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Safer secondary tasks in partially self-driving vehicles

Master's thesis in Industrial Design Engineering

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CHALMERS UNIVERSITY OF TECHNOLOGY
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MASTER'S THESIS 2022

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Master of Science Thesis

In collaboration with Autoliv Sverige AB

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Cover illustration: Steering wheel screen concept, by Chenglin Song & Ran An

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Abstract

This Master Thesis was conducted at the Industrial Design Engineering program at Chalmers University of Technology in collaboration with Autoliv Sverige AB.

Self-driving cars from Level 1 to Level 3 that are currently ready to be put into the market, the proportion of time that the system controls the car gradually increases. In the future, higher-level autonomous driving technology can further reduce the distraction of perception factors, freeing people's hands to do other things, such as checking emails, watching videos, and reading. We believe that there is a possibility of a screen on the steering wheel of the car to perform secondary tasks.

The aim was to come up with conceptual graphical user interface design alternatives for the touch screen control that could provide safer secondary tasks during SAE L3 automation. Academic research in related fields, user study and benchmarking were performed before designing. The deliverables were two concepts for steering wheel screens in different directions, including concept sketches and high-fidelity prototypes of the user interfaces for Gmail and Youtube respectively of the two concepts.

Concept I uses a mobile phone as a screen mounted on the steering wheel to present information and provide control functions. The phone could be connected with the vehicle system to display the user interface through the center screen. In addition the user can use a stick and a voice assistance physical button to control the center screen for secondary tasks. Concept II integrates a touchpad screen on the right-hand side of the steering wheel as a small display and controller for the central display. The screen can switch between a display and a touchpad when performing secondary tasks.

A final user testing was performed after building the high-fidelity prototypes. The test results show that the proposed concepts can meet the project objectives to a certain extent, and further professional testing is needed. This thesis provides a feasible scheme for level 3 autonomous vehicles to perform secondary tasks, and open up new possibilities for level 3 and other autonomous vehicles to perform secondary tasks.

Acknowledge

Over the process of researching and writing this paper, we would like to express our thanks to all those who have helped us.

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We would also like to thank all the participants in the user studies and user tests. Thanks for their time and effort they invested in this project.

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Gothenburg, June 10th 2022
Ran An & Chenglin Song

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1 Introduction

1.1 Background

With the development of AI technology and deep learning algorithms, as well as the arrival of the Internet of Things era, autonomous vehicles are the general trend. People are looking forward to the arrival of fully self-driving cars. Self-driving cars from Level 1 to Level 3 that are currently ready to be put into the market, the proportion of time that the system controls the car gradually increases. As self-driving cars are likely to significantly improve road safety, countries want to be at the forefront of this development (Vellinga, N. E., 2017). In the future, higher-level autonomous driving technology can further reduce the distraction of perception factors, freeing people's hands to do other things, such as checking emails, watching videos, and reading. This will transform our experience of commuting and long-distance travel, keep people away from high-risk work environments, and allow industries to grow and collaborate to a higher degree.In the future, our reliance on and relationship to cars will be redefined - reducing carbon emissions and paving the way for a more sustainable way of life. The development of autonomous driving technology will bring different benefits and challenges to the existing transportation system.

Compared to the advantages mentioned above, there are problems with making rules, re-examining highway codes, public opinion, improving the infrastructure of streets, towns and cities, and so on. Determining ultimate responsibility for road accidents is a bigger issue. As an increasing number of road tests of autonomous driving technology are implemented, countries have successively introduced corresponding laws to adapt to the changes brought about by this new technology as soon as possible. On 6 January 2016, EU member states signed a declaration on strengthening cooperation in the field of connected and autonomous driving. Through this declaration, member states recognize the importance of a coordinated approach to facilitate the cross-border use of connected and autonomous vehicles One of the objectives of the Member States is (…) to work towards a unified European framework for the deployment of interoperable connected and autonomous driving (…). This will promote legal consistency, recognizing that the legal framework is flexible enough to facilitate the introduction and cross-border use of autonomous and connected vehicles (Vellinga, 2017). It can be seen from the speed of response in various regions that autonomous driving technology has been widely concerned and researched. Many car companies and related companies have begun to study new energy vehicles and autonomous driving technologies and related fields.

