide support.

3.5 Key Takeaways of Chapter 3

- SAE defines six automation levels, with higher levels assigning more driving responsibility to the system.
- Level 4 (L4) automation, the focus of this project, gives full driving responsibility to the system within defined conditions.
- By 2035, robotaxis are expected to hold the largest market share among Level 4 vehicles, making them a strategic focus for this thesis

- Real-world incidents in the U.S. show that robotaxis have obstructed emergency responders by blocking fire trucks, entering closed roads, or stopping unpredictably, with few effective coping strategies in place.
- These insights reveal a specific design gap: the lack of manual interaction methods for first responders to safely intervene with a robotaxi during emergencies
- This thesis therefore focuses on emergency responders as a key target group and explores how a physical steering device can support safe, manual intervention in robotaxis.

4

PROJECT SCOPE

Based on the research presented in the previous chapter, this chapter outlines the formulated project scope. It defines the target group, target scenario, the project's limitations, and addresses ethical considerations, including GDPR compliance related to the research process.

4.1 Target Group

The project's target group is first responders, including police, firefighters, and ambulance personnel.

- Definition of first responder

The term first responder refers to a trained professional who is among the first to arrive and provide assistance at the scene of an emergency, which typically includes firefighters, police officers, and emergency medical personnel (National Academies of Sciences, Engineering, and Medicine, 2013; Venes, 2021). These individuals are responsible for ensuring public safety, providing immediate medical care, and stabilizing critical situations before additional support arrives (Kösem & Saribey, 2022).

4.2 Target Scenario: The Emergency Obstruction Removal

The scenario occurs when a robotaxi becomes stuck in a position that interferes with emergency operations and is unable to identify a safe, legal location to reposition itself. In such cases, first responders must intervene to resolve the obstruction, restore access, and maintain emergency response continuity. The final concept aims to support responders in identifying and authorizing temporary alternative locations—whether that means repositioning the vehicle to another drivable lane or to physically safe, though typically restricted, areas such as sidewalks or lawns.

In this scenario, the vehicle is not physically damaged and remains fully functional. The situation is limited to cases where the robotaxi becomes stuck due to non-critical issues such as decision making hesitation caused by uncertainty in recognizing the operational design domain (ODD), delays in remote assistance response, or temporary network or power failures. This means the vehicle is in a suitable condition for safe, low-speed manual maneuvering by first responders.

4.3 Limitations

4.3.1 Other Incidents Involving Robotaxis

There is a wide range of accidents involving robotaxis, but this project does not aim to address all of them. For example, cases where an AV stops due to motor failure or other critical malfunctions that prevent manual control are beyond the scope. Similarly, incidents that occur while the robotaxi is in motion, such as collisions or driving into wet concrete, are also excluded.

4.3.2 Mechanism

The exact mechanism of the final solution will not be developed in detail within this report. However, similar mechanisms that exist elsewhere on the market will be presented to demonstrate that the proposed concept is theoretically feasible.

4.3.3 Components

As requested by the thesis provider, the steering device will not consider functions unrelated to the direct movement of the vehicle. Features such as the horn, turn signals, or airbags are excluded. The final solution will focus solely on essential driving controls, including acceleration, braking, parking, and steering, functions that directly affect the stopping or movement of the vehicle.

4.3.4 Passenger

Passengers were excluded from the user group, as they do not hold the same legal rights as emergency responders in critical situations. If a passenger were to gain control of the vehicle and an incident occurred—such as vehicle theft or a collision—it would raise complex questions regarding accountability. Determining whether responsibility lies with the passenger, the autonomousn system, or a remote operator who authorized the control would be beyond the scope of this project.

4.4 Ethical Consideration

As the Robotaxi emergency steering device project moves forward, several ethical concerns must be carefully considered to ensure safety, security, and public trust while preventing unintended risks for emergency responders, passengers, and regulators.

The issue of vehicle control in emergencies is a key ethical concern. Ensuring that only authorized emergency responders can take control of the vehicle is crucial to prevent misuse or abuse. If the authentication mechanism is not strict enough, there is a risk that unauthorized individuals or even malicious actors could gain access. As a result, passengers may worry that their trip could be unnecessarily interrupted, raising concerns about privacy and security. From a broader perspective, this could undermine public trust and hinder social acceptance of robotaxis.

To address this, it is crucial to implement a secure identity verification process to ensure that only officially authorized emergency personnel can take over the vehicle.

4.5 GDPR

This study is part of a master's thesis conducted at Autoliv Sverige AB in collaboration with students from Chalmers University. Participation is voluntary, and by taking part in the study, participants agree that their input and any collected data may be published in research contexts such as scientific journals or conferences and may become the property of Autoliv Sverige AB, provided that all data is pseudonymized.

Participants in this study have several rights regarding their personal data, protected under the General Data Protection Regulation (GDPR), with Autoliv AB acting as the data controller responsible for handling all personal data in accordance with this regulation. Participation is entirely voluntary, and the participant may withdraw consent at any time without giving a reason. Participants also have the right to access their personal data, request corrections if the data is inaccurate, or have it deleted.

Participants have the right to be informed about how their data is collected and used, both during and after the study. They may also object to the processing of their data or request that its use be limited to specific purposes. In certain cases, participants can request that their data be transferred to themselves or to another organization in a readable format.

If a participant has questions or concerns about how their data is handled, they are encouraged to contact the data controller at Autoliv AB. In addition, participants have the right to file a complaint with the Swedish Authority for Privacy Protection

(IMY) if they believe their data has not been processed properly.

5

PROCESS and METHOD

This chapter provides an objective overview of the academic processes and methods used for the design research and development in the project, without explaining their practical application.

5.1 Double Diamond

The Double Diamond Model (see Figure 5.1) was chosen for this thesis topic since it is a distant and highly exploratory subject with few existing reference products. This aligns well with the Double Diamond framework, which is particularly useful in uncertain and exploratory design challenges and is guided by human-centered design principles.

The first diamond focuses on "Designing the Right Thing." In this phase, the goal is to identify user pain points, market needs, and future trends through extensive research. By diverging to explore possibilities and then converging to define key focus areas, the design direction is ensured to have strong potential and relevance. The second diamond focuses on "Designing Things Right," where the selected concept is refined through brainstorming, iterative prototyping, user evaluations, and refinements. This structured process helps transform an initially unknown and uncertain vision of the next-generation steering device into a well-defined and validated design proposal. (Design Council, 2019)

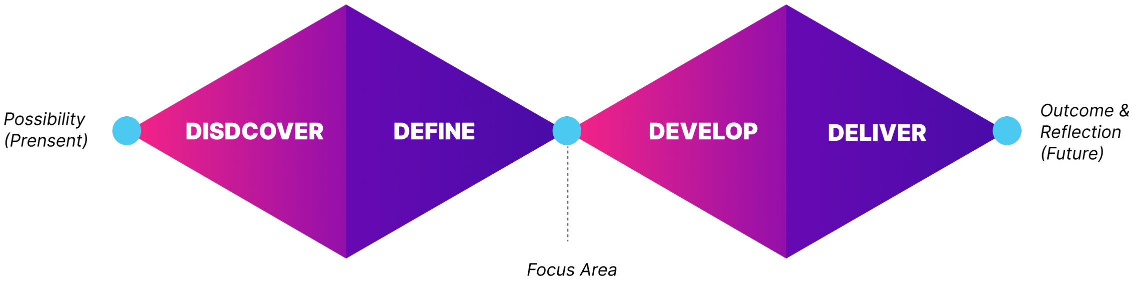


Figure 5.1: Double Diamond

5.2 Gantt Chart

A Gantt chart is used to describe a project and visualize its activities throughout its duration. The various tasks are displayed in a horizontal bar chart and aligned with the project timeline. A Gantt chart provides a clear overview of the different activities, including their start and end times, their durations, any overlaps between tasks, and the overall start and end of the project (Gantt, n.d.).

5.3 Data Gathering Method

5.3.1 Literature Review

A literature review is carried out to collect essential information and background knowledge relevant to a project. This literature may consist of previous project documentation, news as well as academic publications (Bligård, 2015).

5.3.2 Interview

Interviews are a common method for collecting qualitative data from an individual user or a user group. The data and information gathered during an interview are subjective and based on the interviewee's perspective. The main purpose of an interview is to gain a deeper understanding of the user's reasoning and thoughts. There are different types of interview formats. A structured interview involves predetermined questions, giving the user limited freedom to influence the direction of the conversation. In contrast, an unstructured interview allows for an open discussion with the interviewee about a specific topic, providing greater flexibility to explore new insights. In addition to being structured or unstructured, interviews can also be semi-structured. This format is based on predefined questions but allows for a more flexible discussion, giving the interviewee room to deviate from the structure in their responses (Bligård, 2015).

5.3.3 Questionnaire

A questionnaire can be described as a form of structured interview that is suitable when quantitative data is desired, particularly when collecting information from a large number of respondents. Unlike an interview, there is no direct contact between the person administering the questionnaire and the respondent. The questions are answered in writing rather than orally (Bligård, 2015).

5.4 Analysis Method

5.4.1 KJ-Analysis

The KJ analysis, also known as the affinity diagram method, is a qualitative analysis technique used to synthesize large volumes of fragmented data—such as quotes, observations, or insights from user interviews—into meaningful clusters. Each piece of raw data is first written on an individual note, with only one idea or quote per note. Analysts then collaboratively group these notes based on thematic similarity, without applying any predefined categories. Through repeated comparison and discussion, underlying patterns or user needs begin to emerge from the raw data. In this project, the method was used to organize interview excerpts related to first responders' experiences with robotaxis, helping to identify key pain points, behavioral patterns, and unmet needs. (Bligård, 2015).

5.4.2 Requirement List

A requirement list is a method used to systematically collect and organize the demands placed on a product across different design levels. Requirements are formulated progressively, beginning at higher abstraction levels such as Effect and Usage and advancing toward more detailed technical specifications at the Architecture, Interaction, and Element levels (Bligård et al., 2016).

In this project, the requirement list addressed the manual control of stalled robotaxis during emergencies. User needs, particularly from firefighters, emphasized rapid activation, intuitive operation under stress, secure authorization, and operational safety. Additional requirements from stakeholders, such as robotaxi companies, focused on minimizing maintenance costs. The list included technical requirements for machine architecture, interaction interfaces such as the HUD, and subsystem elements like button layout and tactile feedback. By linking requirements to specific design levels, the list ensures traceability and coherence, supporting a top-down design approach where the intended effect informs technical solutions.

5.4.3 User Journey

A User Journey is a visual or narrative representation that illustrates the steps and interactions a user experiences when engaging with a product or service. It maps out the user's experience over time, from the initial point of contact through to the final interaction, highlighting key actions, thoughts, emotions, and potential pain points along the way. This approach helps designers and stakeholders understand the user's perspective, identify opportunities for improvement, and create solutions that better align with real-world behavior. (Gibbons, 2018)

5.4.4 Imageboard

An image board is a collective term for a collage of images used in the design process. An imageboard is created using images, colors, and words to convey a particular feeling or theme, and it can serve as a guide and reference point throughout the project's development (Wikberg-Nilsson et al., 2015).

5.5 Ideation Method

5.5.1 The Morphological Matrix

The morphological matrix, also referred to as a morphological chart, is a problem-solving tool commonly used in engineering and design to generate and evaluate a broad range of solution alternatives. It involves breaking down a system into its essential functions and listing possible methods to fulfill each function. By combining these methods in different ways, designers can systematically explore innovative solutions. This approach supports structured creativity and informed decision-making in complex design problems (Pahl, Beitz, Feldhusen, & Grote, 2007).

5.5.2 SCAMPER

SCAMPER is a creative thinking and problem-solving technique that guides idea generation through seven structured prompts: Substitute, Combine, Adapt, Modify, Put to another use, Eliminate, and Reverse. It encourages innovation by challenging users to rethink existing products, services, or processes in new ways. Commonly used in design thinking and brainstorming sessions, SCAMPER helps individuals and teams systematically explore alternatives and enhancements to current ideas. This method enhances creativity by prompting divergent thinking and is particularly valuable in the early stages of product development or conceptual design (Eberle, 1997).

5.5.3 Braindrawing

Braindrawing is a structured creativity technique used to generate and develop design ideas collaboratively through visual means. In this method, participants individually sketch potential solutions to a problem within a limited timeframe. These sketches are then passed to others, who either build upon or modify them. This iterative visual process encourages divergent thinking and helps break cognitive fixation by allowing ideas to evolve collectively. Braindrawing is especially effective in multidisciplinary teams, as it supports idea development without relying heavily on verbal communication (Lindemann, 2010).

5.6 Idea Evaluation Method

5.6.1 Elimination Matrix

The Elimination Matrix is a qualitative screening tool used in the early stages of design to quickly eliminate alternatives that do not meet essential, predefined requirements. Each alternative is assessed using a color-coded system, where green indicates that a requirement is fulfilled, and red signifies that it is not. This visual representation supports rapid evaluation and clear communication, particularly in group decision-making settings. By filtering out non-compliant solutions at an early stage, the method ensures that only viable concepts proceed to more detailed analysis, thereby enhancing efficiency and decision transparency (Pahl et al., 2007; Ullman, 2010).

5.6.2 Pugh Matrix

The Pugh Matrix, developed by Stuart Pugh, is a relative decision-making method used to compare design alternatives against a reference solution. Rather than assigning absolute scores, each criterion is evaluated as better (+), equal (0), or worse (−) than the reference. These qualitative ratings are summed to generate a net score, allowing alternatives to be ranked systematically.

This method is particularly useful in early design stages, where quantitative data may be limited, and promotes structured group evaluation. It reduces subjectivity by emphasizing relative performance and is widely applied in engineering design (Pugh, 1991; Pahl et al., 2007; Ulrich & Eppinger, 2016).

5.6.3 Kesselring Method

The Kesselring Method is a structured qualitative evaluation tool used for comparing multiple design alternatives based on a set of predefined criteria. Each alternative is assessed on how well it fulfills each criterion using qualitative ratings (e.g., 1 to 5), where both the value (v) and weight (w) are multiplied to produce a weighted score (t). The total score across all criteria is then used to compare alternatives. Additional statistical indicators—such as the average score, standard deviation, median, and the number of weak points—help refine the decision-making. This method promotes a transparent and comparative assessment, particularly valuable in conceptual design phases. (Pahl, Beitz, Feldhusen, & Grote, 2007)

5.6.4 Storyboard

The storyboard was used as a visually communication tool to demonstrate how the final concept would be used in a real-world scenario. By illustrating key steps, user actions, and interactions, the storyboard helped validate the logic and usability of the concept and supported discussion around its practical application. (Truong, Hayes, and Abowd, 2006)

6

PROCEDURE

This chapter outlines how the selected methods were practically conducted during the project. It describes the step-by-step implementation, the context in which each method was used, and the expected outcomes from each method.

6.1 Process Overview

The Double Diamond Model was chosen for this thesis topic since it is a distant and highly exploratory subject with few existing reference products. This aligns well with the Double Diamond framework, which is particularly useful in uncertain and exploratory design challenges and is guided by human-centered design principles.

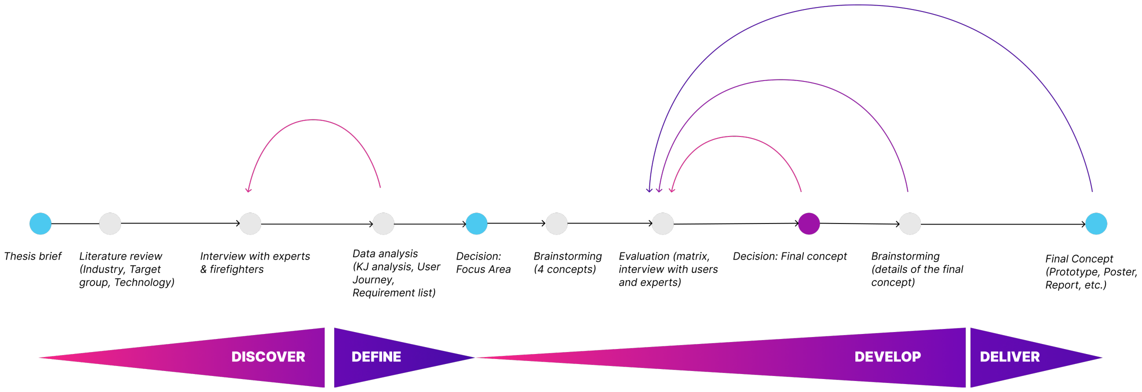


Figure 6.1: Illustration of the process overview

The process has been highly iterative throughout the entire project, meaning that different stages have been repeated, and the development process has not been linear. This is illustrated in Figure 6.1. For example, once the focus areas of Robotaxi were identified, further contextual research and stakeholder interviews were carried out to deepen the understanding of user needs and regulation constraints. Additionally, idea evaluation was conducted continuously throughout the Develop and Deliver phases, incorporating user feedback and expert insights to ensure the relevance and feasibility of the proposed solutions. The summarized version of the procedure is explained below. The blue text corresponds to the blue dots in Figure 6.1 and indicates key milestones in the process:

Phase 1: Discover

To understand the thesis context, a round of literature review and expert interviews was conducted.

FRAMING DESIGN OPPORTUNITIES: Multiple design directions were identified based on the research. **RESLUT GUIDE**

- Chapter 3 Robotaxi
- Chapter 7.1 Design Direction

Phase 2: Define

The gathered data were analyzed using methods including KJ analysis, user journey map and the creation of a requirement list. The aim is to define an actionable problem area for the thesis.

DECISION OF FOCUS AREA: First responders were selected as users, the robotaxi market as the target context, and a specific use scenario was defined.

RESLUT GUIDE

- Chapter 7.2 Problem Statement
- Chapter 7.3 User Journey

Phase 3: Develop

Brainstorming with morphological matrix and brainwriting generated numerous ideas, later refined into four concepts using SCAMPER. These concepts were evaluated using matrices and expert/user interviews to select and refine the final concept. To support user evaluation of the concept, both multiple foam prototypes and a digital prototype for HUD were developed.

DECISION OF FINAL CONCEPT: HALOGRIP was selected as the final concept.

RESLUT GUIDE

- Chapter 8 Concept Development
- Chapter 9 Final Concept Refinement

Phase 4: Deliver

The refined version was created in CAD and 3D printed. High-quality renderings were also produced to visually present the final concept.

RESLUT GUIDE

- Chapter 10 Final Concept: HALOGRIP

6.2 Phase 1: Discover Phase

The project began with a discovery phase. As part of the preparatory work, a Gantt schedule was created to provide an overview of the project planning (see appendix 1). The goal of this phase was to develop a comprehensive understanding of the automotive industry, the potential target group, and their specific needs. A large amount of data was collected through interviews and literature reviews, conducted in multiple rounds as the level of detail increased and the design space gradually narrowed. The insights gathered during this phase formed the basis for defining a higher-level, more abstract set of design requirements.

6.2.1 Literature Review

The initial round of literature review focuses on researching which SAE levels was conducted to analyze which level — L2, L3, or L4— would have the most potential as a target for the steering device concept, based on the expected development of autonomous vehicles by 2035, as defined by the thesis provider.

Second round of literature review, focus on investigating trends in robotaxi development by 2035, including the impact of evolving policies, regulations, and emerging technologies on market share. Analyze past robotaxi accidents, identify potential causes, and examine how companies respond when robotaxis obstruct emergency responders, such as firefighters. The goal is to pinpoint unresolved issues and explore potential solutions through onboard steering devices.

6.2.2 In-depth Interview with Experts

This project was carried out in collaboration with five experts working in the automotive industry. All interviews were semi-structured, tailored to each expert's academic background. They were conducted online and lasted between 30 minutes and one hour. Interview questions for each section were tailored based on that expert´s field. Detailed information about how the experts were selected to participate in this project can be found in appendix 2.

Overall, interviews with experts provided essential insights and up-to-date information on industry trends, which were crucial in guiding the project's design direction. Besides that, each of the experts also provided domain-specific insight.

- Powertrain experts

Interviews with two experts working in powertrain provided a fundamental, high-level understanding of the car industry, how the development of powertrain might affect the development of automotive level, and the broader context of robotaxis.

- Autonomous vehicle expert

An interview with an expert working in the autonomous vehicle field was conducted to evaluate our initial concept for an emergency steering device, as well as to understand what other fallback solution, in case of a robotaxi emergency situation has already been explored in academic research. Additionally, insights gathered from other expert interviews and the literature review were presented during the interview with this expert to help us confirm that our conclusions regarding automotive industry trends were accurate.

- Human factor expert

Moreover, an interview with a human factor expert provided valuable insights into important cognitive ergonomics considerations when designing for use in Level 4 autonomous vehicles.

- A formal employee in a robotaxi company

An interview was conducted with a former employee of a Chinese robotaxi company. This expert shared operational insights related to remote assistance strategies and the management of emergency interventions, which were later used to benchmark aspects of our proposed solution.

6.2.3 In-depth Interview with Users

Four semi-structured in-depth interviews with firefighters were conducted in connection with on-site observations of firetrucks at two different fire stations in Gothenburg. Two interviews were conducted individually with each participant, while another session involved two participants being interviewed together. All the interviews took around 1 hour. All interviews were recorded with the interviewees' consent. Detailed information about how users were selected to participate in this project can be found in appendix 2.

The purpose of these interviews was to gain insight into firefighter work routines and to explore the current strategies and tools used in incidents involving Robotaxis. Since none of the participants had direct experience with Robotaxi-related situations, scenario-based interviews were developed around key pain points to help them engage with realistic situations. (see appendix 3 for specific questions and scenarios) As the participants described how they would respond, particular attention was given to the time, effort, and limitations of their current methods. Furthermore, two processes were presented to the firefighters for evaluation: one based on Waymo's manual steering approach, and the other a redesigned version developed by us. To avoid bias, the origin of each process was not disclosed, and the participants were asked to provide feedback regarding their preferences.

6.2.4 Questionnaire Survey

The questionnaire aimed to investigate public attitudes toward robotaxis and assess whether the presence of an onboard steering device is perceived as a valuable feature that could increase users' willingness to adopt the service. The questionnaire was made available in both Chinese and English. The Chinese version was distributed via links shared in various WeChat groups in China and received 62 responses. The English version was shared on Facebook and gathered 14 responses.

6.3 Phase 2: Definition Phase

The definition phase focused on identifying actionable pain points from the gathered insights. Its purpose was to clarify the user group's key needs and form a solid foundation for idea generation and concept development.

6.3.1 Initial Aim and Early Research Questions

To structure the early stages of the design process, a preliminary aim, a set of research questions, and goals were formulated.

- Initial Aim

The project initially aimed to explore how robotaxis can be designed to better support emergency responders in time-critical situations. The focus was on developing a manual control concept that enables quick and intuitive vehicle management when human intervention is required.

- Early Research Questions

These early research questions were used to guide the initial exploration:

1. What functions should be included in the steering system of a robotaxi to meet the needs of first responders?
2. How can the proposed steering device improve safety for emergency responders, passengers, and other road users during interventions?

- Initial goal

The following goals were set to support the early research phase:

1. Perform a trend analysis to anticipate future developments in the robotaxi market.
2. Conduct interviews with emergency responders' needs regarding their interaction with robotaxis.
3. Establish requirements and design guidelines with hierarchy.
4. Develop multiple low-fidelity models and a high-fidelity prototype to iteratively test and refine the steering device.
5. Evaluating the product based on user feedback and design evaluations methods.

These goals and questions served as a framework for the early project stages, and were later refined and adapted in response to findings from user research and iterative prototyping.

6.3.2 User Journey

The entire process of a firefighter driving the autonomous vehicle (AV) away is envisioned. This includes using a tag to unlock the car door, activating the steering device, manually driving the vehicle, and then resetting the autonomous mode. Throughout these steps, changes in the firefighter's emotions are identified, leading to the discovery of key insights.

6.3.3 KJ-Analysis

Given that interviews played a crucial role in the previous phase, KJ analysis was applied to efficiently categorize relevant quotes into distinct pain points.

The interview material with users was transcribed, and interesting quotes were picked out. Quotes from individual interviews were marked with two unique colors each, while quotes from the joint interview shared the same color. This was done to enable easy traceability in case of any confusion. These quotes were then sorted into nine categories of problem areas. Examples of these problem areas are “Demand of standardization” and “Insufficient strategies for moving stalled cars”. See Figure 6.2 for an overview of the KJ analysis and see appendix 4 or the detailed version. To make them easier to work with, each category was summarized into specific user needs, and conclusions were drawn based on the content of the quotes. While the conclusions help in gaining a deeper understanding of the user group, the identified user needs contribute to determining which features should be included in the Morphological Matrix and form the foundation for the requirements list.

Insuffient strategies - moving stalled cars (fire fighter)

"It's not that easy to move a car like it is to move a flower pot ...I see it's pretty difficult."

using vinsch to connect with the robotaxi and drag away

Problem of using vinsch is needing a large space to move

Our ordinary fire truck face this case can use vinsch, but ladder one doesn't have this tool

"I'm thinking about just pushing it away with a heavy truck."

" if you really use, need to use that fire hydrant, we can just push the car away."

Insuffient strategies - moving stalled cars (fire fighter)

Conclusion

- there are insuffient strategies and tools for moving stalked robotaxi
  - vinsch need too much time and space
  - push need space
  - ask other firetruck to go another way - waste labor

time concern - moving stalled cars (robotaxi company)

"five to 10 minutes is a long time. Yeah, it's too long."

time concern - moving stalled cars (robotaxi company)

Conclusion
- 5 -10 min of driving away robotaxi is too slow
- ideally within 3min

Needs
- should be within 3 min

Concern for passenger in car

If there's a passenger sitting behind and you breaking the window, they may get scared.

I think it depends on if I can move it away and in a safe manner 10 meters, and then it's no problem for the person to sit there.

Concern for passenger in car

conclusion
- in case of too close to the fire scene, let the passanger out
- if just driving a few meter away, and it is safe passenger could just stay

Demand for standlization

"giving the fact that you know, it's not going to be one company, it's going to be large different companies, unless there's a standard,"

if each company will have a slight difference of how to deal with things

Nothing unfamiliar for us. We do it sometimes with cars that are not our own cars

if every company would have 30 pages for us, then we wouldn't be doing anything else than reading

Then maybe we can have a key or something in our firetruck, and then use it as a regular vehicle

" get authorization to drive it ourselves. That would take a long time."

Demand for standlization

Conclusion
- Firefighters have concern of having different kind of steering device and they are used in different way. Increase the risk of error and wasting of time.
- Inplicitly, want law to standralisted the way to work with activation of steering device

Need
- Should align with their mental model, should follow the usual driving behavior pattern

Who will be the one driving the robotaxi

"Those in the back have too much equipment. So the driver will probably be the one who drive it."

five firefighters in a firetruck, one for driving

Who will be the one driving the robotaxi

Need
- should not require overly precis movment to allow fire fighter with more equipment to use the steering device.

Remote operator

It's gonna be a little bit of take on time to be able to contact the remote driver

Local operator

Overall concern about Robotaxi

"Do I even have a possibility to break"

"to steal the car, could you do that the same way? "

Overall concern about Robotaxi

Conclusion
-

Needs
- Want to have possible to stop the driving vehical

Demand - sense of control

Breaking window to unlock the door is quite easy thing for us to do if needed.

"I think I prefer it just to freeze. Just stand still. "

Senario 2: I would like to drive away but depends on situation

"I like the one that will smash the window and open it all."

Its' staying could interfere more with our work

I would not like they to drive away when I'm not aware of it.

Demand - sense of control

Conclusion
- smash the windows to freeze the robotaxi it good
- Some of them want to get direct authorization without going though remote driver
- Some of them want to get assitance from remote assitant to avoid error.
- Concern of unfaimlar technique/rutine
- Local assitance have it limitation of effecietly scenario

Needs
- needs of controll when to freeze
- needs of unlock the car and move
- Direct local authorization
- Provide design clues and instructor (ex. get authorization)
- Get direct contact with help/assitance from robotaxi company.