Autoliv, the world's largest supplier of automotive safety equipment, has also conducted corresponding research. Because autonomous driving technology provides drivers with time and space to perform secondary tasks, there is a possibility of a screen on the steering wheel of the car. In the past years, steering wheels in passenger vehicles include physical buttons to trigger some functions while driving. However, the transition from manual to automated driving is creating lots of assisting functions and features (e.g., speed limiter, adaptive cruise control, lane-keeping assist systems, etc.), which increase the complexity of the driving activity. Consequently, there are possibilities of replacing physical buttons for touch screen displays. Touch screen steering wheel controls enable the possibility of creating a flexible user interface, where functions and buttons can change and adapt according to the driving context.

SAE is the leader in connecting and educating mobility professionals to enable safe, clean, and accessible mobility solutions. The standards set by SAE represent the best technical content developed in a transparent, open, and collaborative process. To advance automation technology, clarify the role of the driver, answer legal questions, and clarify definitions, the SAE On-Road Automated Driving (ORAD) Committee and ISO TC204/WG14 through a Joint Working Group established a working group in 2018. This collaboration brought to bear the knowledge and expertise of global experts in driving automation technology and safety. Several new terms and definitions have been added and multiple corrections and clarifications have been made to address frequently misunderstood concepts and improve the utility of the document. The concept of level 3 mentioned in the article comes from the document proposed by the organization. As a conclusion, a Level 3 self-driving car is a car capable of self-driving in some circumstances but needs the occupant to be able to take-over in a short amount of time. Figure 1 shows the summary of level 3 driving automation in terms of five elements.

Level	**Name**	**Narrative Definition**	***DDT* (1)**		***DDT Fallback***	***ODD***
			Sustained Lateral and Longitudinal *Vehicle* Motion Control	***OEDR***		
***ADS* ("System") Performs the Entire *DDT* (While Engaged)**						
3	Conditional Driving Automation	The *sustained* and *ODD*-specific performance by an *ADS* of the entire *DDT* with the expectation that the *DDT fallback-ready user* is receptive to *ADS*-issued requests to intervene, as well as to *DDT* performance-relevant *system failures* in other *vehicle* systems, and will respond appropriately.	System	System	*Fallback-ready user* (becomes the *driver* during *fallback*)	Limited

Figure 1 : Summary of level 3 of driving automation (Made by SAE INTERNATIONAL)

While the safety implications of this concept in the context of purely assisting systems (where the driver is responsible for the driving activity all the time) are still explored, this concept could have potential benefits in a car with SAE L3 of automation. In this case, while the car is performing the driving the system could provide embedded applications (e.g., reading emails) that allow the performance of safer secondary tasks (compared to e.g., using a smartphone), since the eyesight would be closer to the road and hands would remain on the wheel. Therefore, it is worthy to explore putting a steering wheel screen on a Level 3 self-driving car.

1.2 Aim and Scope

The exploration of the steering wheel screen starts with academic research in related fields so that the knowledge gap can be filled by the study of related technologies and guidelines. We need to study the existing similar products, discover design regulations, and design products that meet the market and users. In addition, we need to think about the design from the user's point of view, user study is required to obtain requirements and build analysis models.

The next task is to come up with a conceptual graphical user interface design alternative for the touch screen control that could provide safer secondary tasks during SAE L3 automation. Besides, evaluate them from the user experience and cognitive ergonomics point of view.

In addition to the conceptual graphical user interface design, we must consider the combination of hardware and software. Because most electronic systems, whether self-contained or embedded, have a predominant digital component consisting of a hardware platform that executes software application programs (De Michell, G., & Gupta, R. K. 1997). To achieve a complete interactive user experience, the design of the user interface is inseparable from the physical implementation, that is, the specific form and implementation of the screen need to be considered. Therefore, in addition to the conceptual graphic user interface design, we also need to design the physical level of the steering wheel screen, explore its specific style, display mode, interaction mode, etc.

Therefore, the aim and scope of the project is to conceive and design a steering wheel screen that meets the design specifications and ergonomics to help users complete secondary tasks for SAE L3 autonomous vehicles, including the industrial design of the screen and the user interface design as a combination.

2 Literature Review

2.1 Aim

The research field of this project is mainly in autonomous vehicles and in-vehicle human-computer interaction systems. Although the team members have basic knowledge and experience in ergonomics and human-computer interaction design, we lack the background and knowledge for autonomous vehicles and in-vehicle interaction. Therefore, the main purpose of this literature study is to fill the knowledge gap in related fields and understand related design specifications.

Some of the specific topics that the literature study investigated are:

- Learn about the field of autonomous vehicles, especially how Level 3 autonomous vehicles work.
- Explore the potential benefits of having a touchscreen on the steering wheel.
- Learn the design guidelines of in-vehicle human-machine interface from the perspective of ergonomics
- Learn and analyze UX guidelines of Android for cars

In addition, in the process of literature study, research vacancies in related fields may be found, which may have guiding significance for the follow-up research direction.

2.2 Findings

2.2.1 The potential advantages of a screen on the steering wheel

Reduce the distractions from using mobile phones

About 1.35 million people lose their lives each year due to road traffic accidents around the world. Between 200 and 50 million people suffered non-fatal injuries from these accidents, many of them permanently disabled. Road traffic accidents have a significant economic impact on victims, resulting in a loss of approximately 3% of GDP for the entire country. Supported by data, driver distraction is the biggest cause of road traffic accidents (Hua, Q., Jin, L., Jiang, Y., Guo, B., & Xie, X., 2021). As the most commonly used multi-functional electronic device, mobile phones are considered to be an important factor causing driving distraction. Drivers need to use mobile phones to complete specific secondary tasks during driving, such as making calls on the highway, sending text messages when waiting for red lights, etc. According to the World Health Organization, the use of mobile phones and other electronic products quadruples the likelihood of road accidents (Chand, A., Jayesh, S., & Bhasi, AB, 2021), and mobile phone use (texting or talking) is associated with 26% of car crashes are related and the frequency is increasing. Cell phone use while driving is directly related to work obligations and overconfidence in the ability to drive while talking/texting

(Engelberg, J. K., Hill, L. L., Rybar, J., & Styer, T., 2015). Due to busy personal affairs or traffic jams, many drivers use fragmented time to read emails and make phone calls in the car. Research shows that drivers text at least some of the time (30%) and at red lights (66%) while driving on the highway (Engelberg, et.al, 2015).

The National Highway Traffic Safety Administration (NHTSA) has categorized three types of driving distraction: visual (eyes off the road), manual (hands off the wheel) and cognitive (mind off of driving) in their policy statement (NHTSA, 2011). So Texting while driving (i.e. any direct manipulation of a handheld device) is considered particularly problematic because the behavior combines manual, cognitive and visual forms of distraction. Likewise, multi-resource theory suggests that visual-manual auxiliary tasks (such as smartphone use) may negatively affect primary visual-manual primary tasks (such as driving a car) because both tasks use the same cognitive resources (Naujoks, F., Purucker, C., & Neukum, A., 2016). Therefore, when the driver looks at the mobile phone, his vision is off the road ahead, at least one hand is off the steering wheel to hold the mobile phone, and his thinking is separated from the actual dynamic driving task, and instead, a lot of cognitive ability is applied to how to reply to text messages. When encountering an emergency, the driver's cognitive ability is limited, and it is impossible to completely separate the cognition from the second task in a short period of time, resulting in the inability to respond in time and the occurrence of danger.

With the advancement of communication technology, autonomous driving technology, and entertainment devices, different levels of autonomous vehicles and manual vehicles will share the road in future mixed traffic environments. Hence, multiple factors will increase the cognitive burden of drivers and lead to distraction (Hua, et.al, 2021). Avoiding danger to drivers requires avoiding the use of mobile phones while driving, but the popularity of automated driving can provide drivers with an opportunity to complete a secondary task in certain situations. This project is based on the L3 autonomous driving technology provided in specific situations, the completion role of the driving task requires frequent switching between the driver and the automatic driving system, which requires the driver to quickly get out of the distracted state to avoid danger in a timely manner. However, using a mobile phone to complete the second task in the process of automated driving still occupies a lot of cognitive resources of the driver, so it is worth exploring adding more interactive functions that can complete the second task to the car itself, and the current car has come with more functions beyond the driving function.