Figure 6.2: Showcases an overview of the KJ analysis

6.3.4 Requirement List

A comprehensive requirements list was created, initially structured around five design levels: effect, usage, architecture, interaction and element. However, the element level was excluded, as it pertains more to production-level requirements and was deemed too difficult to define at this stage, given that the final concept still requires significant future work to resolve technical details. Requirements and guidelines were listed separately. During the discovery phase, the effect and usage levels were defined based on the results from the KJ analysis and the literature review. As the design process progressed, the remaining levels were gradually completed. The detailed reasoning behind each specific guideline and requirement—including their cause-and-effect relationships, supporting sources, and how the final solution addresses them—is documented in the requirement list. The final requirement list could be found in appendix 5.

6.4 Phase 3: Development Phase

The development phase focuses on ideation and concept generation. The brainstorming process was highly iterative, each iteration consisted of two phases: the first focused on generating a large number of bold and unconventional ideas, and the second on refining and narrowing them down to a few concepts and ideas.

6.4.1 Ideation Method

- Morphological Matrix

Based on findings from prior phases, seven sub-functions (e.g., stopping function form, type of steering device, method of assistance in error scenarios) were identified. Multiple options for each sub-function were brainstormed. These options were randomly combined to create six initial design alternatives. Each team member of generated design ideas independently according to each of these design alternatives, resulting in 12 unique concepts.

- SCAMPER and Braindrawing

This method was applied to the 12 initial concepts to stimulate further innovation through SCAMPER prompts. The discussion resulted in four refined design alternatives. Subsequently, a round of braindrawing was conducted—allocating two minutes per rotation—focused on each of the refined alternatives. A second round of SCAMPER followed, leading to the development of five concepts.

6.4.2 Theoretical Evaluation

- Elimination matrix

All five concepts were evaluated against the Use level requirements in the requirement list. This helped eliminate weaker concepts before in-depth evaluation.

- Pugh and Kesselring matrices

Four concepts were brought forward to this stage and evaluated using the Pugh and Kesselring matrices. Both the design guidelines and the requirements from Use level were used as evaluation criteria to assess how well each concept fulfilled them in comparison to the others.

6.4.3 Stakeholders Evaluation Sessions

Three user and one expert evaluation were conducted across development phase of the project. In addition, a design evaluation was carried out with AUTOLIV, focusing on the product's appearance, manufacturability, and estimated production costs.

- Evaluation Round 1 – Concept Comparison

The first evaluation interviews were conducted online with a firefighter and a powertrain expert, both being around 45 min to 1h. This session primarily focused on evaluating the four concepts that had advanced beyond the elimination matrix. All concepts were presented with equal detail to minimize bias.

- Evaluation Round 2 – Ergonomic Feedback

The second evaluation was conducted at an ambulance center in Lundby, Gothenburg, Sweden with one ambulance personnel. The interview lasted approximately 40 minutes. Two foam sheet models were produced to test specific details of the final concept, including the grip design of the steering wheel, the ergonomic pivot points of the steering mechanism when accelerating or braking, and the placement of the buttons. One new foam sheet was developed based on the feedback.

Additionally, the interview provided valuable insights into the role of the ambulance crew during emergencies and helped identify whether any of their needs potentially conflict with those of the firefighters.

- Evaluation Round 3 – System Interaction and HUD Evaluation

The final user evaluation took place at the Gårda Fire Station in Gothenburg, Sweden, and lasted approximately 45 minutes and the whole process had been recorded. One fireman participated in the session. A new foam sheet model was brought in for evaluation. Additionally, a digital prototype of the HUD (Heads-Up Display) was created in Figma, with the goal of illustrating the user journey from a first-person perspective as the user engages with the system.

At the beginning of the session, the user was introduced to the scenario (see appendix 6) and informed about the background knowledge they might possess, assuming some prior training had been provided. The participant was then guided through the full usage process using Figma slides and animations (see Figure 6.3)

The process overview:

1. Identity verification
2. Activation of the steering device
3. Driving and maneuvering
4. Parking
5. Switching back to autonomous mode

Participants were encouraged to think out loud, and additional probing questions were asked throughout the process.

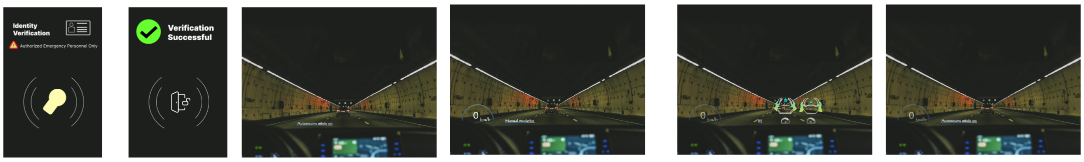


Figure 6.3: Overview of the HUD prototype

- Evaluation Round 4 – Stakeholder and manufacturing

Feedback from the company highlighted the importance of manufacturing cost efficiency, leading to modifications in the shape of the steering device.

6.5 Phase 4: Delivery Phase

6.5.1 Concept Sketching

Based on previous evaluations, the most promising concept was selected for further development. Paper sketching and digital drawing were used to explore the possibilities of the product's form.

6.5.2 Modeling

During this phase, Rhino was used to create multiple models in order to explore different forms, sizes, and combinations of each part. Several rounds of iteration were carried out to refine the design and meet grip ergonomics. After the final form of the steering device was determined, the entire model was reconstructed to ensure high surface quality.

6.5.3 Rendering

Once the final digital 3D model was completed, KeyShot was used to produce high-quality renderings of the steering device. These visualizations not only highlighted the product from multiple angles to showcase its overall form and details, but also simulated various usage scenarios to illustrate how the device would be interacted with in a real-world context. This helped communicate both the aesthetic and functional aspects of the design to stakeholders.

6.5.4 3D Printed Prototype

The CAD model was sent to Autoliv and 3D printed into a high-quality prototype. Afterward, the dimensions were adjusted, and a second version was printed for testing and comparison in terms of ergonomic comfort.

7

DESIGN FOUNDATION

This chapter explains how the design direction for the onboard steering device was determined and presents problem statements based on findings from the KJ analysis and questionnaire results. It also includes a user journey illustrating how the proposed solution would be experienced in practice.

7.1 Design Direction

This section presents the reasoning behind that decision of the design direction of emergency use steering device.

As part of the Discovery phase, a literature review was conducted, resulting in:

- An in-depth analysis of robotaxis
- The identification of two main feasible design directions within the robotaxi context

The detailed analysis of robotaxis, including the rationale for focusing on Level 4 (L4) vehicles and choosing robotaxis as the thesis scope, is presented in Chapter 3: Robotaxi. That chapter also introduces one of the core motivations for exploring onboard steering devices. For instance, SFFD Deputy Chief of Operations Darius Luttropp, in an interview with journalist Timothy B. Lee, emphasized the importance of enabling first responders to manually take control of stalled AVs (Lee, 2024). The literature review revealed two potential design paths:

- Designing a steering device for remote assistants working with robotaxi companies or remote driving service providers
- Incorporating an onboard steering device for emergency use

The second direction—onboard emergency steering—was ultimately selected. The other direction was not selected, based on insights from an interview with a former robotaxi employee. He described a significant shift in remote assistance practices. While there used to be one assistant per three robotaxis, the current ratio has increased to one per fifty, and that trend is expected to continue. Given these factors, it is likely that by 2035, the demand for manual remote steering devices will be too limited to justify further development in this direction.

Moreover, limited public information about remote assistants in robotaxi companies, combined with the project's restricted access to these actors, made it difficult to understand their potential needs for steering devices. This lack of access also prevented user studies, limiting insight into that design direction.

7.2 Problem Statement

This section presents the results from the KJ analysis, supported by questionnaire data on public attitudes toward robotaxis, framed as problem statements. It also discusses how the concept development will address the challenges identified. The requirement list has been placed in the appendix (see appendix 5) despite being considered one of the most important outcomes, as it is too lengthy and would be difficult for the reader to follow within the main text.

7.2.1 Overall Concern about Robotaxi in Emergency Situation

Both first responders and public participants expressed uncertainty about how to interact with robotaxis during emergencies, especially when traditional controls like a steering wheel are removed. Several interviewees pointed out that in high-stress situations, the absence of familiar interfaces may delay appropriate actions.

Similar concerns were reflected in the public questionnaire (see appendix 6). While some participants appreciated the futuristic and spacious qualities of steering wheel-free interiors, the lack of clear means for manual intervention was perceived as a safety risk and could potentially reduce their trust and willingness to ride a robotaxi.

Fostering trust among both users and the public became a central design goal. Making the steering device visible helps establish a clear fallback option, signaling that the vehicle can still be controlled manually if needed.

To further reduce uncertainty, clear and intuitive iconography was prioritized. Where icons might not suffice, short explanatory texts are added to support user understanding, even if this might compromise visual minimalism.

"I'm a little bit frightened for those, because I don't know how they will react."

"I'm not afraid of the fire hose. It's the firefighters, they could be hidden by the robot."

- quote from test participant

7.2.2 Insufficient Strategies

A key finding from the user study is that there is currently no effective strategy for handling situations where a robotaxi becomes stuck and blocks emergency operations. This creates safety risks and hinders firefighters' ability to meet critical response times. While robotaxi company strategies were outlined in chapter 3.3, this section examines both those and firefighters' standard procedures to show why neither is sufficient for managing such scenarios.

- Strategies Provided by Robotaxi Companies

One proposed approach is Waymo's manual override procedure, where first responders must press a button to contact a remote assistant and request authorization before local manual control is enabled. While one firefighter appreciated the potential for reduced errors through guided intervention, most expressed concern about the lack of direct local control. They highlighted that if the remote assistant is unavailable, for example, due to network failure, the users would be unable to act—leaving them inside a vehicle they cannot move or shut down. In addition, even if users can establish contact, some have expressed concerns about potential communication issues. For instance, one speculated that in a chaotic emergency environment, it might be difficult to hear both sides clearly, which could complicate the authorization process and cause delay.

Another strategy involved deploying assistants to the scene to manually drive the vehicle away. However, firefighters questioned the feasibility of this approach due to heavy traffic and the fact that assistance vehicles are not equipped with sirens, making it unlikely that they would be able to reach the scene in time. Even if assistance arrives within the stated 5–10 minutes, it is still perceived as excessively long and directly conflicts with the firefighters' commitment to reach every citizen within 10 minutes.

Therefore, a key design requirement emerging from this insight is that first responders must be able to gain control of the vehicle without needing to communicate with the robotaxi company. The transfer of control from the autonomous system to the responder should occur locally and directly. Additionally, the first responder must hold the highest level of authority when manually operating the emergency steering device. Even if the robotaxi attempts to intervene, it should not override the responder's control within the system hierarchy. This is crucial because any delay caused by conflicting commands between the responder and the autonomous system could cost lives.

"We have a commitment to get in the vehicle in 90 seconds. And then we have a commitment for to reach every citizen 10 minutes"

- quote from test participant

- Strategy from the Firefighter Side

Firefighters typically use two strategies to move a stalled vehicle: either by using a winch or by pushing it with a fire truck. The most common method is pushing with the fire truck. However, this technique only allows movement directly to forward or slightly to the side. If the intention is to push the vehicle at a specific angle, it becomes difficult to do so precisely—especially in environments with surrounding vehicles or obstacles.

Moreover, using a winch is time-consuming and requires a specific setup, including a stable anchor point—such as a tree or pole—to secure the cable. It also demands a relatively large operating space. Because of these constraints, winches are more commonly used in rural or off-road situations, such as when a vehicle has fallen into water. This makes the method less suitable for urban environments where robotaxis are likely to operate, due to limited space and the lack of reliable anchor points.

The main takeaway from the problem statement regarding pushing with a fire truck is that the steering device must allow for precise control over the movement angle and enable movement in both forward and backward directions. In the case of using a winch, the steering device should also function effectively in narrow spaces and require no specific setup. Since both methods typically involve a maximum of two personnel—one to set up and one to operate the winch—the ideal solution should aim to reduce this to a single operator for increased efficiency.

"Problem of using winch is needing a large space to move"

"It's not that easy to move a car like it is to move a flowerpot ...it's pretty difficult."

- quote from test participant

7.2.3 Standardization

All first responder interviewees expressed concern about the lack of standardization in emergency steering devices—particularly regarding their location and operation. One interviewee compared this to the challenges with electric vehicles, where high-voltage components are placed differently across brands. In the case of robotaxis, similar inconsistencies in how to activate and control manual steering could force responders to learn multiple, brand-specific procedures. This increases cognitive load and the risk of errors during high-stress situations.

To address this issue, the design direction focuses on analog solutions that feel familiar to users, aiming to reduce reliance on digital interfaces during high-stress situations. Analog controls are generally easier to learn because they build on users' prior physical experiences—such as turning, pulling, or pushing—and offer immediate, tangible feedback through sound, movement, or resistance. In contrast, digital interfaces often rely on abstract symbols, nested menus, and touchscreen interactions that may vary between systems and require users to interpret visual cues. This can increase cognitive load and slow down response time, particularly in emergency contexts where users may be under pressure and unable to recall or process complex interface logic.

Although standardizing such solutions across different vehicle brands is beyond the scope of this project—since it depends on future regulations—the lack of standardization can be partially compensated for by ensuring that the interface design is universally intuitive and easy to understand. By leveraging users' existing knowledge and minimizing cognitive demands, the solution supports safe and effective action even in unpredictable or chaotic environments.

"if every company would have 30 pages for us, then we wouldn't be doing anything else than reading"

- quote from test participant

7.2.4 Control Over Vehicle Behavior During Ground Operations

A lack of sense of control was one of the major concerns expressed by the first responder interviewees. In the second scenario presented during the interview (see appendix 3), participants were asked whether they would prefer the robotaxi to remain stationary where it became stuck, or to move away as quickly as possible while they were working on the ground. The responses varied significantly, likely due to the participants' different roles. Floor-level firefighters preferred that the robotaxi move away from the scene as quickly as possible, while commanding officers (chief firefighters) favored the vehicle remaining stationary so it could be handled later.

Despite these differing preferences, a common theme emerged—all interviewees emphasized the importance of having some degree of control over the robotaxi's movements during an emergency. This insight led to the identification of a key requirement: the inclusion of a freeze or emergency parking function, allowing first responders to immediately immobilize the vehicle when necessary. At the same time, the system should also support the option for the vehicle to autonomously drive away from the scene.

"I would not like them to drive away when I'm not aware of it."

- quote from test participant

7.3 User Journey

To assess the usability of the fallback steering system, a user journey (see Figure 7.1) was mapped, emphasizing not just functional steps but also the emotional landscape of the user. The journey captures five key stages of interaction, from ID verification to reactivation of autonomous mode, with first responders or trained personnel as the primary users. By analyzing the emotional flow, we identify pain points and reveal how thoughtful design elements address user stress, hesitation, and confidence throughout the process.

1. **ID Certification**

   Emotion: Urgent

   Users begin the journey under pressure, often in time-critical situations. The emotion is characterized by urgency and heightened alertness.

   Design implication:

   To alleviate stress, the ID system must be fast, familiar, and error-tolerant. Swiping a simple tag at the B-pillar ensures quick access. The interface confirms success immediately, reinforcing a sense of control.

2. **Pull Out Steering Wheel**

   Emotion: Unfamiliar → Curious

   Upon entering, users are expected to manually pull out the embedded steering wheel—a gesture not commonly associated with vehicle controls. This moment creates hesitation and friction in an already tense context.

   Design implication:

   Using the tag to trigger the steering device to automatically come out from the dashboard, reducing uncertainty and guiding the next step seamlessly.

3. **Before Driving**

   Emotion: Curious → Learning

   Users activate manual mode and encounter HUD instructions and steering stickers. They shift from curiosity to a focused, instructional mindset. Although the process is short, users momentarily pause to decode speed control interactions.

   Design implication:

   To support this “learning mode,” HUD feedback uses iconography rather than text, and physical stickers act as persistent, low-effort reminders. This ensures that users can proceed without requiring prior training, while still feeling supported in their decision-making.

4. **During Driving**

   Emotion: Confident & Focused

   At this point, users are fully engaged in maneuvering the vehicle. With prior steps having established control logic and reassurance, the emotional state transitions to confidence and task-oriented focus.

   Design implication:

   HUD content is simplified to essential driving indicators only, allowing users to concentrate on their surroundings and road conditions. The physical design of the wheel also supports natural hand positioning and proprioception, helping users drive intuitively without over-relying on display cues.

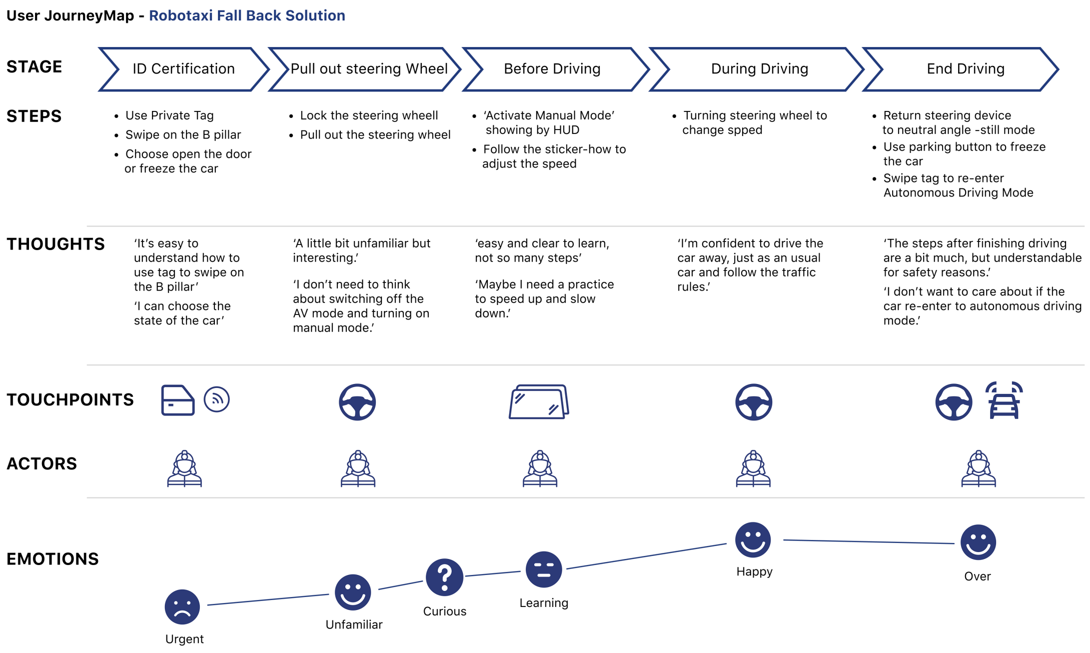
5. **End Driving**

   Emotion: Confident → Closure

   Users complete the task by returning the wheel to neutral, pressing the parking button, and reactivating autonomous mode via tag swipe. Although it involves several steps, users understand these actions serve as a safeguard.

   Design implication:

   To close the loop, the system guides users through clear, progressive feedback (visual and tactile). Final confirmation tones and HUD messages signal successful disengagement, helping users mentally and emotionally transition out of the task.



STAGE	ID Certification	Pull out steering Wheel	Before Driving	During Driving	End Driving
STEPS	• Use Private Tag • Swipe on the B pillar • Choose open the door or freeze the car	• Lock the steering wheell • Pull out the steering wheel	• 'Activate Manual Mode' showing by HUD • Follow the sticker-how to adjust the speed	• Turning steering wheel to change spped	• Return steering device to neutral angle -still mode • Use parking button to freeze the car • Swipe tag to re-enter Autonomous Driving Mode
THOUGHTS	'It's easy to understand how to use tag to swipe on the B pillar' 'I can choose the state of the car'	'A little bit unfamiliar but interesting.' 'I don't need to think about switching off the AV mode and turning on manual mode.'	'easy and clear to learn, not so many steps' 'Maybe I need a practice to speed up and slow down.'	'I'm confident to drive the car away, just as an usual car and follow the traffic rules.'	'The steps after finishing driving are a bit much, but understandable for safety reasons.' 'I don't want to care about if the car re-enter to autonomous driving mode.'

Figure 7.1: User Journey Map

8

CONCEPT DEVELOPMENT

This chapter presents the various design alternatives explored throughout the process, along with the proposed concept suggestions.

8.1 Design Alternative

After one round of morphological matrix 6 initial design alternatives were formed. (See Figure 8.1 and Figure 8.2) for an overview of the initial layout of the morphological matrix and the 6 initial design alternatives. Based on that a round of brainstorming and SCAMPER was conducted, and four refined design alternatives were developed:

- **Screen and Pedal:** This concept uses a foot pedal to control speed, while steering is managed via a screen with a mechanism directly attached to it.

- **Traditional steering wheel with pull-out mechanism:** A more analog solution that involves a conventional steering wheel which can be pulled out when needed

- **Removable modular steering wheel:** This design consists of separate steering components that remain hidden when not in use and can be assembled when needed

- **Decision-making-based steering device:** This concept temporarily downgrades the vehicle's autonomy from Level 4 to Level 2 or 3. The user supports decision-making and maintains situational awareness, while the vehicle executes tasks such as navigating to a selected destination automatically.

After another round of brainstorming and SCAMPER under each of those 4 refined design alternatives, multiple concepts were developed.

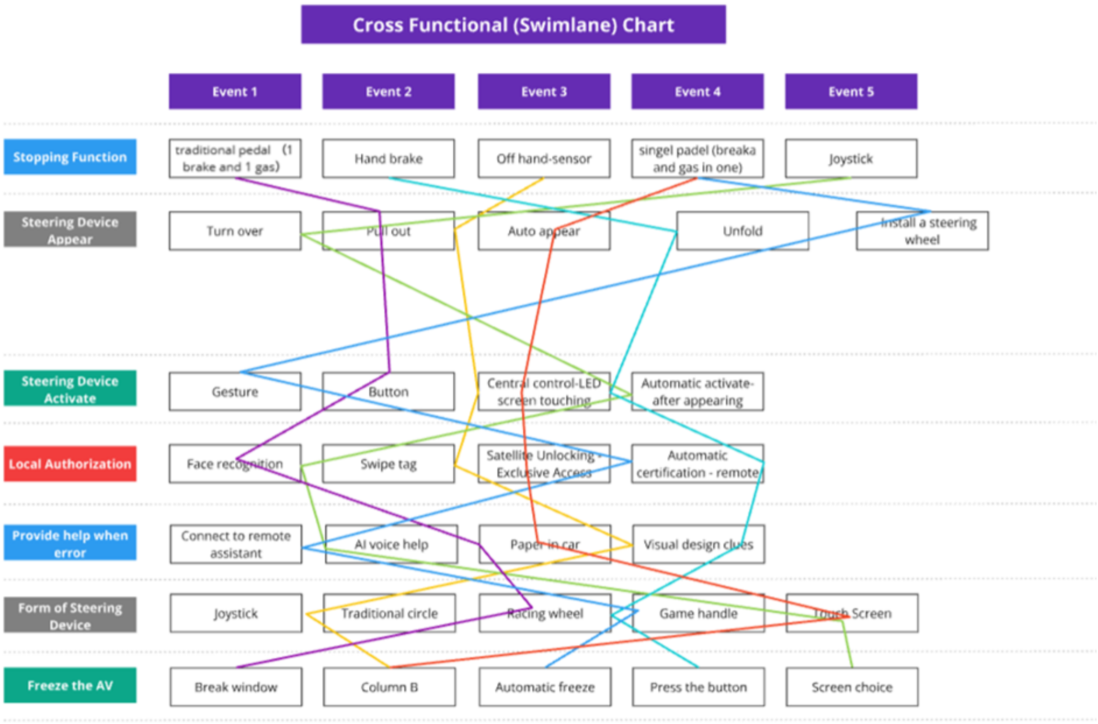


Figure 8.1: layout of the initial round of morphological matrix

1	traditional pedal (1 brake and 1 gas)	Pull out	Button	Face recognition	Paper in car	Racing wheel	Break window
2	Off hand-sensor	Pull out	Central control-LED screen touching	Swipe tag	Visual design clues	Joystick	Column B
3	singel padel (breaka and gas in one)	Auto appear	Central control-LED screen touching	Satellite Unlocking - Exclusive Access	Paper in car	Touch Screen	Column B
4	singel padel (breaka and gas in one)	Install a steering wheel	Gesture	Automatic certification - remote	Connect to remote assistant	Game handle	Automatic freeze
5	Hand brake	Unfold	Central control-LED screen touching	Automatic certification - remote	Visual design clues	Racing wheel	Press the button
6	Joystick	Turn over	Automatic activate-after appearing	Face recognition	AI voice help	Touch Screen	Screen choice

Figure 8.2: The overview of the six initial design alternative that form by combing different sub-solutions in the morphological matrix

8.2 Concept Suggestion

In the previous chapter, 5 concepts were developed, but only 4 will be presented below. Concept 3, which falls under the design alternative "Removable modular steering wheel" will not be presented as it was eliminated in the initial round of theoretical evaluation (see chapter 8.3 for the complex result of evaluation phase).

- Concept 1: Screen and pedal

This concept explores a novel steering solution that brings together interaction, functionality, and form in a single unit. At the center of the dashboard sits a display screen, surrounded by a circular track. Along this track moves a small, round handle that is intuitively designed to be operated with one hand. By guiding the handle along the edge, the user can steer the vehicle with precision, adjusting direction and angle through a smooth and continuous motion. (see Figure 8.3)

To manage speed, the concept proposes two alternatives. One solution is a foot pedal that controls both acceleration and braking. Another option is a hand-operated control, allowing the user to regulate speed with the free hand, since steering only requires one.

The screen also supports daily activities within the robotaxi service. It can be used to listen to music, follow route guidance, or confirm customer information. In critical situations, the screen becomes an information hub, displaying real-time data such as current speed, traffic conditions, and emergency alerts. Because its primary role is to support everyday use, and its emergency function is only occasional, the screen is thoughtfully positioned in the center to ensure visibility and accessibility.

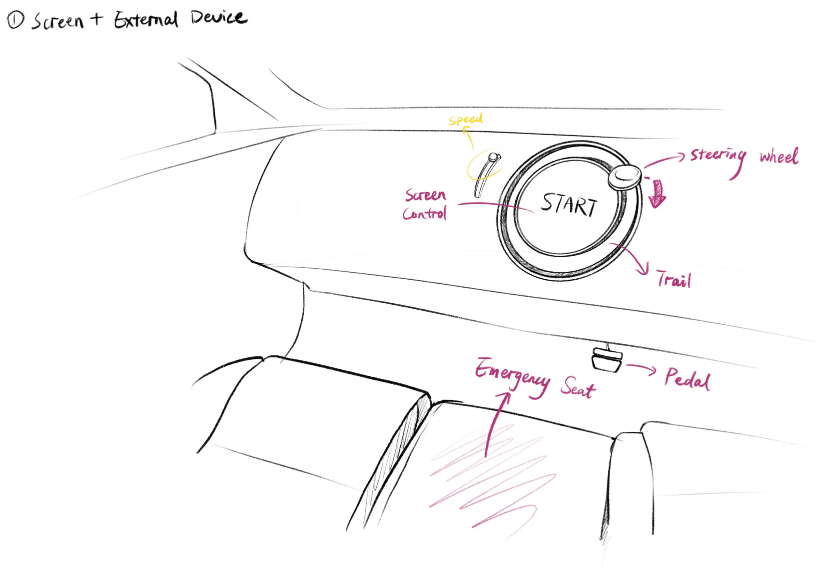


Figure 8.3: Screen and pedal

- Concept 2: Traditional steering wheel

This concept builds upon the familiarity of a conventional steering wheel while introducing a space-efficient and purposeful design. (see Figure 8.4) When not in use, the steering wheel is discreetly embedded within the dashboard, remaining visible to the user at all times. Its visibility ensures that it can be quickly located and deployed when needed.

To activate the steering wheel, the driver simply pulls it out from the dashboard into position. The speed control mechanism is seamlessly integrated into the wheel itself. By tilting the wheel forward, the vehicle accelerates, while pulling it toward the driver initiates deceleration. This removes the need for a traditional foot pedal and creates a fully hand-operated driving system.

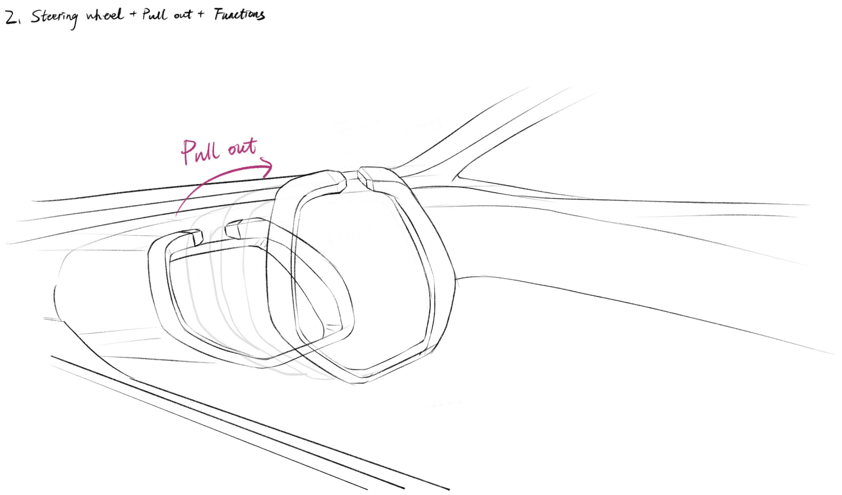


Figure 8.4: Traditional steering wheel

- Concept 4: Decision making

This concept addresses decision-making support for autonomous vehicles. One of the key challenges faced by robotaxis is handling unfamiliar or ambiguous situations, where the system may hesitate or become stuck while attempting to interpret the environment and decide how to proceed. This concept introduces a collaborative decision-making interface designed to support the vehicle in such scenarios.

1. Concept 4a: Touch screen

   Through an interactive screen, the vehicle can ask context-specific questions such as “Is there a fire nearby?” or “I would like to move to this location, do you think it is safe?” (see Figure 8.7 for an example) These prompts allow a human operator or first responder to quickly assess the situation and assist the vehicle in making a decision.

   When movement is required, the screen presents suggested destinations or routes, which the operator can select or modify to match the specific situation. In addition, the interface may include an emergency brake function that the user can activate manually if the vehicle fails to stop in the presence of an obstacle. (see Figure 8.5)

By combining autonomous capability with human judgment, this concept enhances the flexibility and safety of robotaxi operation in unexpected or complex scenarios.

While the use of a screen opens up opportunities for more varied forms of input, it also brings certain challenges. One concern is that looking down at the screen may distract the operator and reduce their awareness of the surrounding environment, particularly in traffic-demanding situations. To respond to this issue, an alternative version of the concept was created, known as Concept 4b.

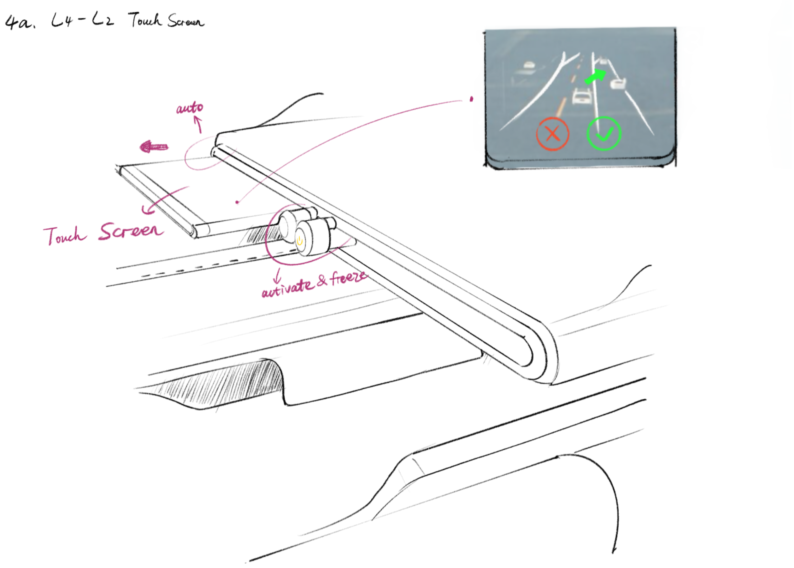


Figure 8.5: Touch screen

2. Concept 4b: HUD + Joystick

   Instead of relying on a touchscreen, this concept introduces a new combination of a head-up display (HUD) and joystick. With this setup, the user no longer needs to look down, as all relevant information is projected directly onto the HUD within their line of sight. The decision-making process is intentionally simplified, presenting only two clear options at a time (see Figure 8.6). The user can make a selection easily using the joystick, allowing for quick and focused interaction without shifting attention away from the surrounding environment for a prolonged period of time.

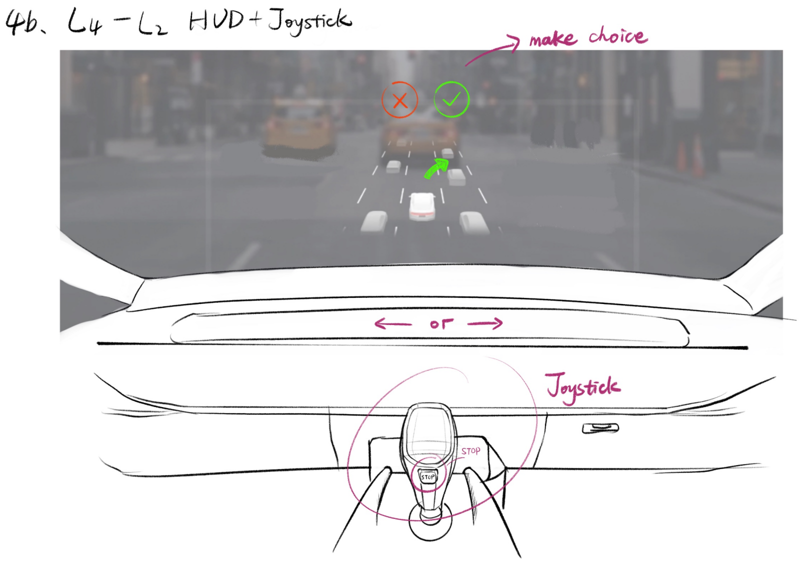


Figure 8.6: HUD + Joystick

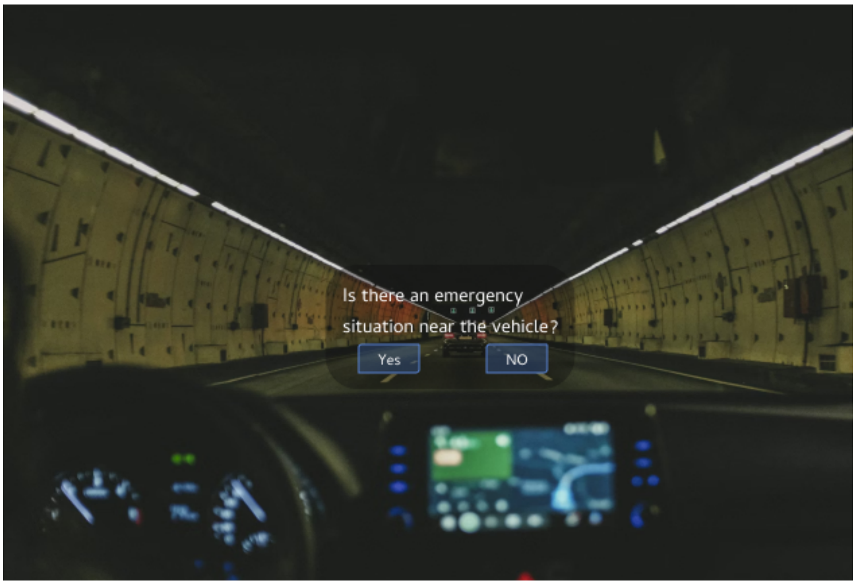

Is there an emergency situation near the vehicle?

Figure 8.7: An example of question

8.3 Concept Evaluation

This section presents the results of the evaluation of the concepts, using theoretical methods, and user evaluation.

8.3.1 Elimination Matrix

Concept 3, (see Figure 8.8) the Removable Modular Steering Wheel, failed to meet a key requirement: “Unfolds within 3 seconds and allows the vehicle to be moved within 3 minutes” (see appendix 8). Since the concept relied on manually assembling separate components, it was considered too slow and impractical for emergency use. The risk of losing parts further reduced its feasibility, leading to its removal from further development.

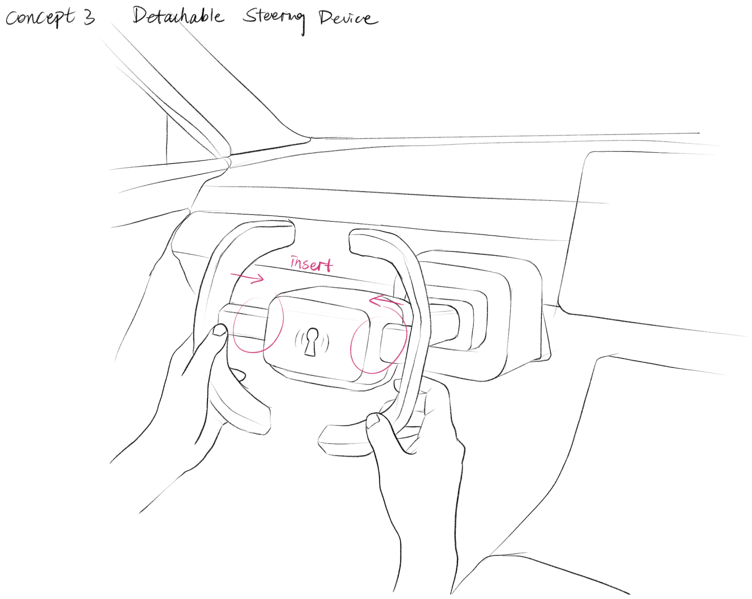


Figure 8.8: Concept 3: ’Detachable’ steering device

8.3.2 Pugh Matrix

The remaining four concepts were analyzed using the Pugh matrix. The evaluation revealed that Concept 4a performed the weakest and was therefore excluded. The other three concepts—Concepts 1, 2, and 4b — received comparable scores, indicating similar levels of alignment with the evaluation criteria (see appendix 9).

8.3.3 Kesselring Matrix

All four concepts were also evaluated using the Kesselring matrix. Concepts 2 and 4b received the highest overall scores, followed by Concept 1, while Concept 4a ranked the lowest (see appendix 10).

8.3.4 User and Expert Evaluation

The firefighter favored Concept 2, which features a traditional steering wheel, describing it as the most trustworthy option due to its analog nature. This preference reflects the user's mental model, in which analog systems are seen as mechanically reliable, immediately usable, and less susceptible to unexpected failure. In contrast, digital or software-based solutions were perceived as more prone to technical errors and harder to predict—especially under stress. The user also pointed out that software-driven systems often require regular updates, which may change how the interface behaves over time. This lack of consistency reduced their confidence in being able to operate the system precisely when needed. These concerns were particularly evident in the feedback on Concepts 4a and 4b, which rely on decision-based digital steering. The firefighter noted that such systems could vary between robotaxi manufacturers, both in interface design and update schedules. Moreover, since the system would only be used in rare emergency situations, there is a high risk that users may forget how to operate it. Without regular exposure, even well-designed digital interfaces can become unfamiliar, increasing the likelihood of hesitation or error in time-critical moments.This feedback aligned with the outcomes of the matrix-based evaluations and supported the decision to prioritize Concept 2 for further development.

When comparing the concepts individually, the powertrain expert acknowledged that users might lean toward Concept 2 due to its conservative and familiar design, which could be better suited as an emergency tool. However, he offered a broader perspective, suggesting that Concepts 2 and 4 might not be mutually exclusive but instead operate on different functional layers—likely referring to a decision layer and an execution layer. In his view, the decision-based interface (Concept 4) could be used to initiate control, while the physical steering (Concept 2) could execute the maneuver. He envisioned a hybrid system in which, after making a decision through the digital interface, the steering wheel would automatically deploy and handle the task—with the option for manual intervention if necessary.

This idea was discussed within the thesis group, but it was ultimately concluded that developing such a hybrid solution would require significant time and technical resources beyond the scope of the current project. As a result, and based on both user feedback and theoretical evaluation, Concept 2 was selected for continued development.

9

FINAL CONCEPT REFINEMENT

This chapter outlines the refinement process of the final concept, covering key stages from early sketch iterations to digital modeling. It includes feedback gathered from stakeholders, the development of the final design sketch, and the translation of the concept into a 3D model and rendered visuals to communicate form and function.

9.1 Iteration

This section presents the refinement process of the final concept, which is based on the selected alternative: a traditional steering wheel integrated with a pull-out mechanism.

To support further ideation, a morphological matrix (see Figure 9.1) was revisited, breaking down the steering device into its core components such as moving function, screen integration, form, pull-out mechanism, and user authorization. By exploring multiple combinations across these variables, several promising directions were identified. These insights laid the foundation for the next stage of concept sketches and evaluations.

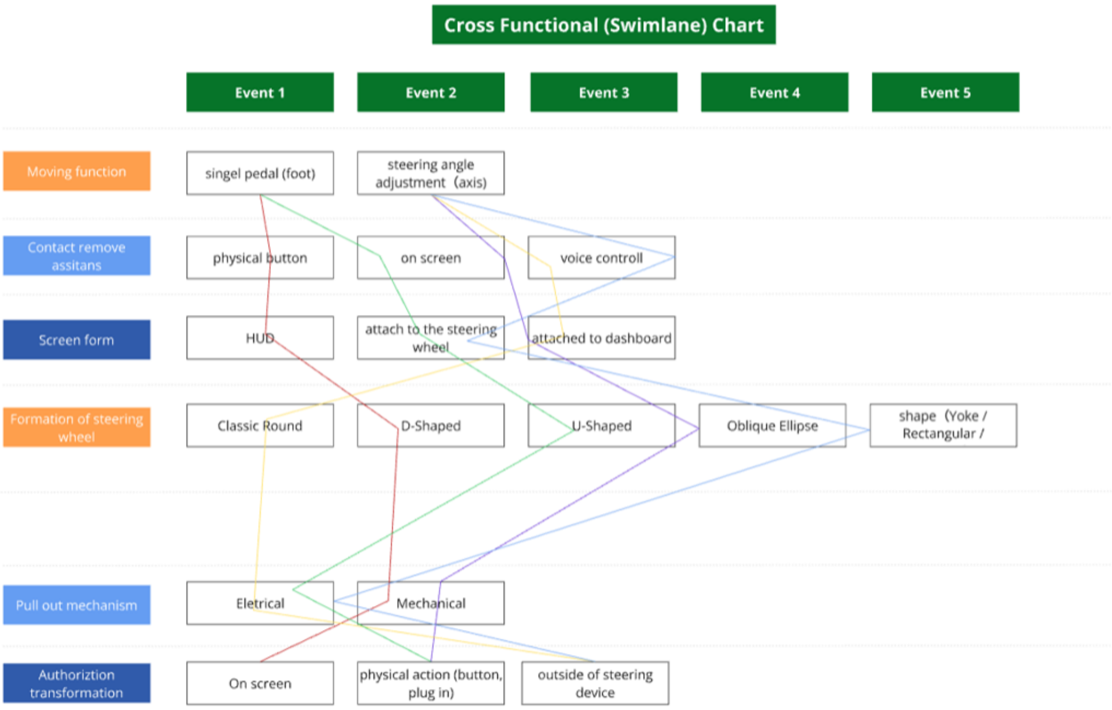


Figure 9.1: Cross Functional Chart

Among the sketches, this sketch explored a combination of a D-shaped steering wheel, single-pedal operation, mechanical pull-out mechanism, and on-screen interaction, with key system feedback displayed via a head-up display (HUD).

One of the key takeaways from Sketch 1 is the use of HUD (see Figure 9.2) to replace the conventional dashboard screen typically positioned behind the steering wheel. By relocating essential driving information (e.g., speed, direction, system status) to the HUD and limiting its activation to emergency situations, the interior layout can be simplified, and valuable space and hardware components can be reduced.

Another advantage lies in the mechanical pull-out mechanism. Once the system is activated, the steering wheel is designed to automatically rise from its stowed position. This motion provides a clear visual cue for availability and minimizes the physical effort required from the user to prepare the device for operation, thereby enhancing usability in time-sensitive or stressful scenarios.

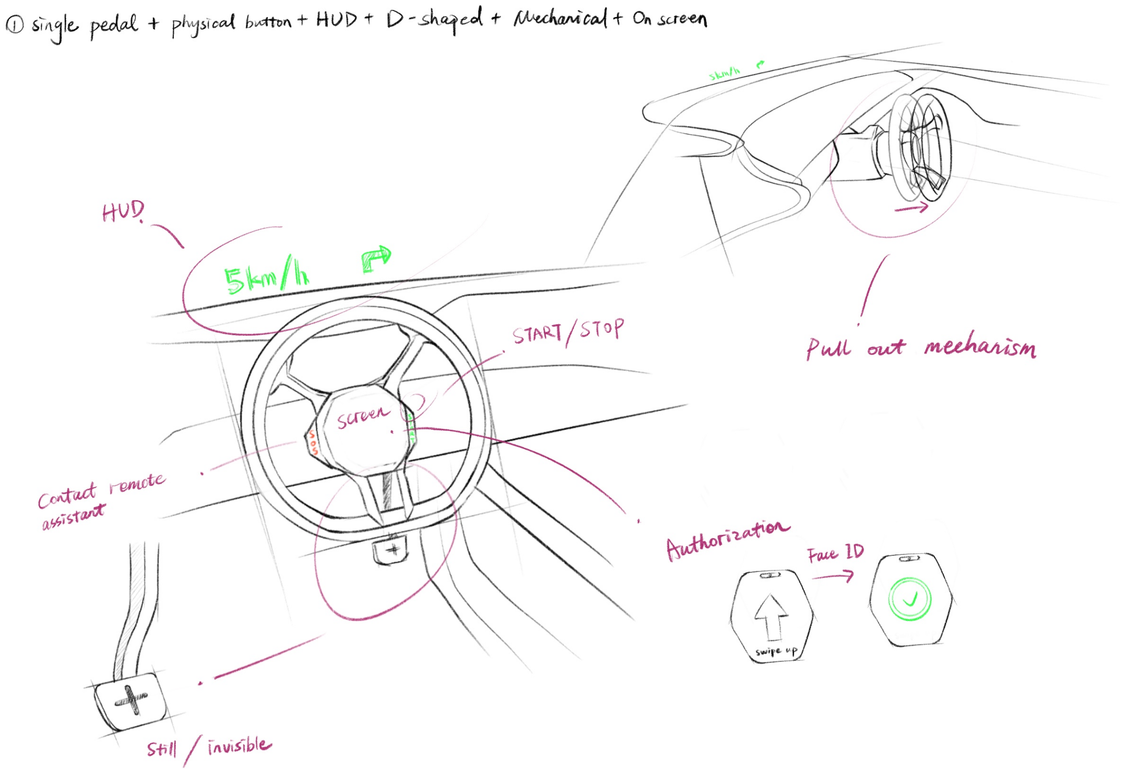


Figure 9.2: Sketch 1

Sketch 2 explores a U-shaped steering device with a simplified control interface, featuring single-pedal operation, an integrated on-screen display, and an electrically actuated mechanism. (see Figure 9.3)

Placing the emergency contact button directly on the steering device supports intuitive understanding by creating a strong functional association between manual vehicle control and emergency communication with remote assistants. This spatial and functional proximity helps users form a clear mental model: when manual intervention is required, support is just one press away. Compared to placing the button elsewhere on the dashboard, this placement reduces cognitive load, improves reaction time, and minimizes hesitation during high-stress situations where every second matters.

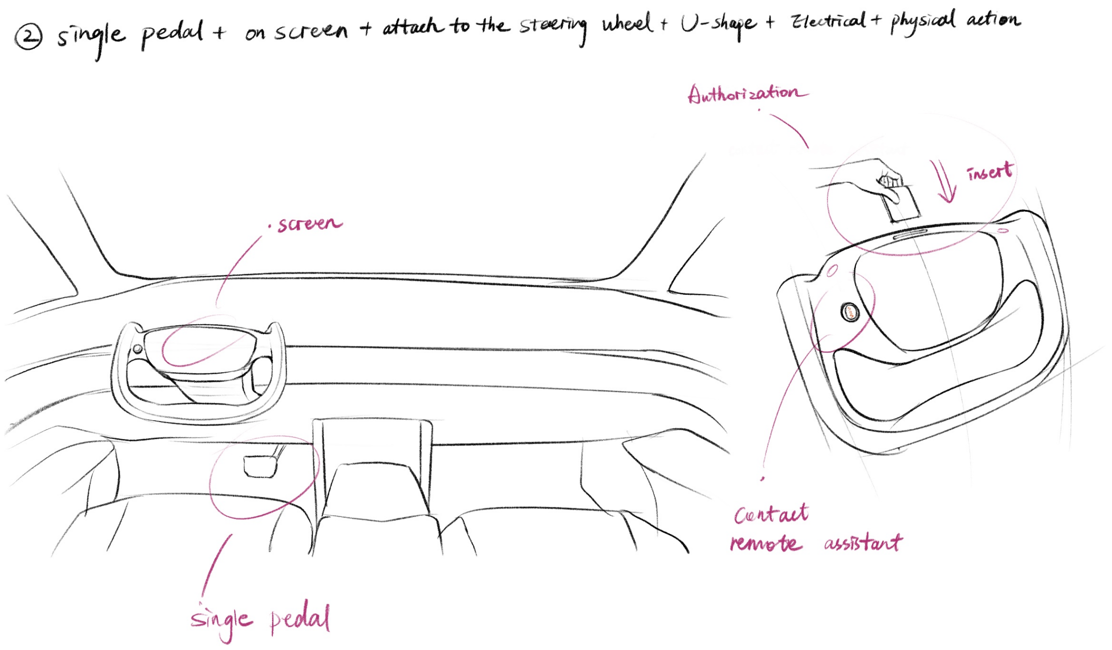


Figure 9.3: Sketch 2

Sketch 3 features an oblique elliptical steering device mounted on the dashboard, combined with a mechanical pull-out mechanism and physical button interaction. The design includes NFC-based authorization and a speed control system that mimics the throttle lever found in aircraft cockpits.

A key insight from this concept is the innovative speed control system. (see Figure 9.4) By adopting a lever-based mechanism rather than a traditional foot pedal, the design introduces a new, intuitive way to control speed that is both engaging and easy to learn. This approach not only enhances the user experience with a sense of futuristic novelty but also eliminates the need for foot pedals—freeing up valuable cabin space and simplifying the vehicle's interior layout.

Additionally, the oblique elliptical form allows the steering device to be seamlessly integrated into the dashboard when not in use. Its asymmetric geometry departs from conventional automotive forms, conveying a youthful and forward-looking design language. This non-traditional shape opens up new possibilities for interface placement, visual expression, and spatial integration within next-generation vehicle interiors.

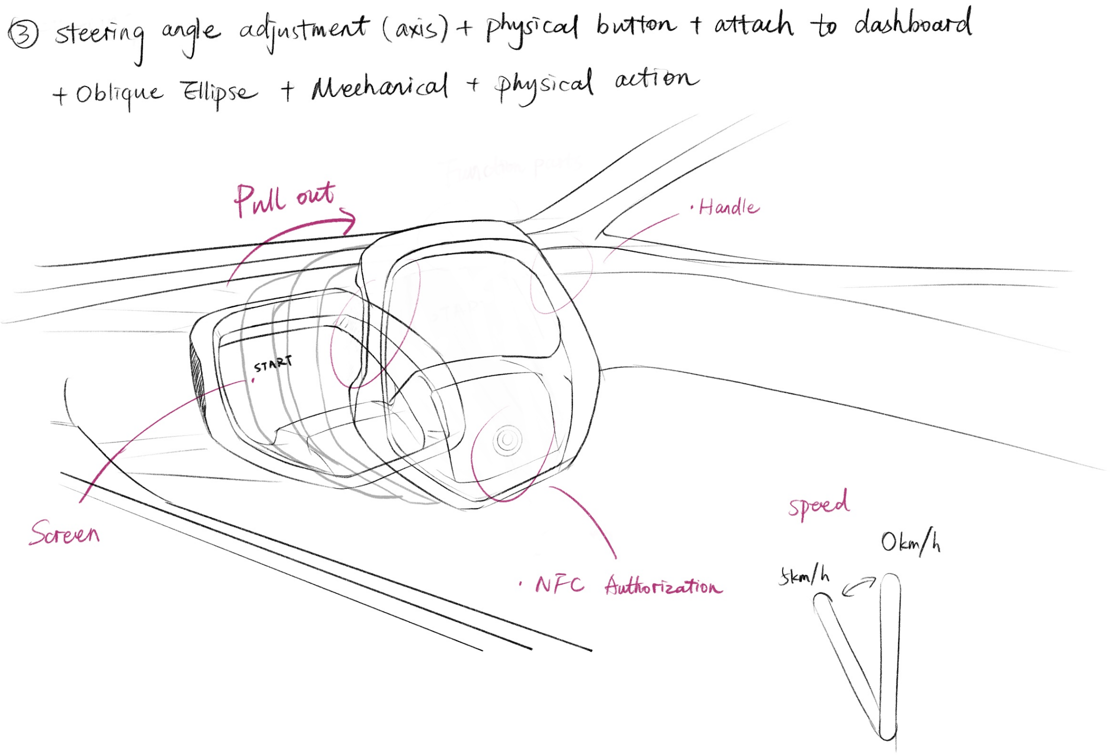


Figure 9.4: Sketch 3

Sketch 4 (see Figure 9.5) features a classic round steering wheel mounted on electric slide rails, allowing it to move laterally across the dashboard. While this design was intended to provide flexibility between left-hand and right-hand drive configurations, it was ultimately assessed as impractical. In practice, countries have established norms—such as left-hand drive in Sweden or right-hand drive in the UK—and drivers are highly accustomed to these fixed positions. Introducing a movable steering wheel could lead to operational confusion and increase the risk of user error. Therefore, the steering wheel should remain fixed on the side corresponding to the country's standard to ensure safety and ease of use.

Furthermore, the decision to place the ID verification system on the B-pillar was made to improve secure access and address current challenges seen in autonomous vehicle entry. For instance, incidents involving Waymo vehicles have shown that emergency responders sometimes resort to breaking windows to gain access. By placing an NFC-enabled verification point externally on the B-pillar, authorized personnel are provided with a secure and clearly designated access method.

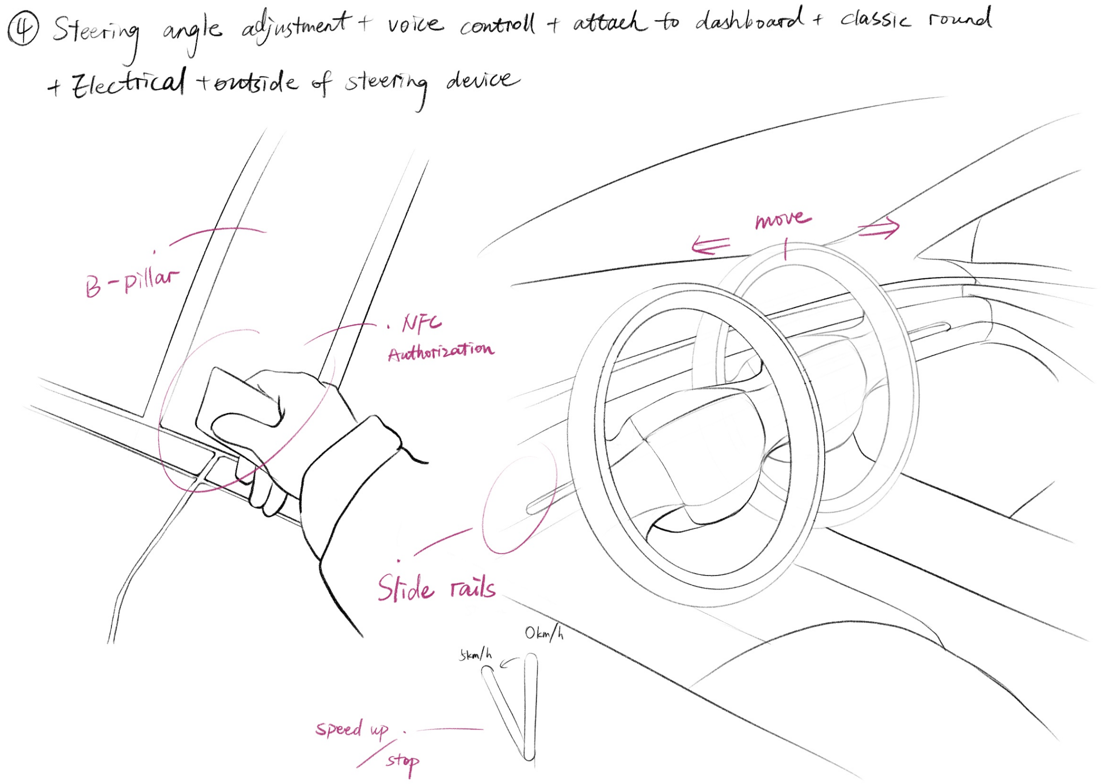


Figure 9.5: Sketch 4

Conclusion

The four concept sketches explored a range of form factors, interaction methods, and system configurations for the emergency steering device. Through these iterations, several key insights emerged to inform the next stage of development.