In order for the driver of an automated car to safely complete the second task of driving, it is first necessary to make the driver's field of vision as close to the road ahead as possible, thereby reducing the degree of visual distraction. The degree of manual distraction can be reduced by keeping the driver's hands on the steering wheel as much as possible. So exploring the steering wheel user interface allows the driver to quickly switch between their roles (ie, action initiator and system supervisor). This is also the starting point of this project, providing the driver with a user interface on the steering wheel that can complete the secondary task interaction. We need to explore its possibility to ensure the life safety of the driver of the automated car. This is in line with the goal of UN sustainable development goal 3 to reduce future fatalities from traffic accidents through the development of vehicle safety equipment.

Steering wheel related factors

Since the design objective is the steering wheel, there are many factors to consider when a touch screen is installed on the steering wheel. We should understand the basic structure of the steering wheel to decide where to install the screen without affecting the basic functionsl. In addition, the ergonomics of the steering wheel is also important, which affects the operability of the screen and the user's willingness to use it. So we decided to study the basic structure of the steering wheel and the way drivers generally hold the steering wheel. Through the study of the steering wheel, we intend to further understand the form of the screen and the possibilities of how to use it.

As shown in figure 2, take the steering wheel of Porsche 997 II as an example, which consists of basic structure, steering wheel corpus, steering wheel cover with horn function and airbag (Harrer, M., & Pfeffer, P. (Eds.)., 2017). It is well known that the airbag module in the center of the steering wheel is a mature and effective life safety protection device, and its position cannot be changed at will, which adversely affects the driver's safety. So the airbag is a compromising factor in the design of the steering wheel screen, which limits the size, material and shape of the user interface. At the same time, the car horn is currently in the form of a bulky physical button. For the driver, requiring them to hold the steering wheel at the 9 o'clock position with the left hand and the right hand at the 3 o'clock position or lower prevents the airbag from pushing the driver's hand back onto the driver's body in the event of a injury (Meschtscherjakov, A., 2017). Which is also one of the factors that limit the form of the steering wheel screen.

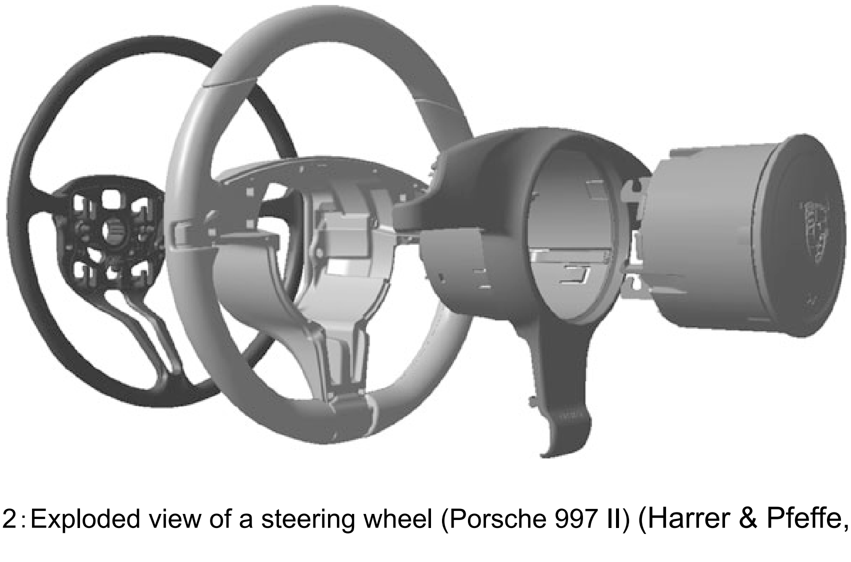


Figure 2：Exploded view of a steering wheel (Porsche 997 II) (Harrer & Pfeffe, 2017)

Steering wheels have been added more and more electric functions and elements. One of the most widely used components is the multifunction switch, for example, to operate a car computer or a navigation system/radio. Gearbox operation/manually selected automatic or double-tight gearboxes tend to be moved to the steering wheel, etc. In addition, modular design and customized steering wheels are a future development trend (Harrer & Pfeffe, 2017), especially after the popularization of automated driving technology, more functions are added to the car and even the steering wheel. When the steering wheel is fully customized, it can achieve stronger inclusiveness, such as accommodating the use of skilled left-handers, or it can satisfy drivers of different types of work. This is another reason to explore the possibilities of steering wheel user interfaces.