- Placing the emergency contact button directly on the steering device enhances usability by fostering a clear and intuitive mental model.
- All dynamic driving information—such as speed, direction, and system state—is displayed via a Head-Up Display (HUD), which is only activated during emergency operation.
- Unconventional forms like the oblique ellipse offer a youthful, futuristic aesthetic.
- Alternative speed control interfaces eliminating the need for traditional foot pedals and freeing up floor space.
- Using a single NFC-based tag supports to ensure usability and safety.

Based on these findings, the next step focuses on synthesizing the most promising elements from each concept.

9.2 Stakeholder Evaluation

9.2.1 Evaluation Round 1 - Ergonomic Feedback

The ambulance personnel provided hands-on ergonomic feedback using two foam sheet models. (see Figure 9.6) She found the model with the pivot point placed higher (the left one) to be less intuitive, as it was difficult to remember whether pressing down resulted in acceleration or deceleration. In contrast, the other model—with a lower pivot point—supported a clearer mental model: pressing forward (away from oneself) corresponded to acceleration, while pulling back indicated braking.

She also felt that the shape of the second model made it more obvious where to grip and that it was more comfortable to hold. Regarding the button placement, she appreciated that the buttons were located on the steering wheel, noting that they were unlikely to be pressed unintentionally. At the same time, their placement made it easy to understand that the buttons were functionally linked to the steering system.

Figure 9.6: Two initial versions of the foam prototype (left with high pivot point and right with low)

9.2.2 Evaluation Round 2 - System Interaction and HUD Evaluation

A user engaged with a HUD prototype created in Figma together using a refined version of the foam prototype (see Figure 9.12). This evaluation was set up as a walkthrough through the whole user journey. The insights were then transferred to the refinement of the final concept.

- B-Pillar Interface

The user understood that the tag in action is required to unlock the vehicle. However, the user expressed uncertainty about whether the door had been successfully unlocked, as the icon alone did not provide sufficient confirmation.

Design Iteration:

Based on the feedback, the door unlock icon was enlarged and accompanied by explanatory text. Additionally, the circular line that could be misinterpreted as requiring further action on the screen was removed to avoid confusion.

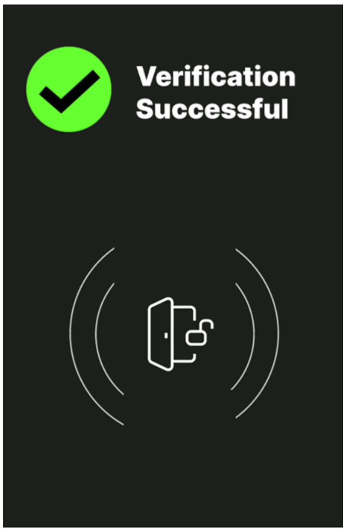


Figure 9.7: Verification interface before design iteration

Figure 9.8: Verification interface after design iteration

- Instruction Stickers

The user had difficulty interpreting the graphics for instruction sticker, indicating that pulling out the steering wheel activates manual mode and pushing it in activates autonomous mode. He also found the scale and visual indicators representing the transition between modes confusing.

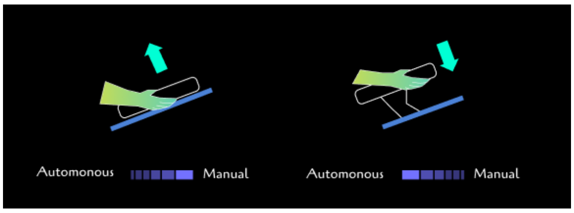


Figure 9.9: Initial version of activation instruction sticker

Additionally, the user suggested that the visual representation of acceleration via angle adjustment could be better communicated using side-view illustrations, especially to clarify ambiguous operations.

Design Iteration:

Due to concerns about the potential risk of unintentionally accelerating or decelerating while manually pushing the steering wheel in and out, the mechanism was redesigned to automatically pop out and retract during mode transitions. As a result, this sticker about pulling in and out of the steering wheel manually was removed.

The acceleration/ braking sticker was redesigned to use a side-view angle. It was also discovered that the previous version did not indicate backward movement. In the updated version, it is now clearly stated that pulling the device toward the user will cause the vehicle to move in reverse.

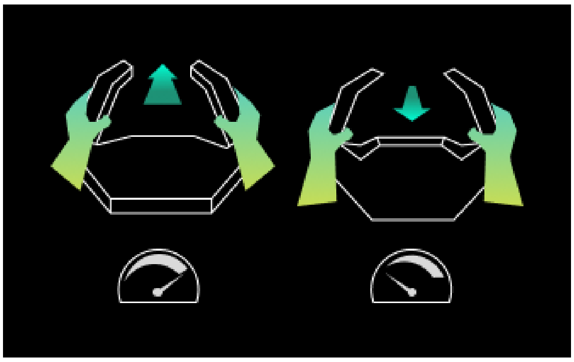


Figure 9.10: Speeding instruction sticker before design iteration

Figure 9.11: Speeding instruction sticker after design iteration

- HUD Tuturial and Confidence

The absence of pedals initially made the user hesitant to proceed with the operation. However, the guidance and feedback provided by the Head-Up Display (HUD) increased their confidence and encouraged them to continue testing the system.

- Button Design

The user pointed out that buttons on the steering wheel should be larger and more visually prominent ("big and bright") due to the operational context—firefighters often wear gloves and face masks, which makes smaller or subtle controls impractical.

- Tag Logic

The user expressed uncertainty about whether tagging in both unlocked the door and transferred vehicle control, as it was not clear that a single action triggered both functions. They suggested that this could be better communicated, possibly through additional information displayed on the HUD.

The user also proposed that reactivating autonomous mode could involve pushing the steering wheel back in and then tagging out. They appreciated the tag-out function, as it clearly marked the end of the manual takeover.

Design Iteration:

In the refined version of the concept, the first swipe of the tag unlocks the car door. After entering the vehicle, a second swipe on the steering device formally activates the system and transfers vehicle control to the user.

The same logic applies when exiting: the first tag-out ends manual control, and the second tag-out locks the door, indicating that the full handover is complete.

9.2.3 Evaluation Round 3 – Form and Manufacturing

Initially, the chosen form featured an open lower section, as shown in the physical prototype (see Figure 9.12). This design intended to provide users with more flexibility: the upper grip area could be used to adjust speed, while the lower part served as a hand-rest to enhance comfort.

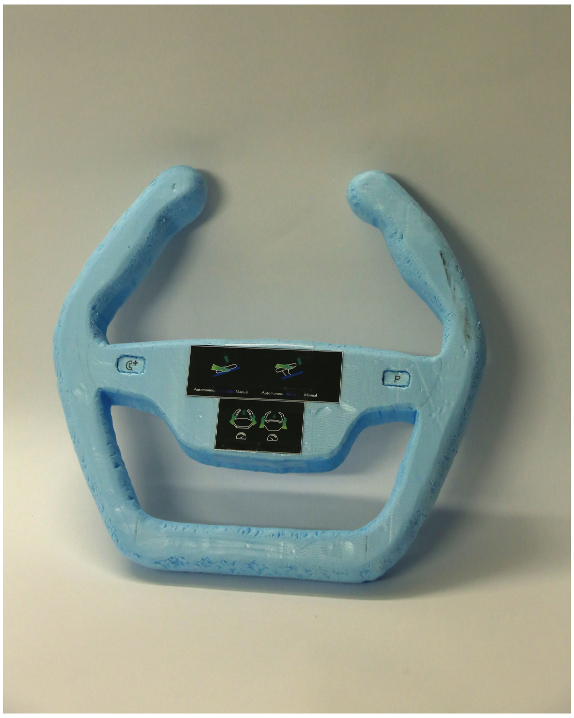


Figure 9.12: Initial prototype with lower section

However, after presenting the concept to the company, feedback of deleting the lower part of the steering wheel was received. Since the steering device is intended primarily for emergency situations in highly automated vehicles, it is not expected to be used for extended periods. As a result, long-term ergonomic comfort is not a priority. The lower section, originally designed to support the hand, was deemed unnecessary. It would add extra material, increase manufacturing complexity, and lead to higher production costs without functional benefits. Based on this input, we removed the lower portion of the design in subsequent iterations.

9.3 Refinement

9.3.1 Final Sketch

A set of keywords was defined to capture the emotional and visual qualities intended for the final design—such as Robust, Stylish, Minimal, Futuristic, Conceptual, and Floating. Based on these keywords, a curated collection of reference images was assembled into the mood board shown above (see Figure 9.13). This mood board served as a visual guide throughout the form development of the steering device, helping to ensure that the evolving aesthetics aligned with the desired mood and characteristics.

The final concept (see Figure 9.14) evolved through a series of explorations in form and proportion. The image below documents the refinement process from initial shape studies to the final selected form, with each iteration addressing both usability and manufacturability concerns.

The final steering device adopts an asymmetric, compact design tailored for emergency use. Compared to earlier, more traditional forms, this version removes unnecessary lower structure to reduce material use, production complexity, and visual weight. Only the essential features are retained: two physical buttons located on the side of the central module for emergency contact and stop functions. The rest of the driving information is delegated to the HUD system, activated only during emergency intervention.

The form of the final concept allows the device to be seamlessly integrated into the dashboard. It can remain hidden when not in use and rise forward during activation. The upper grip zone offers a firm and intuitive hold, while the angular silhouette communicates directionality and a high-tech, futuristic character.

Figure 9.13: Mood Board

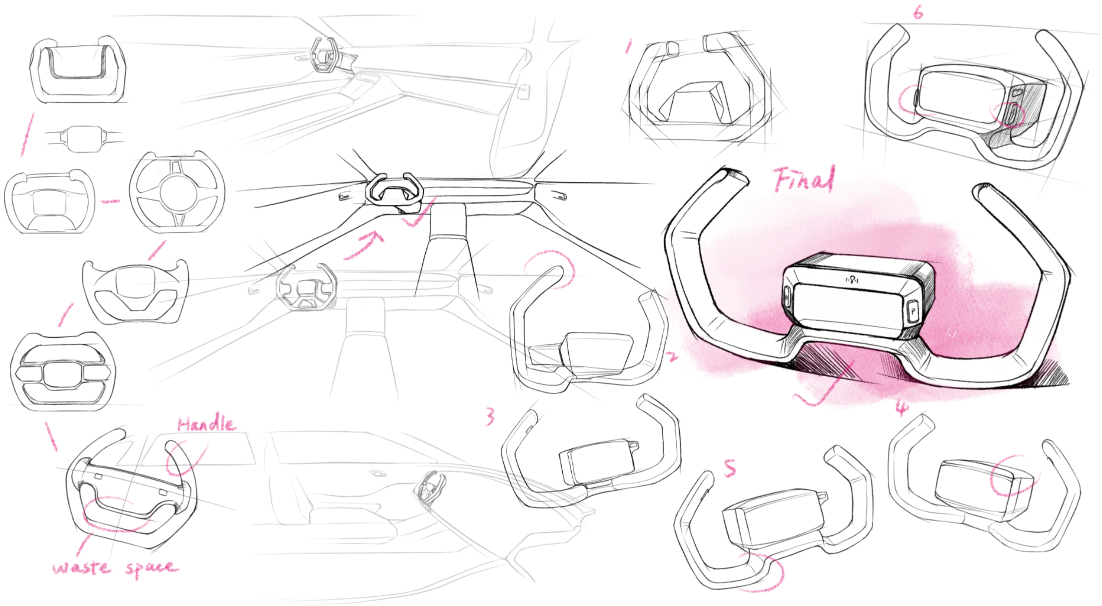


Figure 9.14: Final Concept Sketch

9.3.2 Digital Modeling in Rhino

Following the refinement of the final concept through sketching, the design was translated into a detailed 3D model using Rhino. This stage focused on accurately capturing the proportions, surface transitions, and interface integration defined in the final sketches, while also considering feasibility for physical prototyping and potential manufacturing. The modeling process began with the main body of the steering device, using curve-based surface construction to ensure smooth transitions and well-controlled reflections. Special attention was given to the grip areas, which were sculpted to match ergonomic expectations without overcomplicating the form. The overall geometry was kept intentionally clean and minimal, echoing the functional reduction of the design.

The central module—housing the emergency contact and stop buttons—was modeled as a distinct but seamlessly integrated volume. Edge fillets and subtle contouring were applied to convey a sense of robustness while maintaining visual softness.

To explore the interaction between the steering device and the vehicle interior, additional context elements—such as the dashboard cutout and mounting mechanism—were also modeled in Rhino. This allowed for precise positioning and testing of the pull-out motion range.

The resulting model served as the foundation for rendering, prototyping, and further evaluations. It reflects both the formal intent, and the practical requirements derived from the previous stages.

9.3.3 Rendering in Keyshot

To visualize the final concept and effectively communicate its form, materials, and interaction logic, the 3D model was rendered using KeyShot. The rendering process focused on achieving realistic surface finishes, accurate lighting conditions, and a clear representation of the interface elements.

A matte black finish was applied to the steering frame to convey a sense of robustness and tactile comfort, with a subtle leather-like texture suggesting grip-friendly materiality. The central module was rendered with a satin plastic housing and a glossy display interface, highlighting the sticker of speed control system.

Two high-resolution renderings were generated from different perspectives:

Figure 9.15: Angled top view showing the asymmetric form of the steering device and the intuitive layout of the sticker of speed control system. The sticker displays three core driving states: Forward, Still, and Backward, accompanied by iconography for quick comprehension.

Figure 9.16: Frontal view emphasizing the compact footprint of the product and the placement of the two physical buttons on each side of the sticker—one for emergency contact, and the other for parking or stopping the vehicle.

These visuals help convey both the technical clarity and the visual identity of the design. They also serve as references for future physical prototyping and communication with stakeholders.

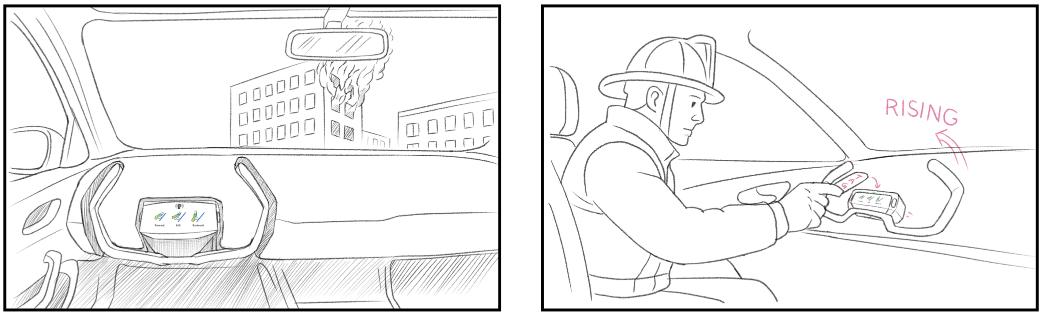
9.3.4 Storyboard

The following storyboard was developed to visualize and evaluate a critical emergency interaction scenario in the context of highly automated vehicles. As Level 4 autonomous systems increasingly remove the human driver from the control loop, special consideration must be given to exceptional cases where external actors—such as first responders—need to assume control. The storyboard serves as both a communication tool. (see Figure 9.17)

The storyboard illustrates a use case in which a firefighter must intervene when a robotaxi obstructs emergency access during an active fire response. The sequence portrays the firefighter approaching the vehicle, initiating a secure authentication process via a tag, activating the vehicle's manual control interface, and relocating the robotaxi to a designated emergency lane. The scenario highlights key design elements such as interface accessibility, control mode transition, and ergonomic steering operation under gloved-hand conditions.

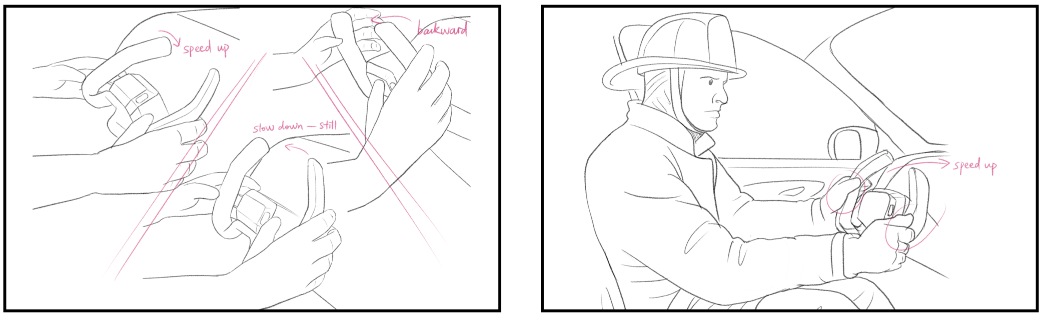
1. Robotaxi blocks the way, preventing a fire truck from passing through

2. Firefighter attempts to unlock robotaxi using a tag



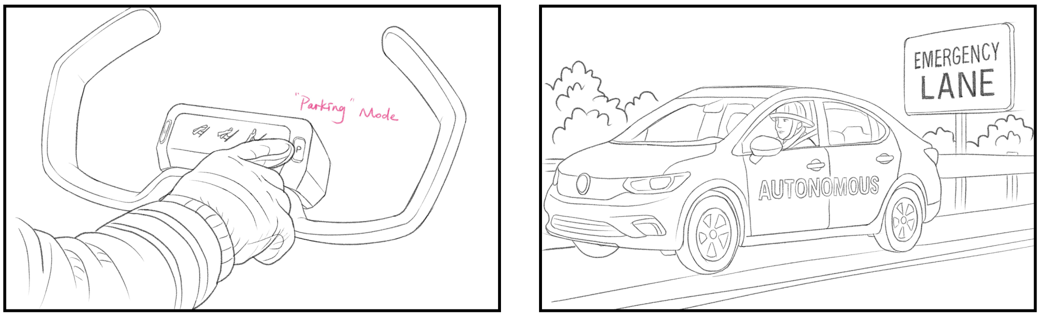
3. Firefighter observes the steering wheel and read the sticker

4. Firefighter taps the tag on the steering module to unlock it



5. The steering gestures: rotate to speed up, slow down, or reverse

6. Firefighter is driving through tilting the steering wheel



7. Firefighter presses the "P" button to activate parking mode

4. Robotaxi is now safely parked on the emergency lane

Figure 9.17: Storyboeard

10

FINAL CONCEPT: HALOGRIP

In this chapter, the final concept developed in the project is presented.

10.1 Brief Description

“The final concept HALOGRIP offers a dependable fallback for first responders to manually reposition the vehicle in emergency scenarios when algorithms failure. While not in use, the steering wheel remains visibly integrated into the dashboard and can be quickly activated via ID verification. It enables short, low-speed maneuvers to safely clear obstructions when needed. The system supports two modes: in autonomous mode, control is handled either by onboard algorithms or remote operators; in manual mode, authorized personnel can locally maneuver the vehicle with full control.”

10.2 Form Language

The final design adopts a compact and futuristic form language that aligns with the envisioned 2035 autonomous vehicle interior. The overall geometry (see Figure 10.1) adopts a flattened U-shaped profile with strongly angled forward-tilting grips. The side grips feature subtle curvature and thickened cross-sections that guide the user’s hands naturally into position without relying on overly sculpted ergonomic details.

The central part of the steering device is a simple, rectangular volume positioned between the two hand grips. Instead of a digital display, a printed sticker is applied to the front surface to indicate basic control instructions, such as forward, stop, and backward. These icons serve as static visual cues to assist the user during emergency operation.

On either side of the central block are two physical buttons. These buttons are raised physical elements designed to provide clear tactile feedback, even when operated with gloves. Made from the same material as the main body but in a contrasting color, they are easily noticeable at a glance. Intuitive icons further clarify their individual functions, supporting quick and confident use.

Figure 10.1: Final concept

When installed into the dashboard, the steering device is housed in a recessed slot, remaining partially visible in its inactive state. The shape of the grips and the orientation of the unit allow users to quickly identify and engage with it when necessary. The form is intentionally kept simple and easy to manufacture, while ensuring it is distinguishable from everyday vehicle components. The design supports fast recognition and operation in emergency scenarios without introducing unnecessary visual or functional complexity. (see Figure 10.2)

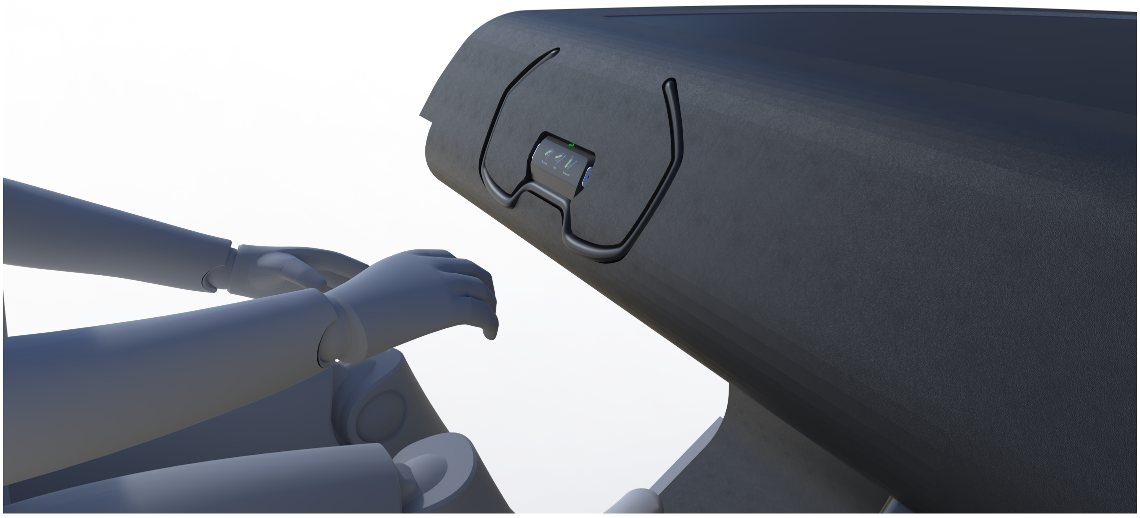


Figure 10.2: Steering wheel embedded in dashboard

10.3 Function

10.3.1 Tilt-Based Control System Design

Unlike traditional steering systems, this design eliminates foot pedals entirely. Instead, acceleration and braking are handled through a tilt-based mechanism integrated into the lower part of the steering wheel: tilting forward increases speed, while pulling backward reduces speed or activates braking. If pulled further, the system engages reverse mode. The vehicle remains stationary when the wheel is in its neutral position.

Directional input is handled through conventional lateral steering motions. To prevent unintended reverse activation, the wheel offers mechanical resistance at the rear threshold. This provides a tactile cue to help users recognize when they are about to switch directions.

The goal is to allow a single user, typically a first responder in an emergency scenario, to quickly and intuitively move the vehicle at low speeds without the need for training or divided limb control.

10.3.2 Activation and Deactivation Workflow

Activation is carried out in two steps using an ID tag system. First, the tag is used to unlock the vehicle door. Once inside the cabin, the same tag is scanned a second time on the steering wheel to unlock the steering system (see Figure 103). This action causes the wheel to automatically fold out from the dashboard and enter manual mode.

Once the vehicle has been repositioned to the desired location, the authorized user must swipe their ID tag again to conclude the manual control session. The steering wheel will then automatically retract into its embedded position within the dashboard. If parking mode was activated prior to retracting the steering wheel, the vehicle will remain stationary. However, if parking mode was not engaged, the system will automatically notify the remote assistant, and autonomous operation will resume in accordance with predefined algorithms.

In the event that the ID verification interface on the b-pillar is damaged or unresponsive, first responders can still gain access by breaking the window. Once inside, they can bypass the exterior verification step and proceed with the activation and maneuvering of the steering wheel using the interior interface.

Figure 10.3: a tag icon indicating that scanning is required, placed on the central block

10.3.3 Buttons

The control system is analog by design, avoiding the use of touchscreens or capacitive buttons. Instead, two large physical buttons are placed near the steering wheel: one to activate parking mode and one to request remote assistance. Both are clearly marked, tactile, and sized for use with gloves.

10.3.4 HUD

The HUD is intended to display essential information related to the vehicle's status. The specific content varies slightly depending on whether the vehicle is operating in autonomous or manual mode. The following section provides further details.

- Autonomous Mode

When activated, the HUD displays the full message "Autonomous Mode On." After a few seconds, this message is replaced with a simple "A" to indicate the current mode.

Figure 10.4: Autonomous mode full text

Figure 10.5: Transition to" A"

Figure 10.6: A” indicating ongoing manual mode

- Manual Mode

Upon activation, the HUD shows “Manual Mode On,” which is then replaced with “M” as the ongoing mode indicator.

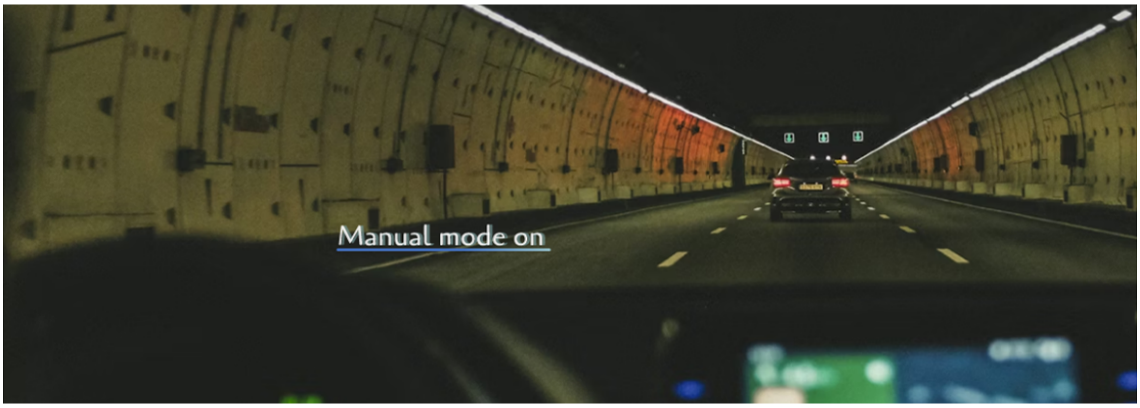


Figure 10.7: Manual mode full text

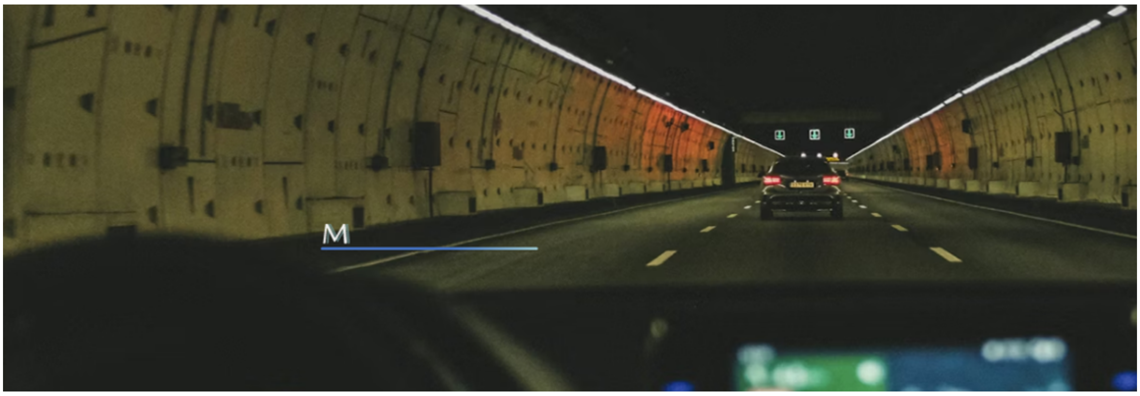


Figure 10.8: Transition to “M”

Figure 10.9: “M” indicating ongoing manual mode

Then, a speed-related instruction is displayed for 5–10 seconds, mirroring the information shown on the steering wheel stick.