Hruška, M. (2018) studied the ways and actions of the current left-hand drive car drivers to grip the steering wheel through experiments, and expressed the proportion of the number of people holding the steering wheel and the gender ratio in the corresponding position. From the study we can see that drivers of different genders hold the steering wheel differently. According to the experimental conclusion, the number of males holding the steering wheel with one hand accounts for more than 50% of the total male subjects in the experiment, 40% of the males hold the steering wheel with both hands, and nearly 75% of the females hold the steering wheel with both hands. In addition, the experiment obtained the position combination of the left and right hands of all-gender drivers holding the steering wheel, of which R3 and L9 accounted for the highest proportion, followed by R2 and L10. Through this experiment, we understand the user's holding habits, and the most suitable position on the steering wheel to place the interactive interface, which can help the user to achieve the purpose function faster and more accurately.

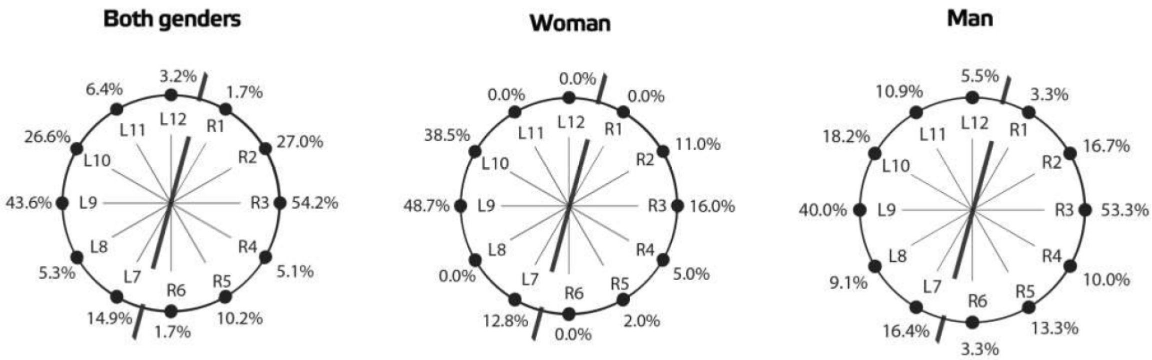


Figure 3：Schematic depiction of the resulting grip percentage representation values in individual positions. Note: The values in percentages are calculated separately for the left and right hands.

In addition to the experiments on the driver's holding habits, Hruška (2018) also conducted experiments on the body posture of the driver who gripped the steering wheel with one hand. Holding in this position for a long period of time results in significant lateroflexie with significant muscle strain, in particular m. quadratus lumborum, m. obliquus externus abdominis, m. obliquus internus abdominis and m. erector spinae. Long-term driving in such a position can lead to pain in the lumbar spine and, in extreme cases, to permanent damage to the postural system. In the study, males using this unhealthy posture to drive are more than females. However, the design of the steering wheel interface can affect the driver's holding posture. Encouraging drivers to use both hands to hold the steering wheel through the design of the steering wheel screen is a direction worth exploring. It will help more drivers stay healthy, especially for long-term driving drivers. However, the emergence of autonomous driving will inevitably free the hands of drivers, but as far as the current situation is concerned, L3 autonomous vehicle drivers still need to frequently take over driving tasks, which highlights the importance of steering wheels beneficial to health.

Location of visual display and controls

The location of the user interface also affects the driver's sight and operation. The location of the in-vehicle user interface has an impact on both the driver's reception and input of information. The suitable location of the user interface makes it easy for the driver to get information and perform actions. Because the steering wheel is located in front of the driver, it is one of the few things inside the car that offers excellent visibility and reachability (Meschtscherjakov, 2017). For conditional self-driving vehicles, a touch screen control on the steering wheel can provide drivers with a safer secondary task path in self-driving mode than looking at a cell phone or electronic device in other places.