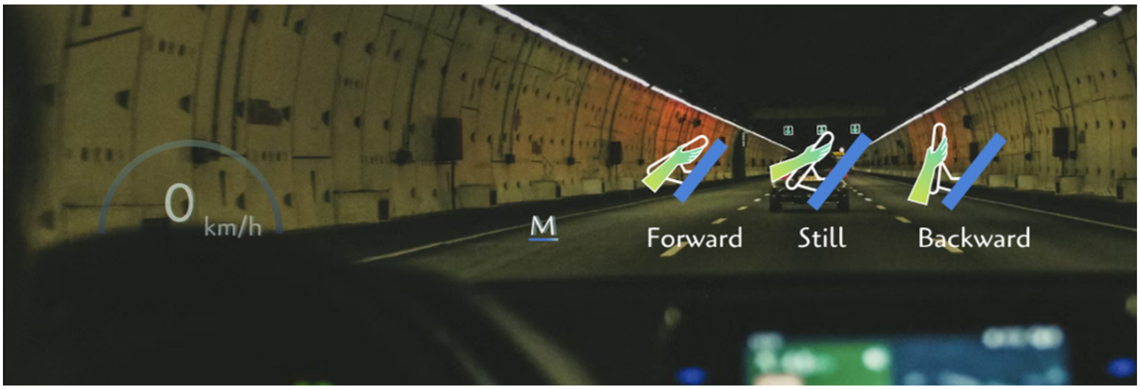


Figure 10.10: Instruction for steering

The following images illustrate the interface during driving and upon arrival at the destination, when the vehicle is parked.

Figure 10.11: Information while driving

Figure 10.12: Parking mode activated

10.3.5 B-Pillar Screen

To allow user access to the vehicle, a B-pillar interface is used for identity verification, ensuring that only authorized individuals can enter. The following illustrates one possible approach.

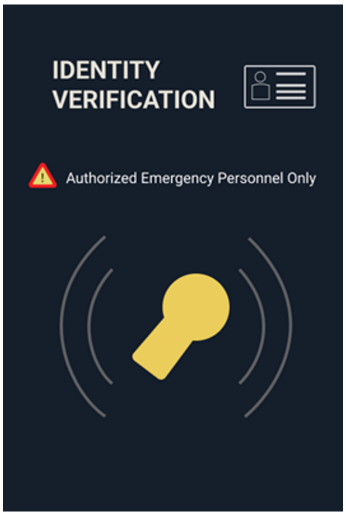


Figure 10.13: Pre-verification state displayed on the interface

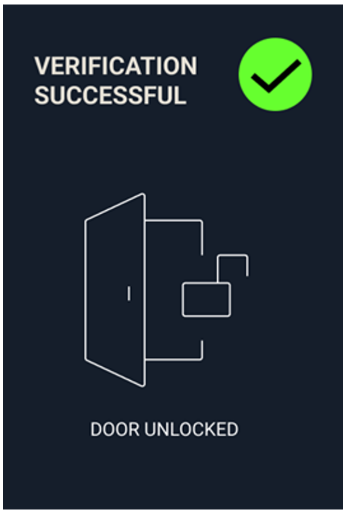


Figure 10.14: ID verification successful – access granted

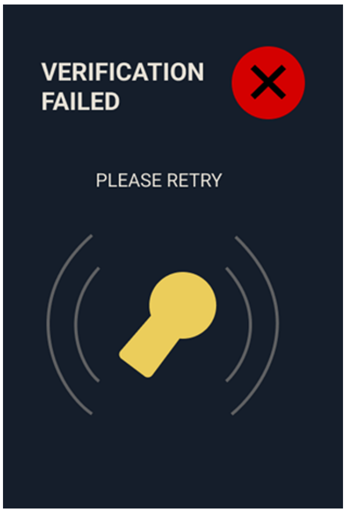


Figure 10.15: ID verification failed – access denied

10.4 Feathers

10.4.1 Speed Limitation

Manual control is intended for short-term, low-speed use, with a maximum speed of 15 km/h. This speed restriction is a deliberate design choice that supports three critical objectives:

- Sufficiency for Intended Use

Based on the target scenarios outlined in Chapter 4.3, manual repositioning typically requires short-distance travel, and a preliminary range of up to 500 meters was considered sufficient in most cases. Interviews with firefighters revealed that a duration of 5–10 minutes already feels long in emergency situations. Therefore, the goal is to complete the entire process—from ID verification to final positioning—within five minutes.

To meet this target, the system should reach a ready state within three minutes, leaving up to two minutes for movement. At 15 km/h, the vehicle can travel approximately 250 meters per minute, covering 500 meters in two minutes. This ensures the entire operation stays within the critical five-minute window.

- Minimized Risk of Injury

First responders face high cognitive loads during emergencies, which may reduce situational awareness. Additionally, the manual control method is unfamiliar and could lead to mistakes during early use. The low-speed limit helps reduce the likelihood of severe injury to both responders and other road users.

- Theft Prevention

Limiting the vehicle's speed also functions as a security feature. If unauthorized individuals gain access, the restricted speed ensures the vehicle cannot be used for escape or driven far, reducing the risk of theft or misuse.

10.4.2 Automatic Steering Wheel Deployment for Safe Activation

Since acceleration is controlled by tilting the steering wheel, it is essential to prevent unintended input during physical interaction with the device. To mitigate this risk, the steering unit is designed to extend and retract automatically following ID verification, eliminating the need for manual handling. This not only reduces the likelihood of accidental motion but also enables a cleaner, more integrated dashboard design by removing the need for dedicated grip space.

10.5 Mechanism

10.5.1 Tilting-based System

The actual mechanical design of the tilting technique falls outside the scope of this project. However, a comparable application of such a technique is presented below to support the argument that the approach is both technically and human-machine interaction-wise feasible.

- Angle-Based Input for Thrust and Steering: A Technical Perspective

Tilt-based input is widely used in high-tech simulation settings, particularly in flight control systems. The Thrustmaster T.Flight HOTAS One flight simulator controller provides a compelling technical reference for this project's proposed integrated interface (Thrustmaster, n.d.).

In this system, forward and backward tilt of the control stick directly modulates thrust: pushing forward increases speed, while pulling back decreases speed or triggers reverse thrust. At the same time, lateral tilting or rotation of the stick controls aircraft roll. While physically different from ground vehicle steering, this lateral input shares the same angle-based interaction logic.

Although thrust and direction are controlled separately in the HOTAS layout, both rely on angular input, enabling a consistent and intuitive interaction model. This approach aligns with natural human spatial-motor perception and remains effective even under high cognitive load.

- Retractable Mechanical

To ensure system dependability in emergency contexts, mechanical reliability is prioritized. Because mechanical components are generally less prone to failure than electronic ones, the system adopts a minimal-electric approach. However, a fully mechanical design is not feasible. As discussed in Section 9.4.3, a purely mechanical push-in deployment poses a risk of triggering unintended vehicle movement. Therefore, a limited amount of electrical power is still required to drive the steering wheel's automatic extension.

Manual control is only enabled once the steering device is fully extended and mechanically locked in place. A tactile "tick" or audible cue confirms readiness for use. To avoid startling the user, both deployment and retraction are deliberately gradual and controlled.

- Implementation Suggestion

One suggestion of mechanism that could potentially achieve the intended effect is presented below.

The deployment system can be powered by a compact electric actuator designed for mechanical stability and reliability. A motor-driven worm gear or spindle mechanism moves the steering unit along robust linear guide rails. The actuator features a self-locking capability, ensuring the unit remains in place even in the event of power loss. Additionally, a damping system is integrated into the motion path to provide smooth and controlled movement.

To further enhance safety, the locking mechanism includes redundant engagement points. A primary latch is supplemented by a secondary detent, ensuring the steering unit remains securely fixed in either the deployed or retracted position—even if one component fails.

A commercially available actuator that meets these requirements is the TiMOTION TA2P (TiMOTION, n.d.), which offers a compact form factor, self-locking functionality, and reliable linear motion—making it particularly well-suited for automotive and emergency-use applications.

11

DISCUSSION

This chapter discusses the project's results, how well the defined aim has been fulfilled, and other aspects that may be relevant to reflect upon regarding the final outcome and the project's approach.

11.1 Comment on Result

- Fulfillment of Aim

This project builds on identified challenges in emergency scenarios involving autonomous vehicles, exploring how a device could enable first responders to manually reposition stalled vehicles and reduce obstruction in critical situations. The final concept, HALOGRIP, fulfills this aim by allowing authorized personnel to safely move a stalled robotaxi to a nearby safe location within five minutes. This significantly improves the efficiency of on-ground operations—for example, by removing the need to work around a blocked vehicle when placing ladders or deploying hoses. In cases where the robotaxi obstructs the path to the emergency site, HALOGRIP offers a more controlled and deliberate method of repositioning than previous strategies. The solution thus addresses the core challenge and supports safer, smoother emergency response workflows.

Part of the aim of the project was to create a product that visually aligns with the aesthetic and spatial expectations of future robotaxi interiors. As the vision for form language and expression was developed through a mood board, HALOGRIP was found to integrate seamlessly into that visual framework. This suggests that the design meets the intended visual expectations for 2035 autonomous vehicles.

- Potential challenges

One challenge of the solution is that its activation relies on a physical tag. If the tag is lost, it could delay the maneuvering process and also pose a security risk by allowing unauthorized individuals to gain access to the robotaxi.

Secondly, the embedded design of the steering device introduces integration challenges. As AUTOLIV is a component supplier rather than a vehicle manufacturer, it remains uncertain whether OEMs will be willing to accommodate such an embedded form in their vehicle platforms. Successful implementation would require early coordination during vehicle design and production phases. In the current concept, the form and mechanical integration of the embedded module are not fully resolved and should be explored in more depth.

Lastly, the long-term development potential of the product still lacks a clear evaluation framework. There is no established method yet for assessing the concept's viability over a 10-year horizon.

Future research could examine its potential across multiple dimensions—including form evolution, functional relevance, manufacturing feasibility, and market adaptability—to better understand its role in the future of autonomous mobility.

11.2 Comment on Method and Procedure

- Overall Discussion about Chosen Method and Procedure

The Double Diamond model proved to be a suitable framework for this highly exploratory project. It supported both divergent and convergent thinking throughout the process and helped structure the transition from research to concept development in a clear and iterative way.

The approach chosen for the requirement list was also effective. By moving from high-level abstractions to detailed, component-specific requirements, we ensured that no critical aspect was overlooked. This gradual narrowing allowed us to maintain both a broad perspective and focused depth during development.

Conducting interviews with both users and experts was another strength of the process. Engaging end users allowed us to gather concrete, grounded insights which we then clustered and interpreted using methods like KJ analysis. This informed our early concept ideas, which were subsequently evaluated and refined with input from experts. This two-step approach provided layered insight—from practical needs to professional feasibility.

However, there was a trade-off. Due to time and access limitations, we were unable to conduct a broader user study or gather quantitative data from first responders. This limited our ability to validate certain aspects of the design on a larger scale.

The brainstorming methods used during ideation worked well. We were satisfied that the process generated a diverse range of concepts, covering different directions and levels of innovation.

One challenge emerged during the theoretical evaluation of the concepts. Concepts 4a and 4b, which emphasized innovation and future-oriented thinking, were disadvantaged in frameworks focused heavily on practical criteria such as ergonomics and technical feasibility. This suggests a potential mismatch between evaluation methods and concept intent.

- Information Source

One of the major challenges during the research phase was the difficulty in finding unbiased and detailed sources regarding robotaxi-related accidents. Most available information came from news articles or blog posts written by journalists and experts, where personal opinions may have influenced the narrative.

Access to first-hand data was particularly limited, as most robotaxi operations and related accidents occur in the U.S. Without a direct network in these regions, we had to rely heavily on secondary sources. Even in relatively well-documented cases, critical contextual details—such as how long a vehicle was obstructing emergency operations—were often missing, making it difficult to form a complete understanding of the events.

In addition, information about robotaxis in China is limited online, making it difficult to determine whether similar problems have occurred there or how widespread they may be.

- Expert and User Interview

Collaboration with automotive experts played a vital role in helping us define the scope of the thesis and in validating or discarding initial assumptions. Their insights were especially valuable during the literature review and in shaping the design direction. However, their feedback was sometimes difficult to act upon, as it was often communicated from a systems-level perspective and involved technical terminology unfamiliar to us as industrial design students.

Firefighters were involved early in the process, partly due to their relatively more flexible schedules, which allowed for multiple sessions and deeper exploration of their professional needs. In contrast, ambulance personnel were only available for a single session much later in the process, after key design decisions had already been made. As a result, their input primarily served to evaluate the existing concept rather than to inform its development. This limited engagement means that certain profession-specific needs may not have been fully uncovered, leaving potential needs from the ambulance perspective unexplored.

Police personnel, although part of the broader first responder group, were not included in the user study due to time constraints. Given the need to prioritize, the focus was placed on firefighters and ambulance crews—those most likely to face the physical access issues HALOGRIP is designed to address. Police vehicles are typically smaller and more maneuverable, making them less affected by stalled robotaxis.

- Design Tension: User Familiarity vs. Technological Progress

A recurring discussion throughout the project was whether the steering device should adopt an analog or digital interface. From the beginning, users consistently expressed a preference for analog and simple interactions, emphasizing the need for immediacy and clarity in high-pressure emergency situations. However, there was also a counterargument raised—both within the team and from some experts—that users often resist unfamiliar technologies at first but may eventually adapt and even prefer them once the product is introduced and integrated into practice.

This debate played a significant role in our design decision between Concept 4b, a more futuristic and experimental solution, and the final concept, which is intentionally more analog and arguably less visually innovative. The deciding factor came from analyzing existing emergency procedures with electric vehicles: different car manufacturers provide varying methods for disconnecting power, creating a complex and inconsistent system that emergency responders must memorize and manage under stress.

Given this context, we felt it would be unfair—and even burdensome—to expect first responders to adapt to yet another unfamiliar and potentially unintuitive system. While the idea that "users will eventually accept it" is often used in innovation-driven design, in this case, it felt misaligned with the real-world constraints and responsibilities of emergency personnel. Therefore, we chose to prioritize usability and user input by pursuing an analog solution that aligns with the cognitive and operational needs expressed by our users.

- Ecological Sustainability

HALOGRIP is a fallback steering device intended for rare emergency use in autonomous robotaxis, a vehicle category that will likely grow significantly in the coming decades. Given the increasing global awareness of sustainability, it is important to assess its ecological impact, both in terms of embedded materials and long-term use.

The concept includes mechanical components, tactile buttons, and an ID tag interface. While most parts are passive or low-power, the electronic tag and control interface involve semiconductors—components that are increasingly scarce due to rising global demand. The total quantity is, however, minimal compared to the vehicle's overall electronic load.

As the product is embedded into the dashboard, questions around repairability, disassembly, and recycling become relevant. Designing the module as a detachable unit could support circular economy principles. Since HALOGRIP is only used in emergency cases, its operational energy consumption is expected to be negligible, yet standby power draw may require further optimization.

Future work could involve a life cycle analysis (LCA) or material footprint study to determine how the solution might be refined to reduce environmental impact without compromising safety or usability.

- Societal and Ethical Considerations

HALOGRIP was developed as a response to this emerging challenge, aiming to enable first responders to manually reposition stalled autonomous vehicles and thus reduce delays or obstacles during critical operations. By focusing on safety and operational usability, the project contributes to broader goals of social sustainability.

Throughout the development process, the team worked to incorporate ethical considerations and practical needs, especially those of emergency personnel. Interviews with both floor-level firefighters and commanding officers helped ensure that different perspectives were captured—ranging from direct usability during action to procedural concerns related to authority, timing, and equipment compatibility. This dual input shaped a solution designed not just for theoretical scenarios but for the reality of high-pressure environments.

One societal issue the project highlights is the current lack of standardized manual override systems for autonomous vehicles in public settings. Participants expressed concern about the cognitive strain posed by inconsistent vehicle interfaces, particularly during time-sensitive responses. HALOGRIP addresses this by prioritizing analog interaction, tactile feedback, and visibility—key elements that participants emphasized as critical in emergency situations. However, while this design direction is promising, its long-term implementation depends on broader regulatory and industry-level adoption, which remains uncertain.

Ethical challenges also emerged during the project. The system's activation depends on physical ID tags, which introduces questions about security and responsibility. If a tag is lost or misused, unauthorized access may become a risk, and mission-critical operations may be delayed. This presents a clear need for further exploration of secure, yet accessible authentication mechanisms—possibly involving biometrics or integration into existing emergency service ID systems.

The project did not specifically address gender, accessibility, or broader inclusivity factors. Given that emergency responders represent a diverse population, future development should consider a wider spectrum of user needs, including differences in physical strength, reach, and experience with technology. These aspects are essential if the solution is to be applied at scale across different countries, services, and body types.

Lastly, it is important to reflect on the potential systemic effects of fallback steering devices becoming common in autonomous vehicles. While this project addresses a clear safety gap, the broader implication of relying on manual overrides could introduce new dependencies, responsibilities, or unintended behaviors. Future research should explore not just technical feasibility but also how these systems shape the roles and expectations of both humans and machines in shared environments.

12

FUTURE WORK

This section will present future work of the project.

- Design Compatibility with Manufacturer Branding

We recognize that the visual language of our concept may not align perfectly with the style or branding of all robotaxi manufacturers. This could potentially become a barrier to adoption, even if the functionality meets user and safety needs. In future iterations, closer collaboration with industry stakeholders may help ensure the design fits more seamlessly within a variety of vehicle interior styles.

- Movement Distance and Speed Constraints

One area that requires further investigation is the assumed maximum distance of 500 meters for moving the vehicle. This value was based on a specific case introduced early in the report, but whether it is sufficient across different emergency scenarios remains uncertain. If this distance proves to be too limited, the maximum speed of the vehicle may need to be slightly increased to ensure the entire process can be completed in under five minutes.

- Usability of the Tilt-and-Turn Interaction

The proposed tilt-and-turn steering method, where tilting controls speed and rotation controls direction, is supported in the literature as not imposing a significant cognitive burden. However, since this interaction style has not been applied in a vehicle context before, it should be tested in a driving simulator to evaluate its usability and effectiveness under realistic, time-pressured conditions. Additionally, further research is needed to determine the most user-friendly tilt and rotation angles for intuitive and accurate control.

- Integrating Two Concepts

A potential improvement for future development was suggested by a powertrain expert: combining the final analog execution-based concept with decision-based elements from Concept 4b. In this setup, the system would handle the physical execution of maneuvers, while the user could assist with decision-making in cases where the algorithm is uncertain. This reduces the risk of manual operation errors and minimizes cognitive load by letting the system perform routine tasks. At the same time, by keeping hands on the steering device—similar to Level 2 driving systems—the user remains in a position to quickly take over control when necessary. This shared control approach could offer a more robust and responsive fallback solution in emergency scenarios involving autonomous vehicles.

- Passengers

Passengers are not actively considered in the current emergency scenarios. For future development, it will be important to create clear instructions and communication strategies to guide passengers during emergencies—both to ensure their safety and to support first responders in carrying out their tasks efficiently.

For example, if the robotaxi comes to a stop and firefighters approach, sensory cues such as lights, sounds, or on-screen messages could instruct passengers to exit the vehicle or move away from the steering area. It is equally important to communicate what will happen next—for instance, whether another vehicle will be dispatched to complete their journey—in order to reduce confusion and anxiety during the incident.

- Mechanism

Many of the technical aspects of the mechanism—such as the deployment system and the tilt-based control unit—require further investigation. As mentioned earlier in the report, only examples of similar mechanisms were provided to demonstrate the potential feasibility of the concept. However, the exact configuration and engineering details of these mechanisms have not yet been developed and remain a subject for future work. The requirements that these mechanical units need to fulfill are listed in Appendix 5.

- Technical Details

The optimal turning and tilting angles of the steering device still need to be investigated to ensure user-friendly interaction. Due to the compact form of the device, it is not suitable for multiple full rotations like a traditional steering wheel. Therefore, future development should determine how much the device needs to be turned to achieve realistic vehicle steering angles, in a way that feels intuitive and easy to control for the user.

- Ergonomic

Ergonomics of the steering device were not the primary focus, as the product is intended for short-term use in emergency situations. However, later evaluations suggested that the cross-sectional size of the initial design may have been too small, with the grip area potentially unsuitable for the typically larger hands of firefighters—a predominantly male user group. A revised prototype was developed with a larger handle, but it may have become oversized, even for the target users. Further development is needed to optimize comfort and usability. To support this, ergonomic considerations have been included in the requirement list (see Appendix 5) to guide future refinement of the design.

- Companies' needs

Robotaxi companies are a key stakeholder in the system. However, since the project was user-centered and we did not have direct access to representatives from these companies, their needs such as low maintenance requirements and minimal manufacturing costs—were not the main focus of the development. Despite this, we made efforts to consider these aspects. The HALOGRIP concept features a minimalistic design and avoids a fully circular form, which reduces material usage and potentially lowers production costs compared to conventional steering wheels. Some of the robotaxi companies' needs, identified through literature reviews and expert interviews, have been included in the requirement list (see appendix 5) to support future development and ensure better alignment with industry expectations.

13

CONCLUSION

This chapter presents the conclusions drawn from the project.

A key outcome of this project was the development of a detailed problem landscape concerning emergency scenarios involving Level 4 autonomous vehicles, particularly situations where robotaxis obstruct the work of first responders. The problem analysis drew from literature reviews, expert interviews, and user studies, and revealed a critical design gap: the absence of standardized, intuitive, and locally accessible manual override systems. These challenges were mapped across several thematic areas, including operational delays, lack of responder control, interface ambiguity, and trust in autonomous technologies. The resulting framework is intended to support continued exploration of safety-critical design solutions in the automated mobility sector.

The project culminated in the final concept: HALOGRIP — a visible, analog, and retractable steering device designed to enable emergency responders to safely and intuitively reposition a stalled robotaxi. The concept builds on findings from user testing, scenario analysis, and evaluations of earlier design proposals. Its function is based on tactile interaction, a tag-based access system, and an integrated tilt-based control mechanism. These features were specifically developed to meet the situational demands of first responders: usability under pressure, minimal training requirements, and safe, low-speed maneuverability. HALOGRIP fulfills most measurable requirements defined in the specification. However, certain performance-related and experiential goals — particularly regarding long-term trust, effectiveness, and cognitive load — require further validation in live emergency response contexts.

A functional prototype should be constructed to test physical interaction fidelity, ergonomic fit, and real-time integration with vehicle control systems. Most importantly, HALOGRIP's potential to reduce intervention times and improve situational control must be tested in realistic, time-critical scenarios. These tests should also examine whether the analog interface improves user confidence or introduces new risks under stress.

While the analog approach was chosen to increase clarity and consistency, it may also limit flexibility or integration across brands. Future iterations could explore modular or hybrid interfaces that combine tactile controls with adaptive digital feedback. Additionally, the design's visual and material language may need to be adapted to align with different robotaxi brands' aesthetics. Finally, sustainability-related improvements — such as energy-efficient actuation, recyclable materials, or integration with broader vehicle reuse strategies — represent an important area for future exploration.

In conclusion, HALOGRIP offers a pragmatic, human-centered solution to an increasingly urgent issue in autonomous mobility: how to empower emergency responders when vehicles no longer include conventional controls. The project reinforces that full automation does not eliminate the need for human intervention — and that trust, clarity, and physical accessibility remain essential pillars of safe interaction in autonomous systems.

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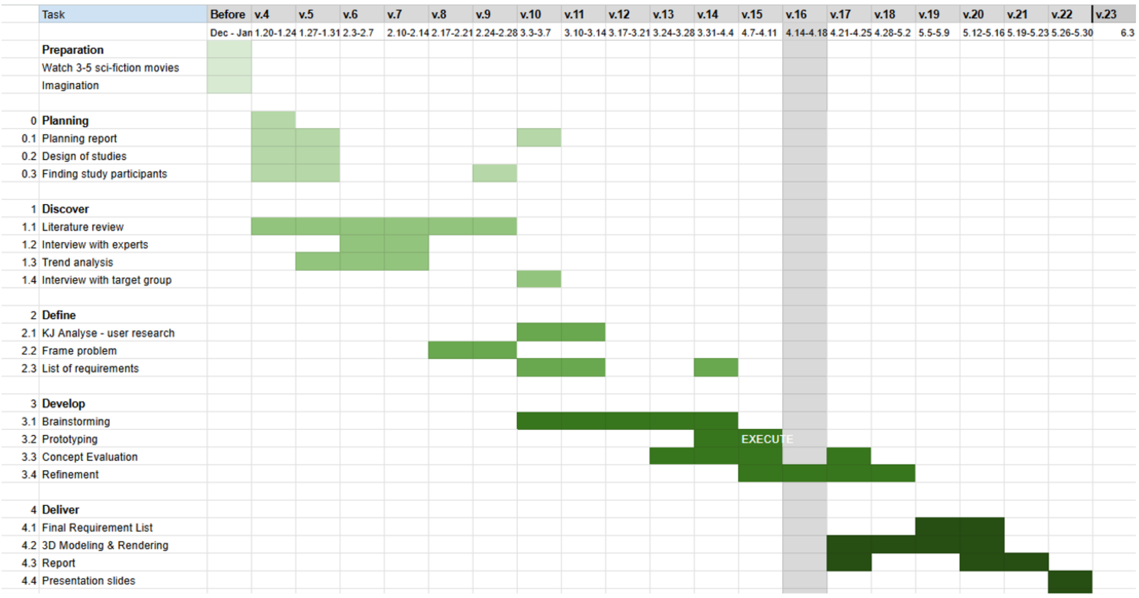
A

Appendix 1 - Gantt Schedule



	Task	Before	v.4	v.5	v.6	v.7	v.8	v.9	v.10	v.11	v.12	v.13	v.14	v.15	v.16	v.17	v.18	v.19	v.20	v.21	v.22	v.23
		Dec - Jan	1.20-1.24	1.27-1.31	2.3-2.7	2.10-2.14	2.17-2.21	2.24-2.28	3.3-3.7	3.10-3.14	3.17-3.21	3.24-3.28	3.31-4.4	4.7-4.11	4.14-4.18	4.21-4.25	4.28-5.2	5.5-5.9	5.12-5.16	5.19-5.23	5.26-5.30	6.3
	Preparation	🟩																				
	Watch 3-5 sci-fiction movies	🟩																				
	Imagination	🟩																				
0	**Planning**		🟩																			
0.1	Planning report		🟩	🟩					🟩													
0.2	Design of studies		🟩	🟩																		
0.3	Finding study participants		🟩	🟩				🟩														
1	**Discover**																					
1.1	Literature review		🟩	🟩	🟩	🟩	🟩	🟩														
1.2	Interview with experts				🟩	🟩																
1.3	Trend analysis			🟩	🟩	🟩																
1.4	Interview with target group								🟩													
2	**Define**																					
2.1	KJ Analyse - user research								🟩	🟩												
2.2	Frame problem						🟩	🟩														
2.3	List of requirements								🟩	🟩			🟩									
3	**Develop**																					
3.1	Brainstorming								🟩	🟩	🟩	🟩	🟩									
3.2	Prototyping												🟩	🟩 EXECUTE								
3.3	Concept Evaluation											🟩	🟩	🟩		🟩						
3.4	Refinement													🟩	🟩	🟩	🟩					
4	**Deliver**																					
4.1	Final Requirement List																	🟩	🟩			
4.2	3D Modeling & Rendering															🟩	🟩	🟩	🟩			
4.3	Report															🟩			🟩	🟩		
4.4	Presentation slides																				🟩	

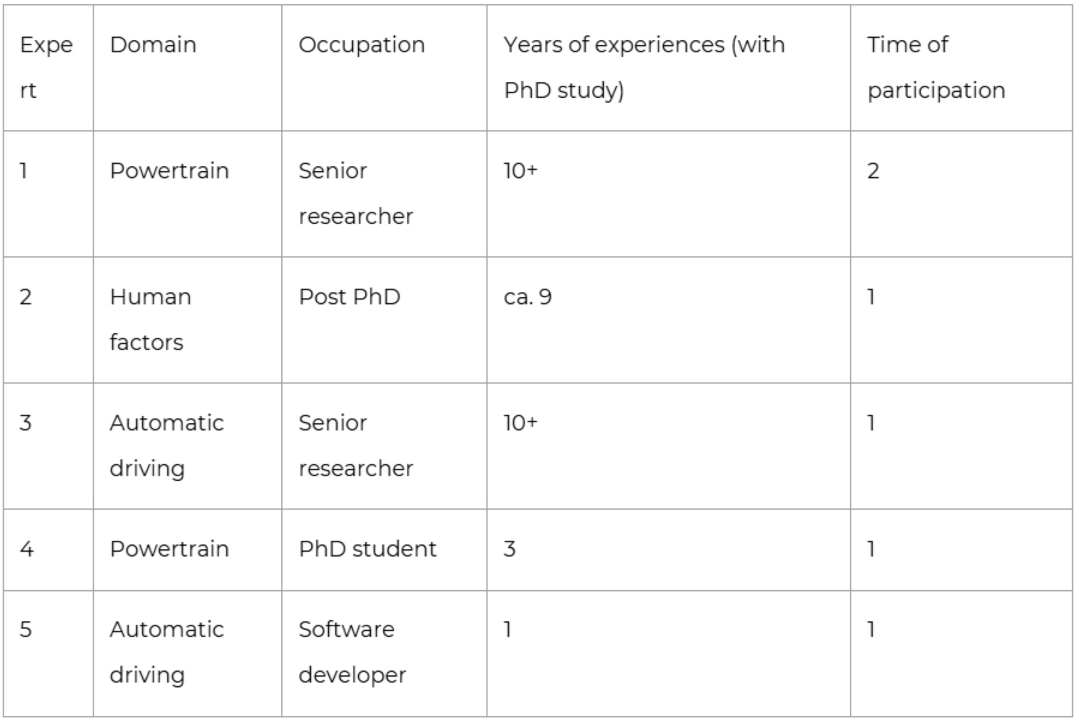
B

Appendix 2 – Selection of Participants

Two groups of participants were involved in the in-depth interviews conducted in this project: experts and users. The rationale for selecting these groups lies in the context of the study, which was conducted in Sweden, where robotaxis have not yet been implemented. Consequently, the target users—emergency personnel—have no prior experience with such vehicles. By combining insights from these users with the knowledge of experts working within the field of automotive, the study aims to produce a more informed and accurate prediction of market expectations and potential user needs.

Experts

The main criterion for selecting experts in this study was their years of experience. Two out of the five experts had over ten years of experience in the automotive industry. Another important criterion was their familiarity with the Chinese car market; three of the five experts had prior experience working in this context. Given that China is one of the leading markets for robotaxi development, their background offered valuable insights into future trends and adoption. As the final solution in this project was intended for end users, and four out of the five experts focused primarily on technical aspects, a human factors expert was also included to ensure that the final concept remained user-centered.

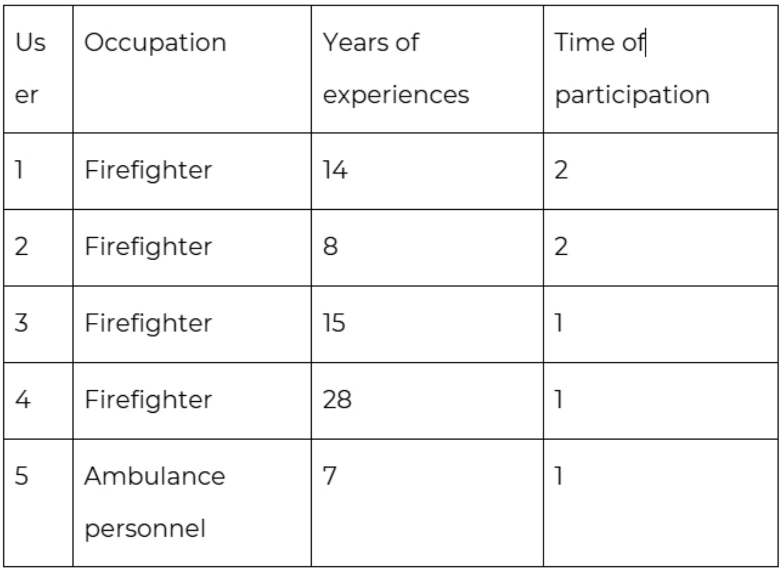


Expert	Domain	Occupation	Years of experiences (with PhD study)	Time of participation
1	Powertrain	Senior researcher	10+	2
2	Human factors	Post PhD	ca. 9	1
3	Automatic driving	Senior researcher	10+	1
4	Powertrain	PhD student	3	1
5	Automatic driving	Software developer	1	1

Users

The selection of the user group within the category of emergency personnel—ambulance, police, and fire services—was based on two main factors: the size of their vehicles and their respective roles in emergency scenarios. Firefighters were chosen as the primary user group, as fire trucks are the largest emergency vehicles and, in Sweden, firefighters are authorized to take any necessary actions to save lives in critical situations. This authority places them in a unique position to potentially address challenges that other emergency personnel, such as ambulance staff, might encounter when interacting with robotaxis. One ambulance personnel was also involved in the study to contribute additional insights from a different perspective within the emergency services.

Participants were selected primarily based on their availability and years of professional experience. The users involved had between 7 and 28 years of experience, which provided them with deep familiarity with a wide range of emergency scenarios. Their extensive expertise enabled them to offer valuable input regarding potential strategies and considerations for future situations involving robotaxis.



User	Occupation	Years of experiences	Time of participation
1	Firefighter	14	2
2	Firefighter	8	2
3	Firefighter	15	1
4	Firefighter	28	1
5	Ambulance personnel	7	1

C

Appendix 3 – Firefighter Interview

Grundläggande frågor

Namn:
Ålder:
Kön:
Längd:
Nationalitet:
Arbetserfarenhet:

Professionella frågor

1. Vilka områden i Göteborg är de mest utmanande för räddningstjänsten? Varför?
2. Har du någon gång stött på extrema väderförhållanden, såsom kraftig dimma, under din karriär? Hur säkerställer du en trygg körning i sådana situationer?
3. Använder du handskar när du sitter i brandbilen?
4. Vilken storlek på handskar är vanligast i användning?

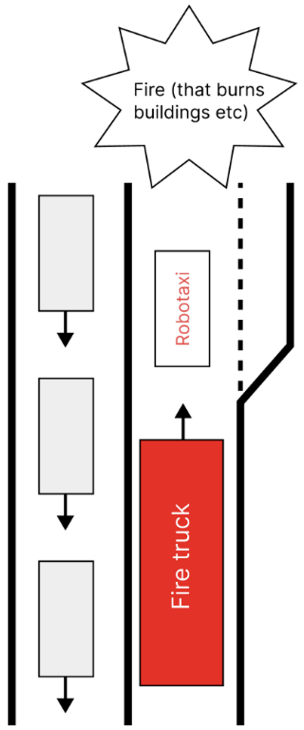
Scenario 1: Fast i en brandbil

Föreställ dig att vi befinner oss år 2035, och robotaxibilar testas i Göteborg.

Robotaxibilar är självkörande taxibilar som navigerar och hanterar situationer med hjälp av avancerade algoritmer. När de stöter på okända eller komplexa situationer tar en fjärroperatör över för att fatta beslut. Dessa robotaxibilar är generellt försiktiga och intelligenta och brukar kunna identifiera utryckningsfordon och stanna på en säker plats.

Men en dag, under ett räddningsuppdrag, inträffar en olycka som orsakar en stor trafikstockning. Vägen är blockerad, och en robotaxi har fastnat eftersom den inte kan hitta en säker zon att parkera på. Detta förhindrar dig från att nå olycksplatsen.

Du vet inte hur lång tid det kommer att ta innan fjärrstyrningen tar över och flyttar bilen, men baserat på tidigare erfarenhet kan det ta mellan 5 och 10 minuter. Du börjar känna stress, eftersom varje minut är avgörande.



I en vanlig situation där en stillastående bil blockerar vägen. . .

1. Hur brukar ni hantera sådana situationer?
2. Hur lång tid uppskattar du att det tar att lösa problemet, och hur många personer brukar behövas?
3. Vilka verktyg kan vara användbara?
4. Skulle dessa metoder vara tillämpbara i det här scenariot?
5. Vem skulle sannolikt vara den som styr bort fordonet/robotaxin – brandbilsföraren eller andra brandmän som sitter i baksätet?

Robotaxibolaget föreslår två lösningar för att manuellt styra bort fordonet:

Första förslaget: Efter att ha gått in i det autonoma fordonet (AV), trycker du på en knapp för att ansluta till fjärrassistans och begär tillstånd att manuellt styra. När godkännande ges, får du instruktioner om att trycka på en knapp som aktiverar en styranordning, vilket gör det möjligt att flytta fordonet.

Andra förslaget:

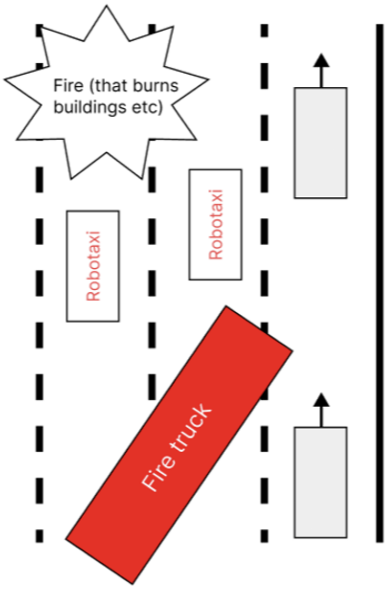
Efter att ha gått in i det autonoma fordonet (AV), använder du en tagg för att begära tillstånd, trycker på en knapp för att avaktivera det autonoma körläget och därefter trycker på en annan knapp som aktiverar en styranordning, vilket gör det möjligt att styra fordonet bort från vägen.

Frågor:

1. Föredrar du någon av dessa lösningar framför er nuvarande metod?
2. Har du några förslag på förbättringar?

Scenario 2: Robotaxi vid en brandplats

I detta scenario har en robotaxi stannat vid en brandplats. Eftersom fordonet identifierar branden som en fara vägrar det att köra vidare och lämna området. Du bestämmer dig för att påbörja räddningsinsatsen medan robotaxin står kvar på platsen.



Vad skulle du föredra?

1. Att robotaxin stängs av helt och förblir stilla tills räddningsarbetet är avslutat, för att undvika risken att den plötsligt får en signal att köra iväg och skadar en brandslang?
2. Eller att den lämnar platsen så snart som möjligt, även om det innebär att den tillfälligt kör över en brandslang?

D

Appendix 4 - KJ-Analysis

Insuffient strategies - moving stalled cars (fire fighter)

"It's not that easy to move a car like it is to move a flower pot ...I see it's pretty difficult."

using vinsch to connect with the robotaxi and drag away

Problem of using vinsch is needing a large space to move

Our ordinary fire truck face this case can use vinsch, but ladder one doesn't have this tool

"I'm thinking about just pushing it away with a heavy truck."

Insuffient strategies - moving stalled cars (fire fighter)

Conclusion

- there are insuffient strategies and tools for moving stalked robotaxi
  - vinsch need too much time and space
  - push need space
  - ask other firetruck to go another way - waste labor

time concern - moving stalled cars (robotaxi company)

"five to 10 minutes is a long time. Yeah, it's too long."

time concern - moving stalled cars (robotaxi company)

Conclusion
- 5 -10 min of driving away robotaxi is too slow
- ideally within 3min

Needs
- should be within 3 min

Concern for passenger in car

If there's a passenger sitting behind and you breaking the window, they may get scared.

Concern for passenger in car

conclusion
- in case of too close to the fire scene, let the passanger out
- if just driving a few meter away, and it is safe passenger could just stay

Demand for standlization

if each company will have a slight difference of how to deal with things

Nothing unfamiliar for us. We do it sometimes with cars that are not our own cars

if every company would have 30 pages for us, then we wouldn't be doing anything else than reading

Then maybe we can have a key or something in our firetruck, and then use it as a regular vehicle

" get authorization to drive it ourselves. That would take a long time."

Demand for standlization

Conclusion
- Firefighters have concern of having different kind of steering device and they are used in different way. Increase the risk of error and wasting of time.
- Inplicitly, want law to standralisted the way to work with activation of steering device

Need
- Should align with their mental model, should follow the usual driving behavior pattern

Who will be the one driving the robotaxi

five firefighters in a firetruck, one for driving

Who will be the one driving the robotaxi

Need
- should not require overly precis movment to allow fire fighter with more equipment to use the steering device.

Remote operator

It's gonna be a little bit of take on time to be able to contact the remote driver

Local operator

Overall concern about Robotaxi

"Do I even have a possibility to break"

"to steal the car, could you do that the same way?"

Overall concern about Robotaxi

Conclusion
-

Needs
- Want to have possible to stop the driving vehical

Demand - sense of control

"I think I prefer it just to freeze. Just stand still."

Senario 2: I would like to drive away but depends on situation

"I like the one that will smash the window and open it all."

Its' staying could interfere more with our work

I would not like they to drive away when I'm not aware of it.

Demand - sense of control

Conclusion
- smash the windows to freeze the robotaxi it good
- Some of them want to get direct authorization without going though remote driver
- Some of them want to get assitance from remote assitant to avoid error.
- Concern of unfaimlar technique/rutine
- Local assitance have it limitation of effecietly scenario

Needs
- needs of controll when to freeze
- needs of unlock the car and move
- Direct local authorization
- Provide design clues and instructor (ex. get authorization)
- Get direct contact with help/assitance from robotaxi company.

E

Appendix 5 - Requirement List

Table E.1: Design Level

Level	**System view**	**Description**
Effect	Socio-technical system	Move a stalled robotaxi away in case of interrupting any emergency rescue
Usage	Human-machine system	Manually and locally input commands into the vehicle about how and where to move
Architecture	Machine system	A steering device that connects to the vehicle's steering system via steer-by-wire to send signals and steer the vehicle away
Interaction	Machine interfaces	Design of the physical form and/or user interface

Level	**Design**	**Detail resolution of requirements and guidelines**
Effect	Move a stalled robotaxi away in case of interrupting any emergency rescue	**(Use, User and Stakeholder) Needs** Firefighter: 1. The solution must have fewer labors than exiting strategies 2. The system must enable rapid vehicle activation to minimize response time 3. The system must prevent unauthorized use 4. Easy operation, without requiring highly precise movements 5. The firefighter must have full control over the robotaxi's movement and stopping to ensure operational safety 6. The system must allow stable maneuvering in high-pressure and cluttered environments while ensure safety of the operator and other pedestrian 7. The system must allow quick and straightforward authorization for manual control of the robotaxi 8. The system must provide clear guidance and assistance when navigation errors occur **Robotaxi companies:** 1. Require minimal maintenance cost

Use	Manually and locally input commands into the vehicle about how and where to move	**Use requirements** 1. The solution must not require more than one operator per vehicle 2. The vehicle is required to be ready for movement within a maximum of three minutes. 3. Unauthorized personnel must not be able activate the system 4. *The firefighter must have full control over the robotaxi's movement and stopping to ensure operational safety* a. Freeze vehicle functions b. Stopping function c. Activate the manual model 5. The system should operate at a maximum speed of 15 km/h 6. Direct local authorization (from remote operator to local operator) must be supported 7. *The system must provide clear guidance and assistance when navigation errors occur* a. Direct access to robotaxi company assistance **Use Guideline** 8. The system must support operation with reduced precision input and accommodate users wearing protective gear, such as thick clothing. 9. During operation, the product must ensure the safety of the operator, vehicle occupants, and surrounding pedestrians. 10. The product should require minimal learning time

Architecture	A steering device that connects to the vehicle's steering system via steer-by-wire to send signals and steer the vehicle away	**Machine requirements** 1. The system shall automatically activate the Head-Up Display (HUD) when the steering wheel is manually adjusted from its stowed position. 2. There should be tactile feedback indicating the position of the controls, helping the user distinguish whether the movement will result in forward motion, is in the neutral position, or will cause backward motion. 3. The deployment mechanism shall incorporate redundancy in critical components such as springs or latches to ensure fail-safe operation in the event of single-point failure. 4. Increases deployment system reliability in emergency scenarios by minimizing dependence on electronic components. **Machine guideline** 5. The pull-out mechanism of the steering wheel shall be designed to ensure high durability and resistance to damage, while enabling a smooth and rapid extension motion 6. The steering wheel dimensions must be ergonomically optimized to ensure a comfortable grip 7. The angle of acceleration and braking controls must support natural body posture and minimize ergonomic strain.

Interaction	Design of the physical form and/or user interface	**Sub-system requirements** 1. HUD: The text shall be easily legible from the intended driving position without causing strain or distraction. 2. HUD: The speed shall be displayed in a way that enables the driver to quickly and intuitively perceive it while maintaining focus on the road. 3. B pillar interface: The system must provide visual cues during user's ID verification to indicate the current status. 4. Form of steering wheel: The shape and contour of the steering wheel shall support intuitive hand placement and reinforce correct driving posture. 5. Mechanism: The device shall deploy at a controlled speed to ensure a smooth and gradual motion that minimizes the risk of startling the user 6. Buttons: The parking function button and the remote assistance button should be clearly distinguishable from each other to avoid confusion. 7. Buttons: Buttons must be large and tactile **Sub-system guideline** 8. Form of steering wheel : The steering wheel component must have a minimized volume to reduce material costs while ensuring ergonomic comfort and usability.

#	**Effect Guideline**	**Cause/Effect**	**Source**	**Fulfillment**
1	Require minimal maintenance cost (robotaxi companies)	High maintenance cost was flagged by autonomous tech experts as a potential barrier to adoption by robotaxi companies	Interview with experts	Future work

#	**Use Requirement**	**Cause/Effect**	**Source**	**Fulfillment**
1	Require minimal maintenance cost (robotaxi companies)	High maintenance cost was flagged by autonomous tech experts as a potential barrier to adoption by robotaxi companies	Interview with experts	Future work
2	The vehicle is required to be ready for movement within a maximum of three minutes.	Firefighters state "5–10 min is long" → system ready around 3 min, moves arout 500m in 2 min at 15km/h → Totalt under 5 minuter	Interview with firefighters	Theoretically possible, but requires further testing
3	Unauthorized person must not be able activate the system	Allowing an unauthorized person to operate the robotaxi could result in vehicle theft and pose significant safety risks to the vehicle, the individual, and any occupants.	Interview with experts	A tag is required for activation of the system, preventing unauthorized people from using
4a	Freeze vehicle functions	The firefighters want to have full control over the robotaxi's movement and stopping to ensure operational safety	Interview with firefighters	Parking button

4b	Stopping function	The firefighters want to have full control over the robotaxi's movement and stopping to ensure operational safety	Interview with firefighters	Pulling the handle toward the operator activates the brake.
4c	Activate the manual model	Some of the users want to be able to manually steer away the robotaxi.	Interview with firefighters	Touching the sensing tag on the steering wheel activates manual mode.
5	The system should operate at a maximum speed of 15 km/h	Low speed is preferred due to chaotic scenarios and safety	Interview with experts	The system only allows a maximum speed of 15km/h
6	Direct local authorization (from remote operator to local operator) must be supported	The current solution by Waymo, which involves authorization switching from autonomous to manual mode, appears too complex and time-consuming for high-stakes environments.	Literature review	Activation of the steering wheel deployment automatically authorizes manual control.
7a	Direct access to robotaxi company assistance	Firefighters concerned about unfamiliar routines — suggest prioritized direct support channels for emergency personnel.	Interview with firefighters	Remove assistant button

#	**Use Guideline**	**Cause/Effect**	**Source**	**Fulfillment**
8	The system must support operation with reduced precision input and accommodate users wearing protective gear, such as thick clothing.	Most firefighters sitting in the fire truck wear heavy equipment.	Interview with firefighters	The steering movement doesn´t require fine motor control or precise finger movements
9	The product should require minimal cognitive burden during operation.	Some concepts place higher cognitive demands on the user and pose a risk of overlooking movements in the vehicle's surroundings.	Concept development	Only crucial information will be displayed on the HUD.
10	The product should require minimal learning time	Firefighters reported that many brand of electric vehicle requires its own specific setup, which they must memorize in order to interact with the vehicles effectively.	Interview firefighters	The Halogrip is analog and designed to resemble a traditional steering wheel. Its forward and backward steering logic follows the same logic as in gaming controls.

#	**Architecture Requirement**	**Cause/Effect**	**Source**	**Fulfillment**
1	The system shall automatically activate the Head-Up Display (HUD) when the steering wheel is manually adjusted from its stowed position.	Minimizes cognitive effort by removing the need for manual HUD activation	Design principle – Minimize user cognitive load	HUD activates automatically
2	There should be tactile feedback indicating the position of the controls, helping the user distinguish whether the movement will result in forward motion, is in the neutral position, or will cause backward motion.	Prevent error	Prototype evaluation	Provides resistance in the neutral position to signal that a directional change is imminent.
3	The deployment mechanism shall incorporate redundancy in critical components such as springs or latches to ensure fail-safe operation in the event of single-point failure.	The device is intended for emergency use, where failure is not acceptable. Redundancy ensures reliable operation even if a single component malfunctions.	reliability engineering principles, systems intended for emergency use must be fail-safe and tolerate single-point failures (Pahl et al., 2007).	Future work
4	Increases system reliability in emergency scenarios by minimizing dependence on electronic components.	Electrical components are generally more prone to failure than mechanical ones.	According to the reliability engineering principle	Future work

#	**Architecture Guideline**	**Cause/Effect**	**Source**	**Fulfillment**
5	The pull-out mechanism of the steering wheel shall be designed to ensure high durability and resistance to damage, while enabling a smooth and rapid extension motion	Align with other emergency equipment characteristics	Analysis of emergency equipment characteristics	Future work
6	The steering wheel dimensions must be ergonomically optimized to ensure a comfortable grip	Ergonomic	Prototype evaluation	Future work
7	The angle of acceleration and braking controls must support natural body posture and minimize ergonomic strain.	Ergonomic	Prototype evaluation	Future work

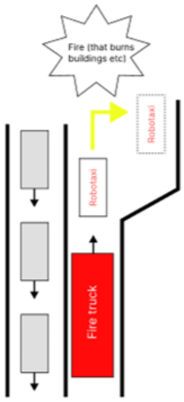
#	**Interaction Requirement**	**Cause/Effect**	**Source**	**Fulfillment**
1	The text shall be easily legible from the intended driving position without causing strain or distraction. (HUD)	Ergonomic considerations.	Human factors and ergonomic design principles	Theoretically, it should work, but require further testing.
2	Crucial information such as speed, shall be displayed in a way that enables the driver to quickly and intuitively perceive it while maintaining focus on the road. (HUD)	Crucial information must be quickly and accurately perceived to enable smooth operation	Human factors and ergonomic design principles	The speed, steering instruction and mode are considered crucial information, and they are placed on the HUD that should not distract the operator.
3	The system must provide visual cues during the users ID verification to indicate the current status. (B pillar)	To reduce user uncertainty and ensure efficient access	Human-machine interaction (HMI) principles	Visual cues in the form of icons and text are provided.
4	The shape and contour of the steering wheel shall support intuitive hand placement and reinforce correct driving posture. (Form of steering wheel)	An intuitive form reduces cognitive load and enables faster response under stress.	Concept development	The grip is positioned for easy recognition and accessibility.

5	The device shall deploy at a controlled speed to ensure a smooth and gradual motion that minimizes the risk of startling the user (Mechanism)	Usability	Concept development	Future work
6	The parking function button and the remote assistance button should be clearly distinguishable from each other to avoid confusion. (Buttons)	Usability	Interview with firefighters	Distinguish with a different logo
7	Buttons must be large and tactile (Buttons)	To enable all the firefighter	Interview with firefighters	Buttons are tactile and should be big enough even for firefighter's heavy uniform

#	**Interaction Guideline**	**Cause/Effect**	**Source**	**Fulfillment**
8	The steering wheel component must have a minimized volume to reduce material costs while ensuring ergonomic comfort and usability. (Form of steering wheel)	Consider of robotaxi companies need	Design-for-manufacturing (DFM) principles	Compared to a conventional circular steering wheel, Halogrip is more compact and does not form a full circle, which contributes to reduced material usage and potentially lower manufacturing costs.

F

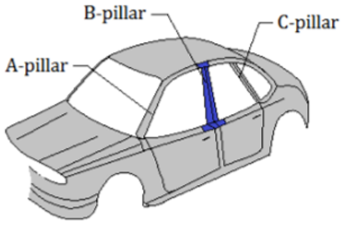
Appendix 6 - HUD Scenario



Here's the situation: you're en route to an emergency scene when a robotaxi ends up blocking the way. Your task is to exit the fire truck and manually steer the robotaxi a few meters away (as showcase in the picture). You already have some knowledge in mind

1. You have a **tag** on you, it is used for verifying your identity in order to **unlock the car door**.
2. To manually move the robotaxi, you'll need to switch it from **autonomous** to **manual** driving mode.
3. A visible steering device will be located somewhere inside the car, which **must be activated** before it can be used.
4. **A button** for calling **remote assistant** will be on or close to the steering device

When you come closer to the robotaxi you see something on the B-pillar ...



Now, imagine yourself in the situation—we're switching to the first-person perspective...

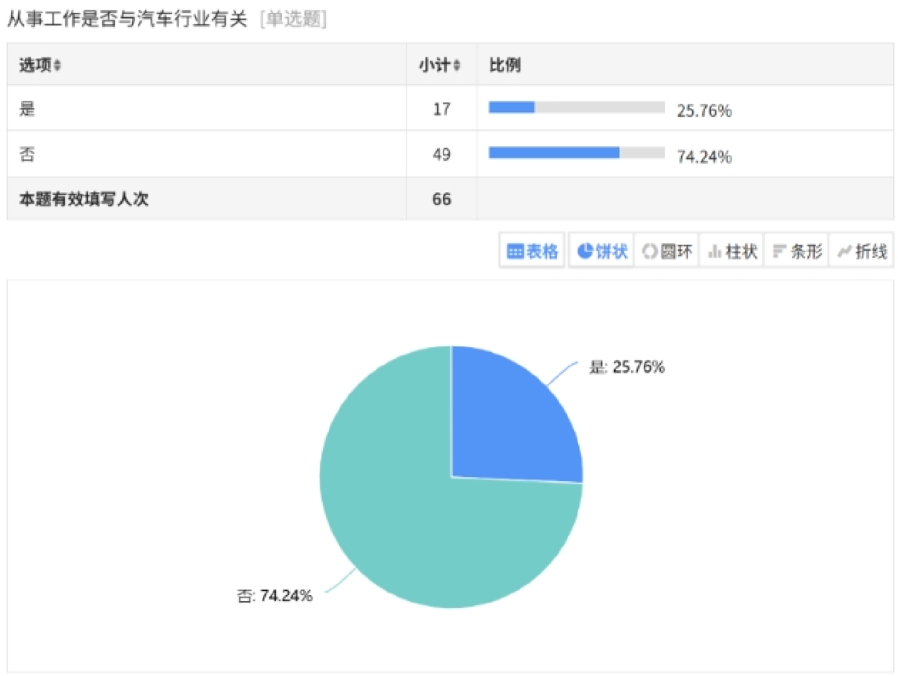
At each step, explain what you think the information means and how you would act based on it.