Current research shows that the position of a visual display has a big impact on how easy it is for drivers to get information. With the continuous development of vehicle assistance systems, more and more information needs to be displayed to drivers. The appropriate location of the information display can reduce the impact of viewing the information on the driver. For manually driven cars, reducing the frequency and time of looking away from the road and increasing the readability of information are possible ways to reduce the impact of displays on the driver. Human Factors Design Guidance For Driver-Vehicle Interfaces from NHTSA approves the study by Lind, H. (2007), arguing that locating the visual warning near the primary driving activity will enhance the likelihood of it being noticed and lower the amount of time required to glance at that information. More specifically, as shown in figure 4, the specification proposed by NHTSA (2016) requires that critical displays for continuous vehicle control or critical warnings related to vehicle forward-path are located within ± 15 degrees of the central line of sight but as close to the central line of sight as practicable. For conditional autonomous vehicles, we expect the driver to perform a secondary task while being able to have a certain degree of perception about the driving situation and can respond promptly when the car requests the driver to do the driving task. Although there is no specific research at present, referring to the standard of traditional vehicles, the driver's eyesight when performing the secondary task should be as close to the road conditions as possible. In addition, taking the Mercedes-Benz S-class vehicle as an example, as shown in figure 5, it will display a red light on the steering wheel when it requires the driver to take over the driving task. If the driver's sight is right on the steering wheel when performing the secondary task, the driver can detect the red light signal on the steering wheel and take over the driving task promptly.

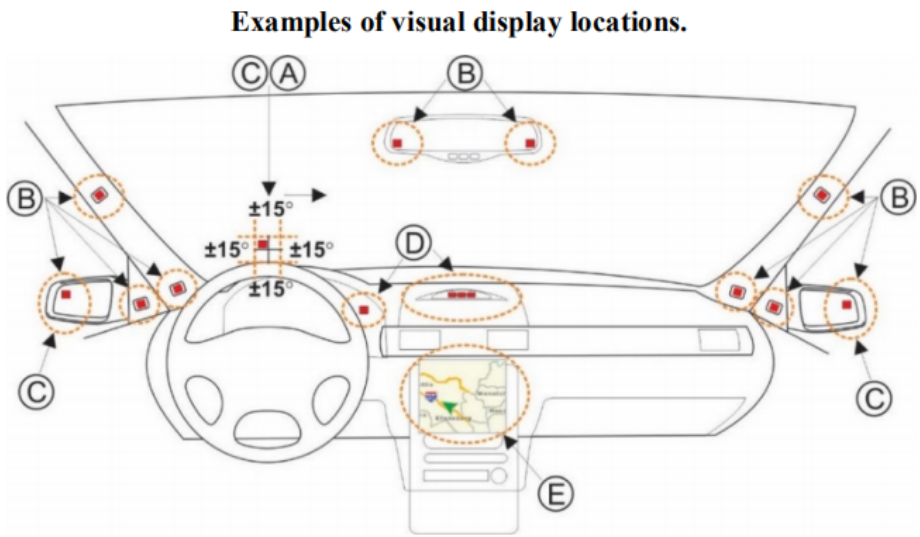


Figure 4: Examples of visual display locations (Made by Human Factors Design Guidance For Driver-Vehicle Interfaces from NHTSA)

Figure 5. The button on the steering wheel will display a red light when Drive Pilot requires the driver to take over the driving task

2.2.2 Autonomous Vehicles

This project is based on Level 3 autonomous vehicles. In order to fully understand the autonomous driving system and its classification principles and driving methods, we studied and analyzed the document written by SAE International: Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles. Below is our summary of definitions that may be used, and analysis of Level 3 autonomous driving systems. The detailed explanation of the definition can be found in Appendix A.

Definition

AUTOMATED DRIVING SYSTEM (ADS)
DYNAMIC DRIVING TASK (DDT)
[DYNAMIC DRIVING TASK (DDT)] FALLBACK
OBJECT AND EVENT DETECTION AND RESPONSE (OEDR)
OPERATIONAL DESIGN DOMAIN (ODD)
REQUEST TO INTERVENE
[HUMAN] DRIVER
[DDT] FALLBACK-READY USER

Level 3 - Conditional Driving Automation

The *sustained* and *ODD*-specific performance by an *ADS* of the entire *DDT* under routine/normal operation with the expectation that the *DDT fallback-ready user* is receptive to *ADS*-issued requests to intervene, as well as to *DDT* performance-relevant *system failures* in other *vehicle* systems, and will respond appropriately.