G

Appendix 7 - Questionnaire (Public Attitude)

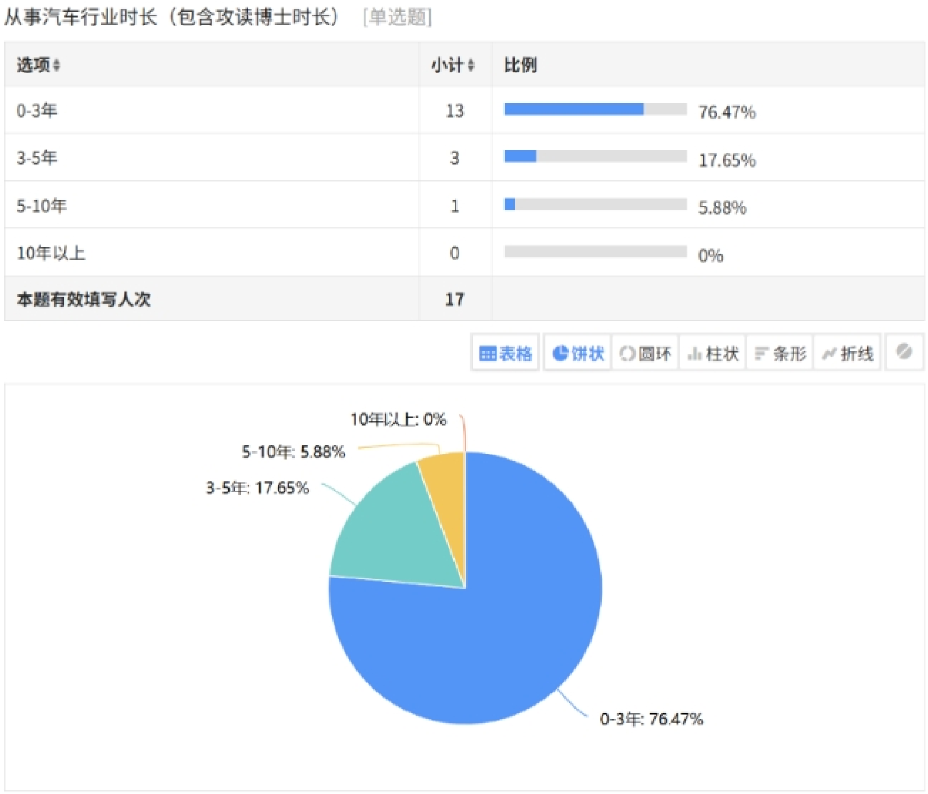
G.1 Result from the Chinese version questionnaire

66 responses



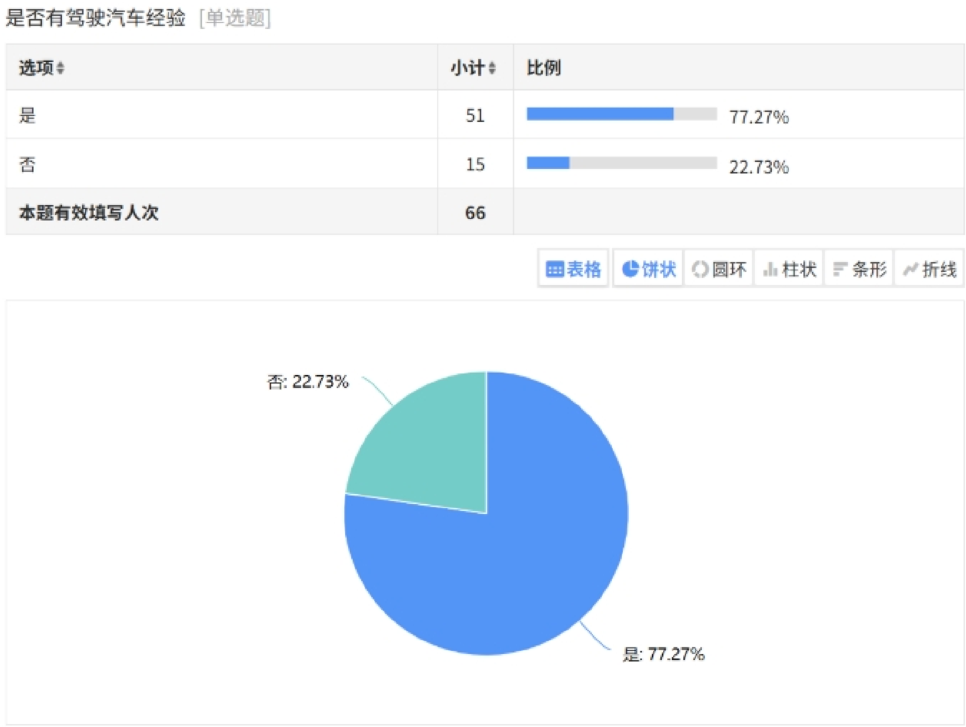
从事工作是否与汽车行业有关 [单选题]

选项	小计	比例
是	17	25.76%
否	49	74.24%
本题有效填写人次	66	



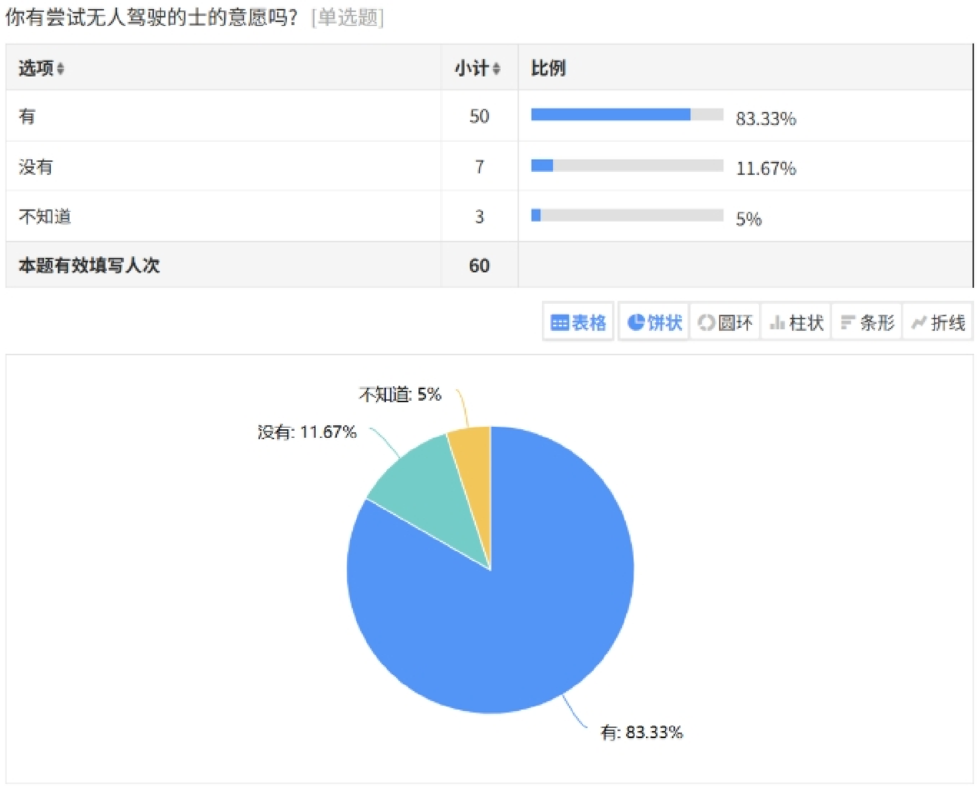
从事汽车行业时长（包含攻读博士时长） [单选题]

选项	小计	比例
0-3年	13	76.47%
3-5年	3	17.65%
5-10年	1	5.88%
10年以上	0	0%
本题有效填写人次	17	



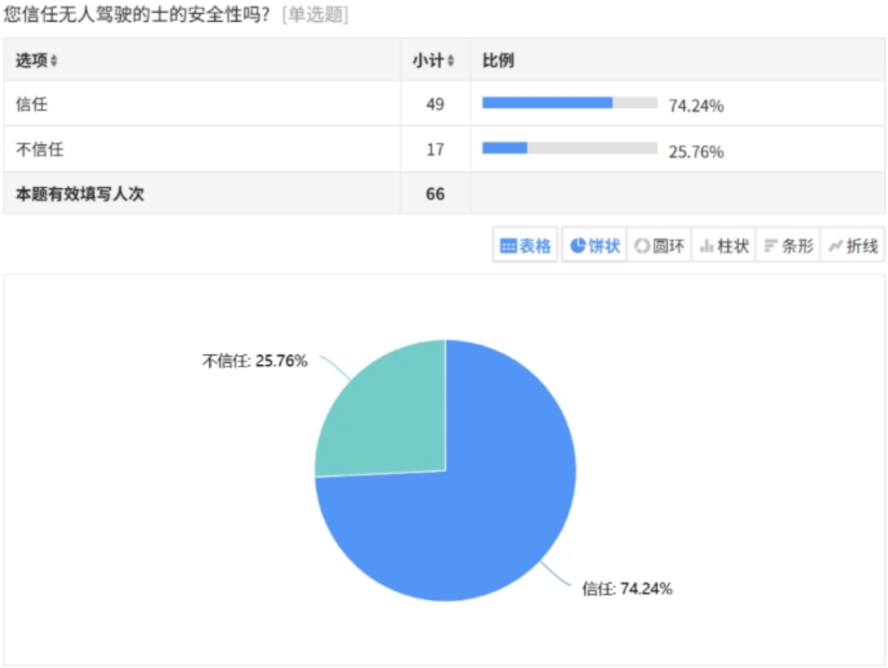
是否有驾驶汽车经验 [单选题]

选项	小计	比例
是	51	77.27%
否	15	22.73%
本题有效填写人次	**66**	



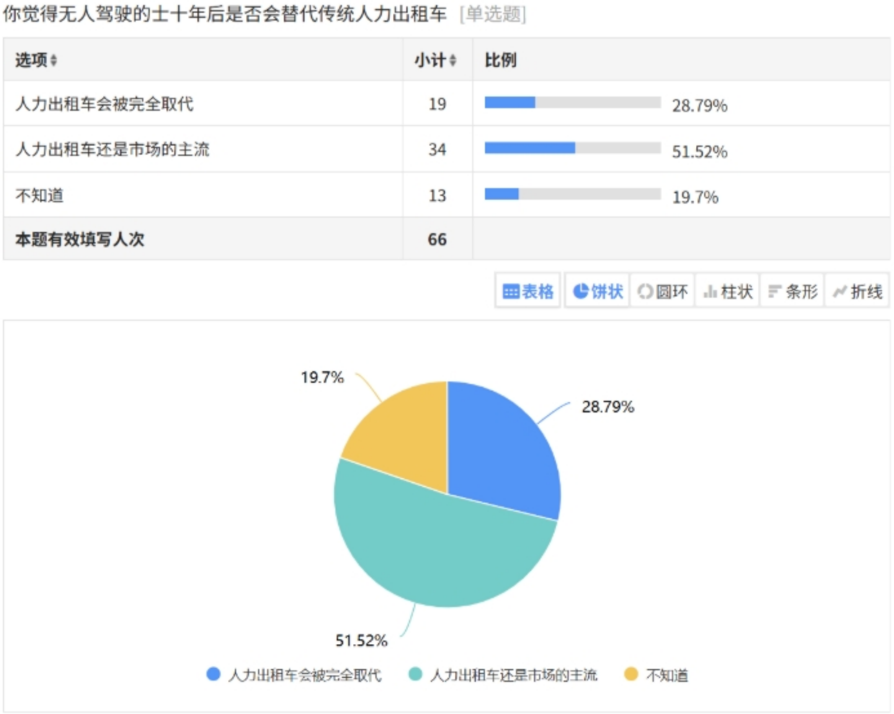
你有尝试无人驾驶的士的意愿吗? [单选题]

选项	小计	比例
有	50	83.33%
没有	7	11.67%
不知道	3	5%
本题有效填写人次	**60**	



您信任无人驾驶的士的安全性吗？［单选题］

选项	小计	比例
信任	49	74.24%
不信任	17	25.76%
本题有效填写人次	**66**	



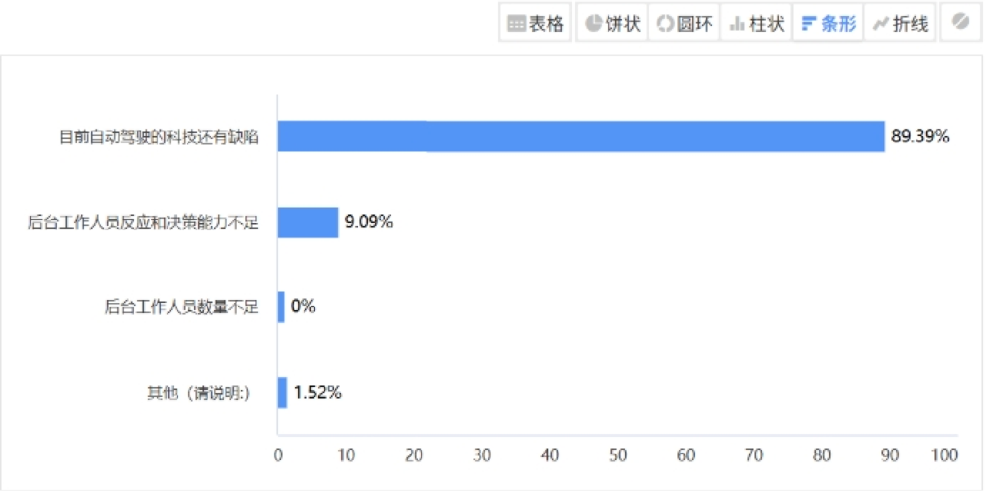
你觉得无人驾驶的士十年后是否会替代传统人力出租车［单选题］

选项	小计	比例
人力出租车会被完全取代	19	28.79%
人力出租车还是市场的主流	34	51.52%
不知道	13	19.7%
本题有效填写人次	**66**	

目前无人驾驶的的士都通常配备远程安全员，这会有助于提高乘客的信任度吗［单选题］

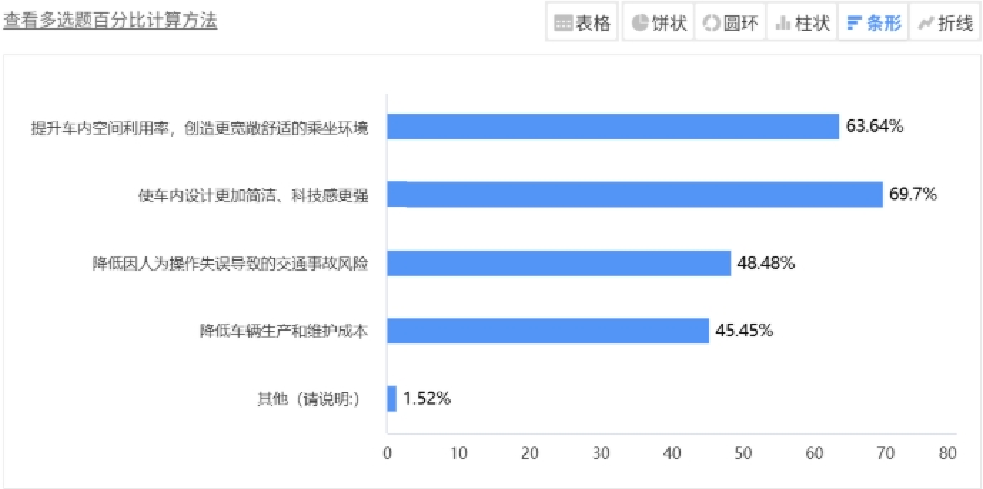
选项	小计	比例
会	60	90.91%
不会	6	9.09%
本题有效填写人次	**66**	

你认为造成这种混乱的主要原因是什么 [单选题]



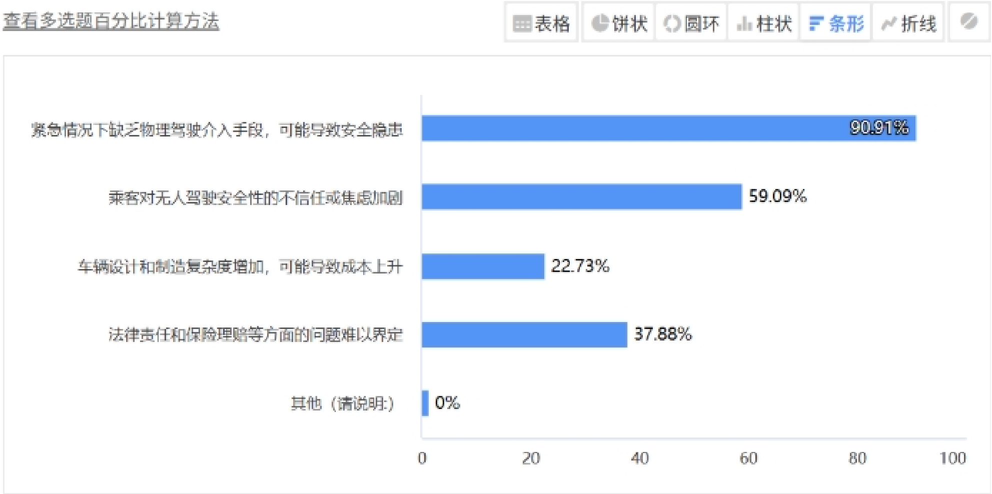
您认为无人驾驶的士取消车内传统方向盘将会带来哪些好处？（可多选） [多选题]

查看多选题百分比计算方法

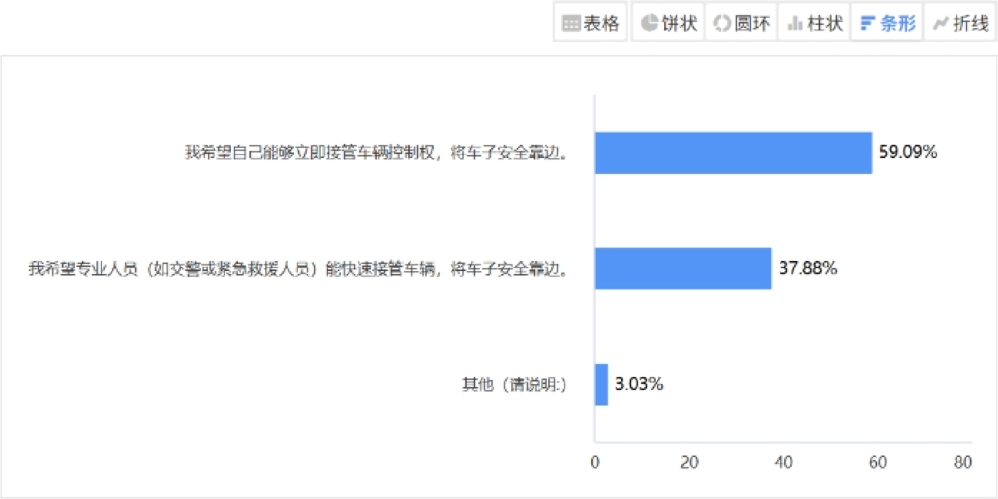


您认为无人驾驶的士取消车内传统方向盘可能带来哪些不利影响？（可多选） [多选题]

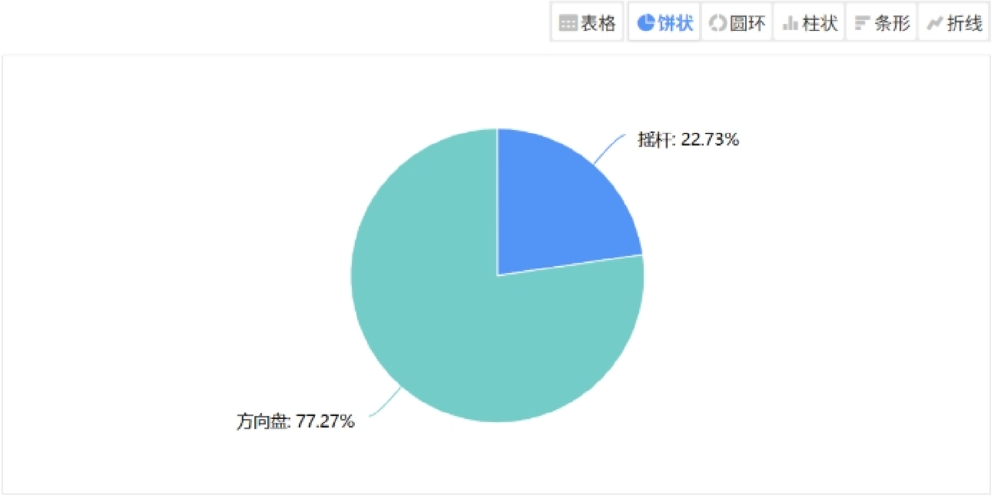
查看多选题百分比计算方法



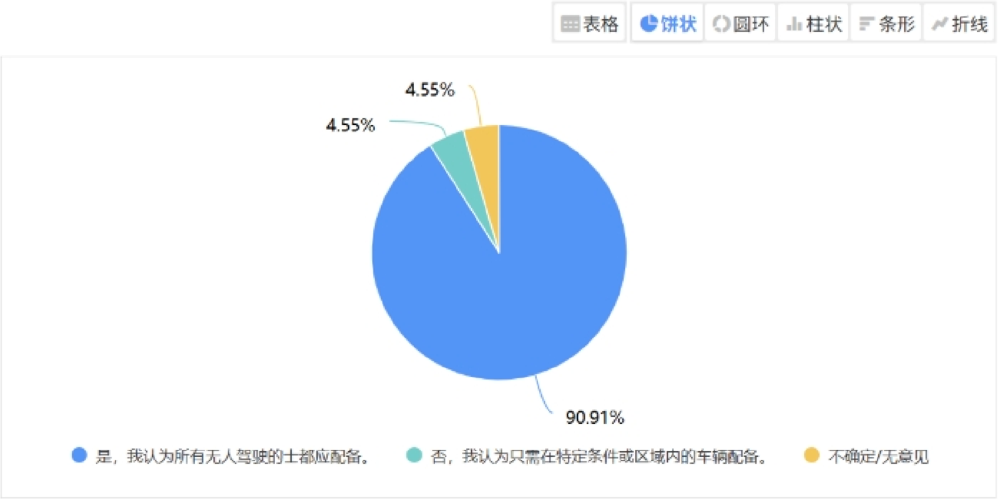
假设您正在乘坐无人驾驶的士，车子突然因故障停下导致交通堵塞，您更希望如何应对？ [单选题]



你觉得这个特殊情况（短距离用低速驶离（10-20km/h））下使用的备用驾驶装置，以下哪个你觉得更可靠更安全，为什么 [单选题]



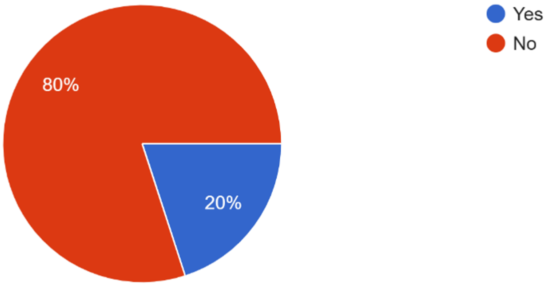
您认为每辆自动驾驶的士是否都应该配备车内紧急驾驶装置？ [单选题]



G.2 Result from the English version questionnaire

14 Resopnses

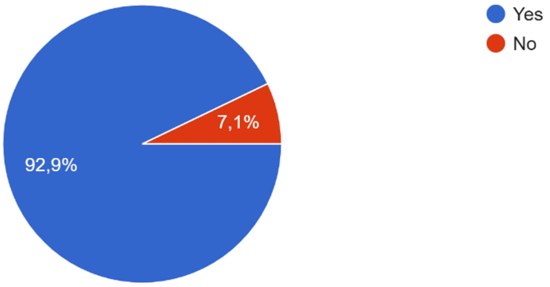
Is the job related to the automotive industry?
10 svar



How many years have you worked in the automotive industry (including time spent during your PhD studies)?
5 svar

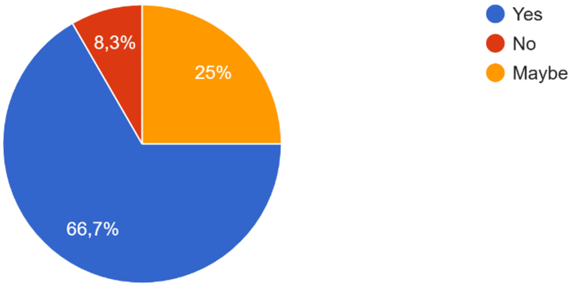
Do you have experience driving a car?

14 svar



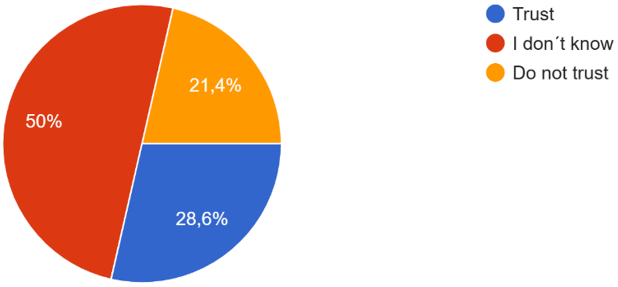
Would you be willing to try riding an automatic taxi?

12 svar



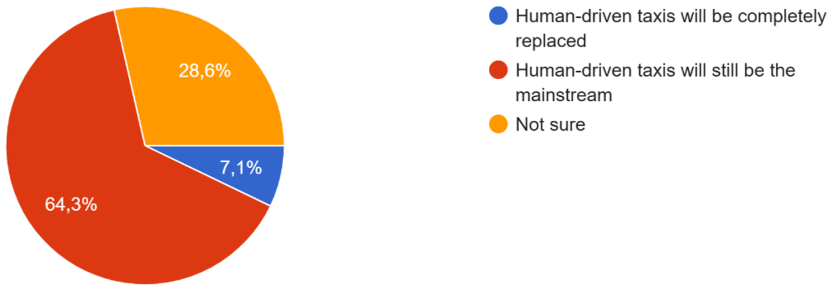
Do you trust the safety of automatic taxis?

14 svar



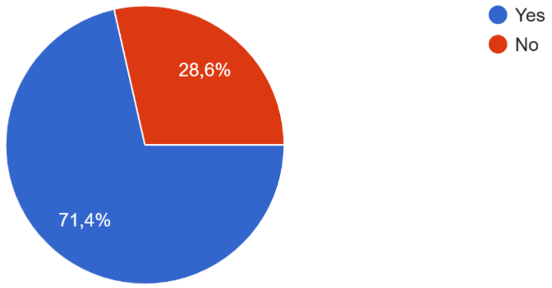
Do you believe that in ten years automatic taxis will replace traditional human-driven taxis?

14 svar



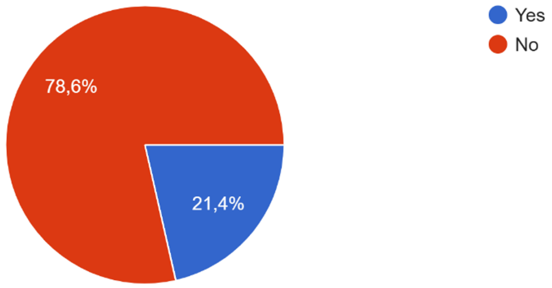
Currently, automatic taxis usually have a remote safety operator. Do you think this will help increase passengers’ trust?

14 svar



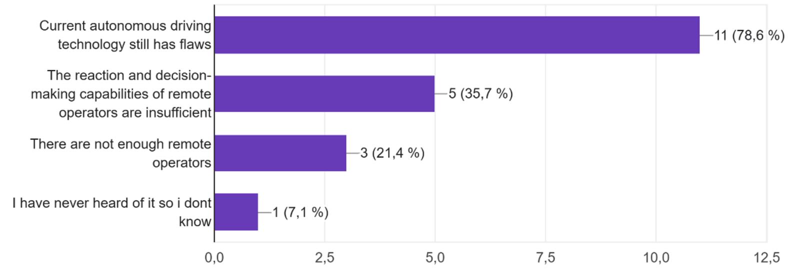
Have you heard of or encountered a situation where an autonomous taxi malfunctioned (e.g., stopping at an inopportune time) and caused traffic congestion?

14 svar



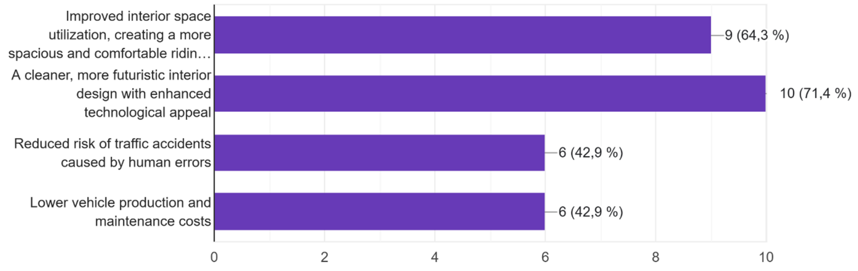
In your opinion, what is the main cause of such traffic disruptions?

14 svar



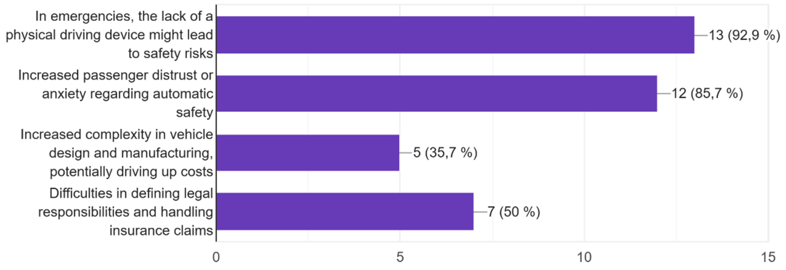
What benefits do you think could result from removing the traditional steering wheel in automatic taxis? (Select all that apply)

14 svar



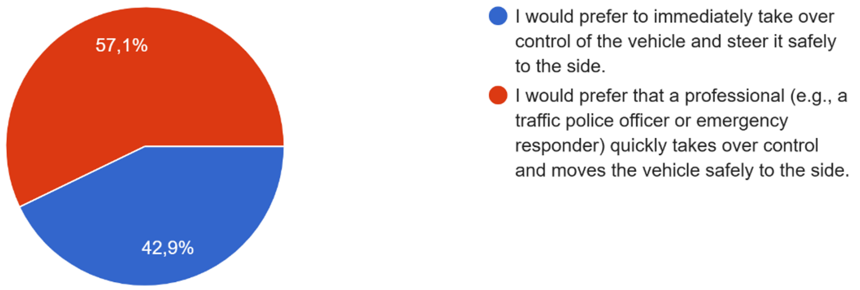
What potential drawbacks do you think could arise from removing the traditional steering wheel in automatic taxis? (Select all that apply)

14 svar



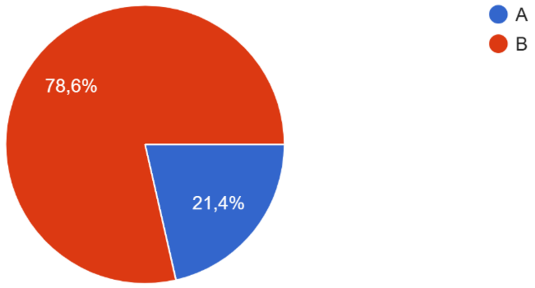
Imagine you're in an automatictaxi that suddenly malfunctions and creates a traffic jam by stopping at an inconvenient location. With remote assistance...uld be your preferred way to handle the situation?

14 svar



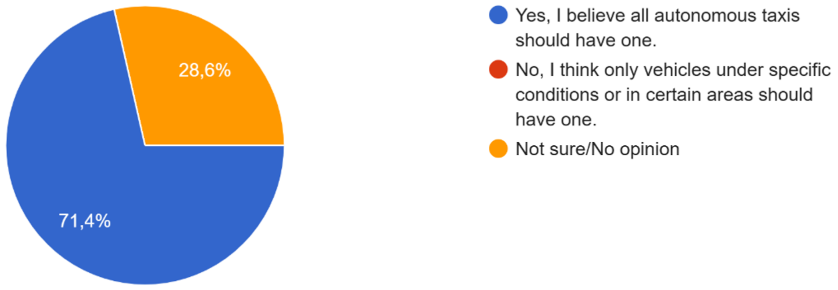
In an emergency situation where you need to use a backup steering device to slowly maneuver the vehicle (at 10–20 km/h) to a safe area, which device ...u believe offers the highest reliability and safety?

14 svar



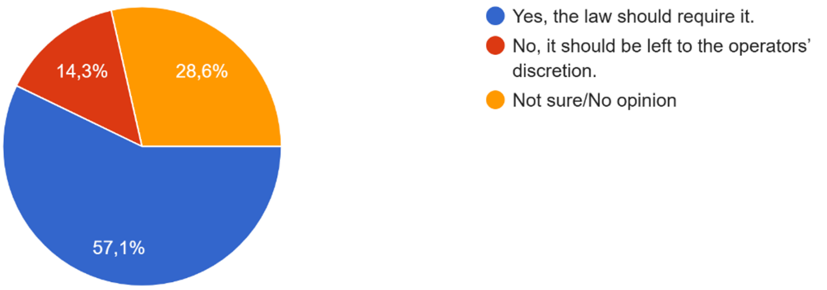
Do you think every automatic taxi should be equipped with an in-cabin emergency driving device in the future?

14 svar



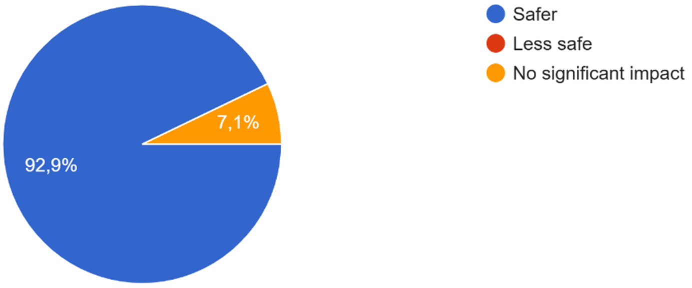
From a regulatory perspective, do you think it should be mandatory by law for every automatic taxi to be equipped with an in-cabin emergency driving device?

14 svar



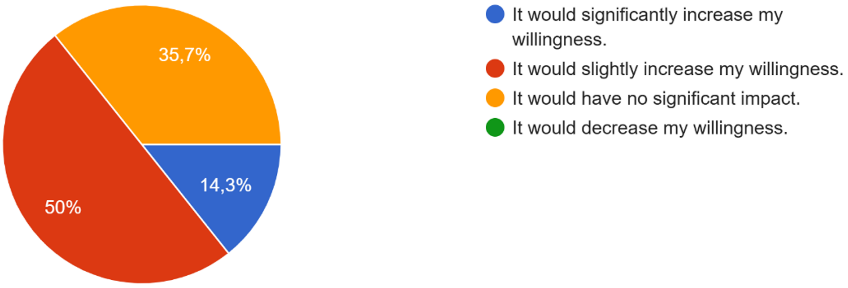
If an emergency driving device is installed inside the vehicle, how do you think it would affect the safety of autonomous taxis during emergencies?

14 svar



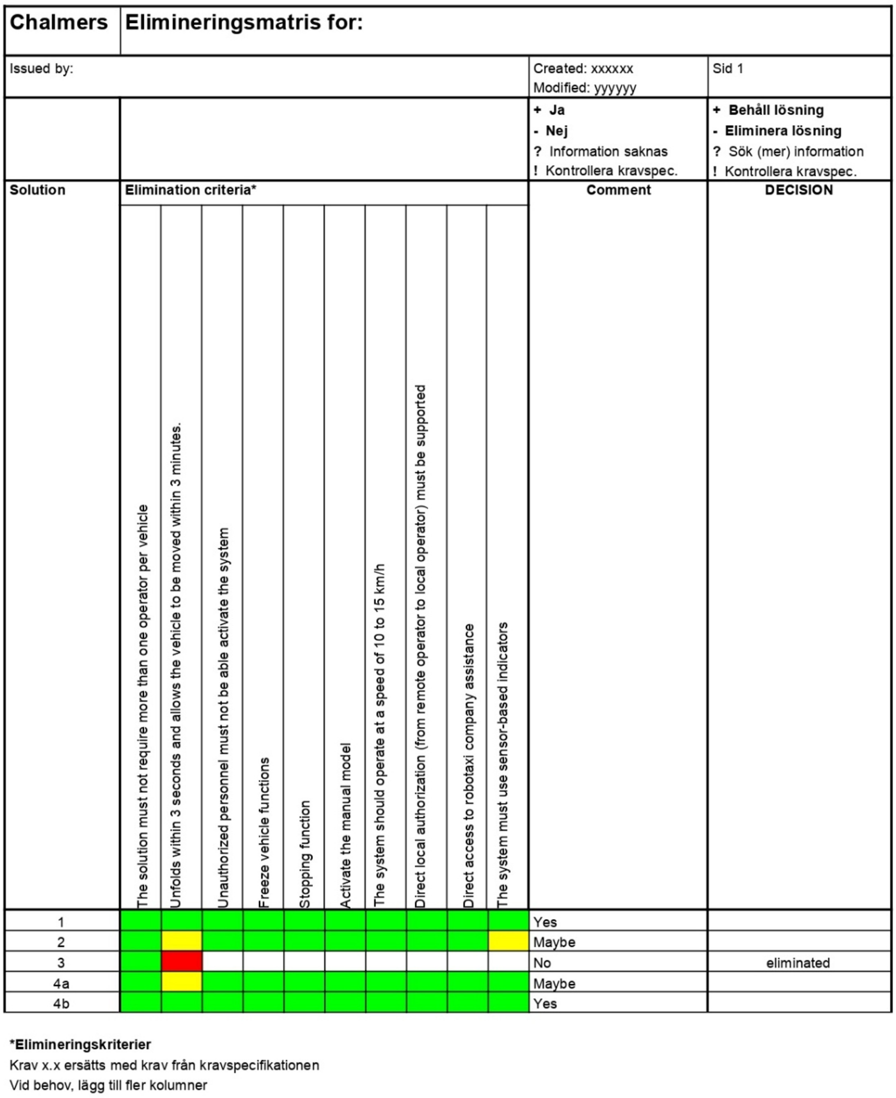
Would the installation of an emergency driving device increase your willingness to ride in an automatic taxi?

14 svar



H

Appendix 8 - Elimination Matrix



Chalmers **Elimineringsmatris for:**

Issued by:

Created: xxxxxx
Modified: yyyyyy

Sid 1

+ Ja
- Nej
? Information saknas
! Kontrollera kravspec.

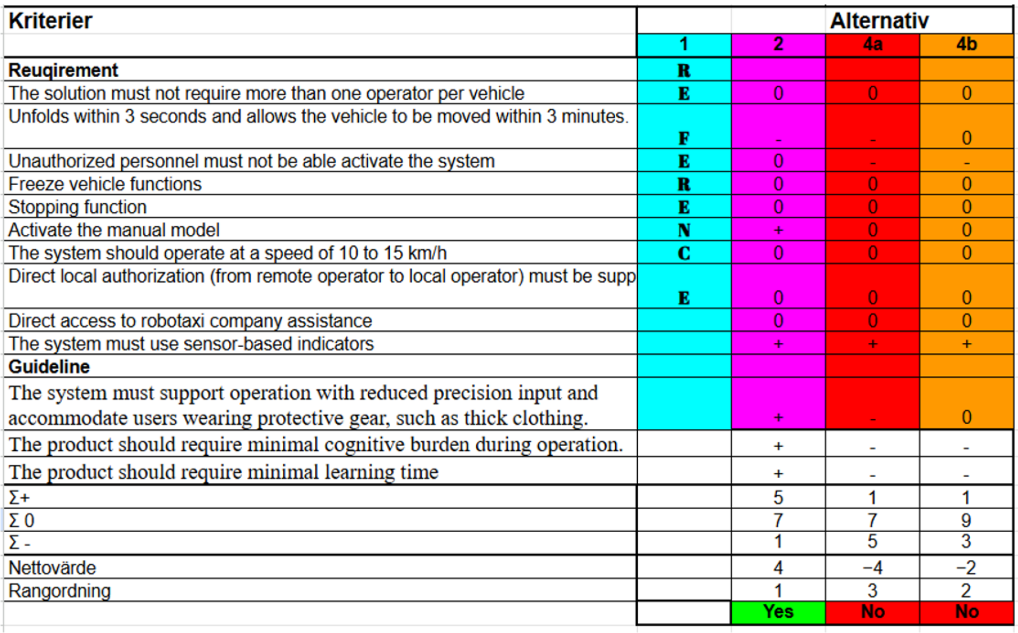
+ Behåll lösning
- Eliminera lösning
? Sök (mer) information
! Kontrollera kravspec.

Solution	**Elimination criteria***										**Comment**	**DECISION**
	The solution must not require more than one operator per vehicle	Unfolds within 3 seconds and allows the vehicle to be moved within 3 minutes.	Unauthorized personnel must not be able activate the system	Freeze vehicle functions	Stopping function	Activate the manual model	The system should operate at a speed of 10 to 15 km/h	Direct local authorization (from remote operator to local operator) must be supported	Direct access to robotaxi company assistance	The system must use sensor-based indicators		
1	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	Yes	
2	🟩	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟨	Maybe	
3	🟩	🟥									No	eliminated
4a	🟩	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	Maybe	
4b	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	Yes	

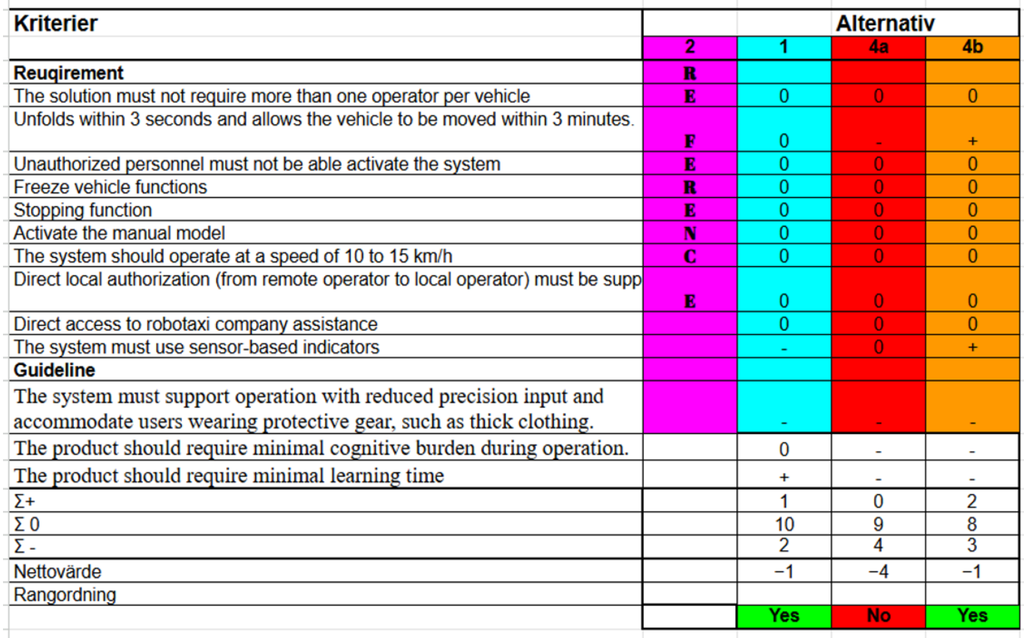
***Elimineringskriterier**
Krav x.x ersätts med krav från kravspecifikationen
Vid behov, lägg till fler kolumner

I

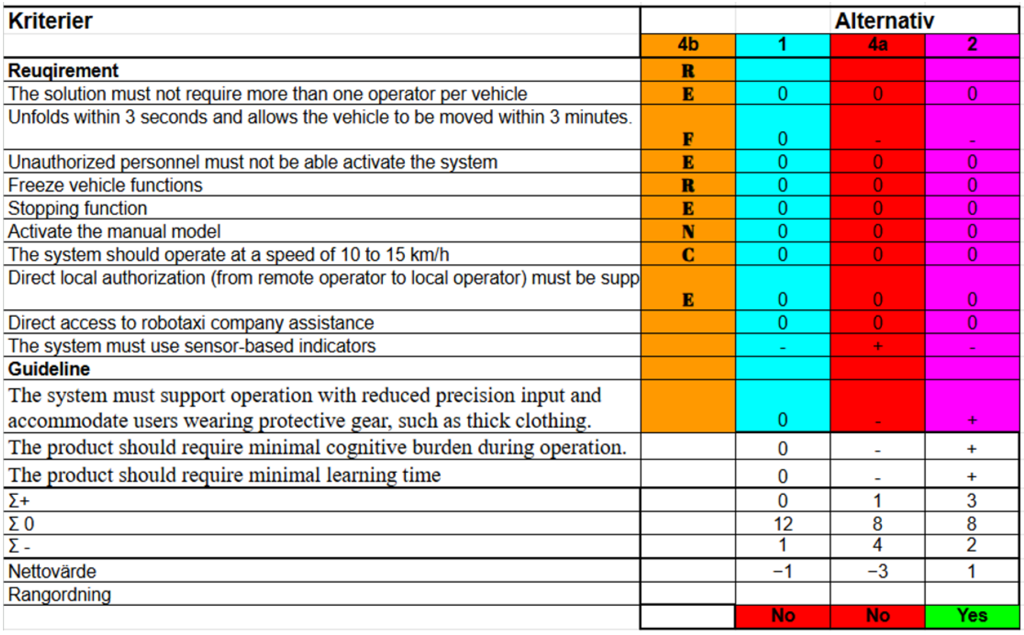
Appendix 9 - Pugh Matrix



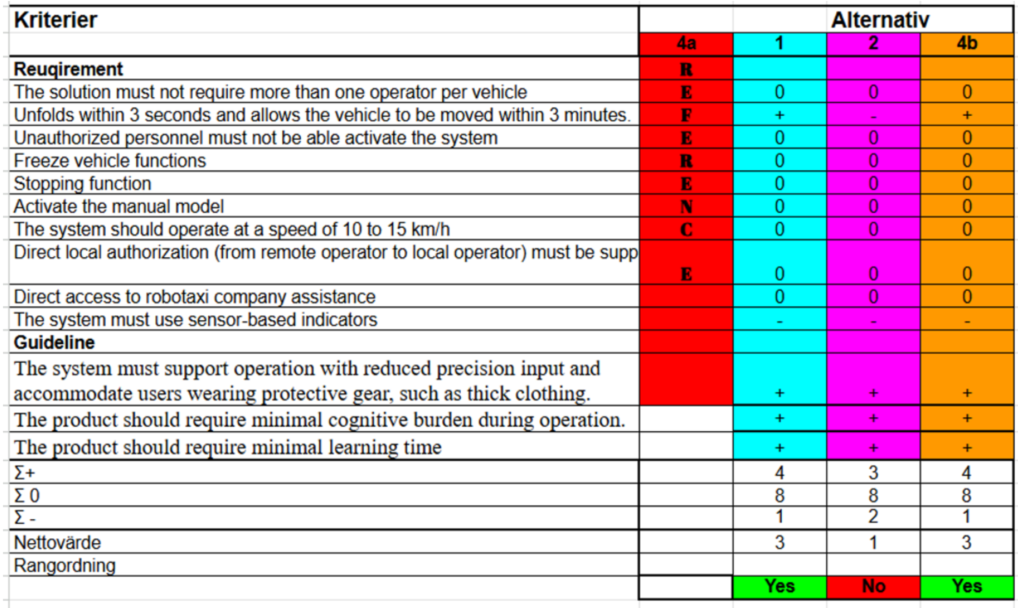
Kriterier	Alternativ			
	1	2	4a	4b
Reuqirement	R			
The solution must not require more than one operator per vehicle	E	0	0	0
Unfolds within 3 seconds and allows the vehicle to be moved within 3 minutes.	F	-	-	0
Unauthorized personnel must not be able activate the system	E	0	-	-
Freeze vehicle functions	R	0	0	0
Stopping function	E	0	0	0
Activate the manual model	N	+	0	0
The system should operate at a speed of 10 to 15 km/h	C	0	0	0
Direct local authorization (from remote operator to local operator) must be supp	E	0	0	0
Direct access to robotaxi company assistance		0	0	0
The system must use sensor-based indicators		+	+	+
Guideline				
The system must support operation with reduced precision input and accommodate users wearing protective gear, such as thick clothing.		+	-	0
The product should require minimal cognitive burden during operation.		+	-	-
The product should require minimal learning time		+	-	-
Σ+		5	1	1
Σ 0		7	7	9
Σ -		1	5	3
Nettovärde		4	−4	−2
Rangordning		1	3	2
		Yes	No	No



Kriterier	Alternativ			
	2	1	4a	4b
Reuqirement	R			
The solution must not require more than one operator per vehicle	E	0	0	0
Unfolds within 3 seconds and allows the vehicle to be moved within 3 minutes.	F	0	-	+
Unauthorized personnel must not be able activate the system	E	0	0	0
Freeze vehicle functions	R	0	0	0
Stopping function	E	0	0	0
Activate the manual model	N	0	0	0
The system should operate at a speed of 10 to 15 km/h	C	0	0	0
Direct local authorization (from remote operator to local operator) must be supp	E	0	0	0
Direct access to robotaxi company assistance		0	0	0
The system must use sensor-based indicators		-	0	+
Guideline				
The system must support operation with reduced precision input and accommodate users wearing protective gear, such as thick clothing.		-	-	-
The product should require minimal cognitive burden during operation.		0	-	-
The product should require minimal learning time		+	-	-
Σ+		1	0	2
Σ 0		10	9	8
Σ -		2	4	3
Nettovärde		−1	−4	−1
Rangordning				
		Yes	No	Yes



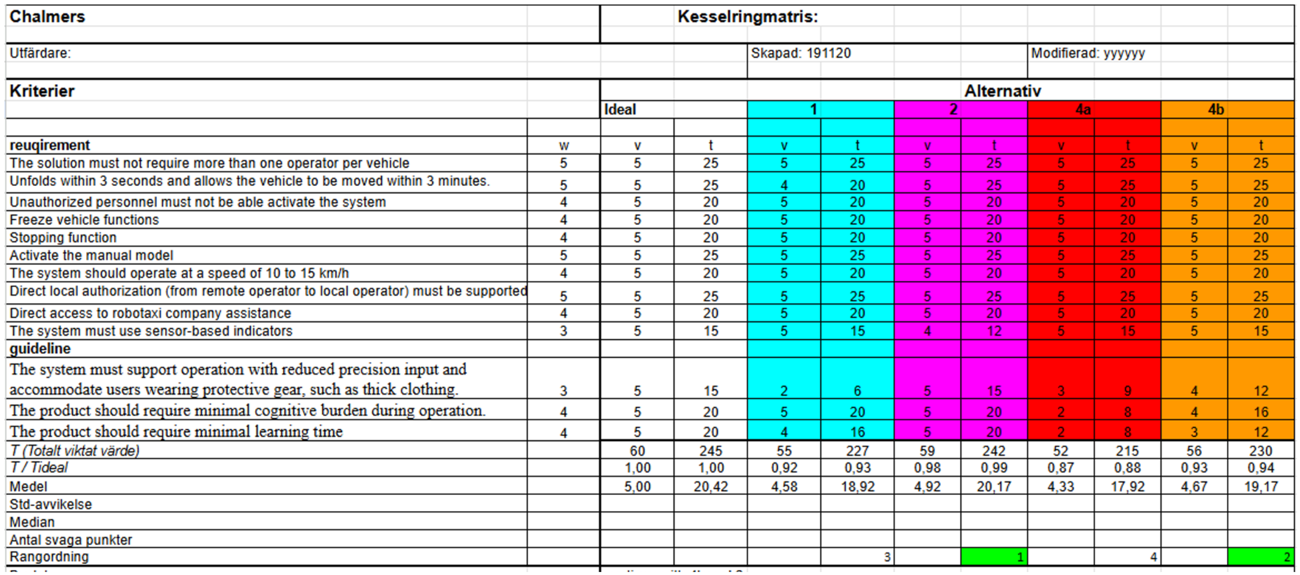
Kriterier		**Alternativ**		
	4b	**1**	**4a**	**2**
Reuqirement	**R**			
The solution must not require more than one operator per vehicle	**E**	0	0	0
Unfolds within 3 seconds and allows the vehicle to be moved within 3 minutes.	**F**	0	-	-
Unauthorized personnel must not be able activate the system	**E**	0	0	0
Freeze vehicle functions	**R**	0	0	0
Stopping function	**E**	0	0	0
Activate the manual model	**N**	0	0	0
The system should operate at a speed of 10 to 15 km/h	**C**	0	0	0
Direct local authorization (from remote operator to local operator) must be supp	**E**	0	0	0
Direct access to robotaxi company assistance		0	0	0
The system must use sensor-based indicators		-	+	-
Guideline				
The system must support operation with reduced precision input and accommodate users wearing protective gear, such as thick clothing.		0	-	+
The product should require minimal cognitive burden during operation.		0	-	+
The product should require minimal learning time		0	-	+
Σ+		0	1	3
Σ 0		12	8	8
Σ -		1	4	2
Nettovärde		−1	−3	1
Rangordning				
		No	**No**	**Yes**



Kriterier		**Alternativ**		
	4a	**1**	**2**	**4b**
Reuqirement	**R**			
The solution must not require more than one operator per vehicle	**E**	0	0	0
Unfolds within 3 seconds and allows the vehicle to be moved within 3 minutes.	**F**	+	-	+
Unauthorized personnel must not be able activate the system	**E**	0	0	0
Freeze vehicle functions	**R**	0	0	0
Stopping function	**E**	0	0	0
Activate the manual model	**N**	0	0	0
The system should operate at a speed of 10 to 15 km/h	**C**	0	0	0
Direct local authorization (from remote operator to local operator) must be supp	**E**	0	0	0
Direct access to robotaxi company assistance		0	0	0
The system must use sensor-based indicators		-	-	-
Guideline				
The system must support operation with reduced precision input and accommodate users wearing protective gear, such as thick clothing.		+	+	+
The product should require minimal cognitive burden during operation.		+	+	+
The product should require minimal learning time		+	+	+
Σ+		4	3	4
Σ 0		8	8	8
Σ -		1	2	1
Nettovärde		3	1	3
Rangordning				
		Yes	**No**	**Yes**

J

Appendix 10 - Kesselring Matrix



Chalmers			Kesselringmatris:								
Utfärdare:				Skapad: 191120				Modifierad: yyyyyy			
Kriterier						**Alternativ**					
		Ideal		**1**		**2**		**4a**		**4b**	
reuqirement	w	v	t	v	t	v	t	v	t	v	t
The solution must not require more than one operator per vehicle	5	5	25	5	25	5	25	5	25	5	25
Unfolds within 3 seconds and allows the vehicle to be moved within 3 minutes.	5	5	25	4	20	5	25	5	25	5	25
Unauthorized personnel must not be able activate the system	4	5	20	5	20	5	20	5	20	5	20
Freeze vehicle functions	4	5	20	5	20	5	20	5	20	5	20
Stopping function	4	5	20	5	20	5	20	5	20	5	20
Activate the manual model	5	5	25	5	25	5	25	5	25	5	25
The system should operate at a speed of 10 to 15 km/h	4	5	20	5	20	5	20	5	20	5	20
Direct local authorization (from remote operator to local operator) must be supported	5	5	25	5	25	5	25	5	25	5	25
Direct access to robotaxi company assistance	4	5	20	5	20	5	20	5	20	5	20
The system must use sensor-based indicators	3	5	15	5	15	4	12	5	15	5	15
guideline											
The system must support operation with reduced precision input and accommodate users wearing protective gear, such as thick clothing.	3	5	15	2	6	5	15	3	9	4	12
The product should require minimal cognitive burden during operation.	4	5	20	5	20	5	20	2	8	4	16
The product should require minimal learning time	4	5	20	4	16	5	20	2	8	3	12
T (Totalt viktat värde)		60	245	55	227	59	242	52	215	56	230
T / Tideal		1,00	1,00	0,92	0,93	0,98	0,99	0,87	0,88	0,93	0,94
Medel		5,00	20,42	4,58	18,92	4,92	20,17	4,33	17,92	4,67	19,17
Std-avvikelse											
Median											
Antal svaga punkter											
Rangordning					3		1		4		2

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