Limitations from Level 3 autonomous vehicles

L3 autonomous driving technology does not fully provide convenience and safety for human life. In an L3 self-driving car, the driving environment does not need to be monitored all the time, but intervention requests need to be responded appropriately. The self-driving system needs to provide "sufficiently comfortable transition times" where the dynamic driving task is handed over from the self-driving system to manual control, in that case, the driver acts as a backup measure to perform dynamic driving tasks. This means that the higher the level of automation, the less the driver will focus on traffic and the system, and the less able to regain control (Seppelt & Victor, 2016). In addition, compared to imperfect automation, manual driving by the driver is further from perfect, with 94% of crashes attributed to key driver-related causes such as identification errors, decision errors, and performance errors. This seems like a classic dilemma, if we don't automate we're stuck with human contributions to collapse, but if we choose to automate, human performance will get worse as automation gets better.

The higher the level of autonomous driving, the more time the driver has to complete the secondary task, so that the more cognitive resources are occupied by the secondary task, it is more difficult for drivers to quickly switch from the secondary task to dynamic driving task. Similarly, L3 autonomous vehicles require the driver to be the supervisor and backup of the autonomous driving system, and also need to pay attention to dynamic driving tasks for a certain period of time, which is different from the autonomous driving systems below L2 and above L4. Level 3 autonomous vehicles will disguisedly increase the cognitive load on the driver as they have to focus on so many things besides secondary tasks during autonomous driving. This is also the reason why Seppelt & Victor (2016) promoted for changing L3 autonomous driving technology or resisting L3 autonomous driving.

Through a critical analysis of L3 autonomous driving technology, the current limitations of this technology and what additional considerations need to be made during the design phase are recognized. Although the automatic driving technology is graded according to the level of automation, the improvement of this system level is not linear with the driver's cognitive load and safety factor. Compared with other levels, L3 will increase the driver's cognitive load. But compared to using mobile phones and other in-vehicle screens to complete secondary tasks during autonomous driving, the advantage of the steering wheel screen is that the user's hands will not be too far away from the driving task, because the steering wheel itself and its position are not too far away from the vehicle control system and the effective field of view, the driver can take over faster. The steering wheel screen may be a rare possibility for L3 autonomous driving technology to help users safely complete secondary tasks.

The Level 3 autonomous car produced by Mercedes-Benz

The Mercedes-Benz Drive Smart Level 3 autonomous driving feature will become available in the S-Class luxury sedan and EQS electric luxury car in Europe by early 2022.

Germany has taken a pioneering role in this with the opening of the Road Traffic Act (StVG) for Level 3 systems in 2017. On December 09, 2021, Mercedes-Benz became the first automotive company in the world to meet the demanding legal requirements of UN-R157 for a Level 3 system.

Level 3 or conditional driving automation enables the vehicle to react to its environment and make decisions without urging the driver to take control. The autonomous driving of Mercedes-Benz is achieved through the Drive Pilot system.Mercedes-Benz's updated Drive Pilot system can take over the driving chores while the vehicle is traveling at the legally permitted speed of 37 mph (60 kph). After activating Drive Pilot via a pair of haptic buttons above the steering wheel, the system controls the driving speed and following distance while independently performing evasive or braking maneuvers – all without physical driver intervention.

The Drive Pilot can be activated via two buttons on the steering wheel rim. If self-driving is available, they will turn white. If the Drive Pilot is activated, they will turn turquoise.If the buttons in the steering wheel rim turn red, the vehicle requests the driver to retake control within ten seconds.

The S-Class is capable of reliable conditionally automated driving in traffic jams or when traffic density is high. The Drive Pilot controls the speed, the distance to the vehicle ahead, and confidently steers the car within its lane. As it does so, it can also recognize unexpected traffic situations and handle them on its own by means of braking or evasive action within the car’s lane. However, the Drive Pilot is designed to recognize its limits of conditionally automated driving. When the traffic environment does not conform to the conditions predetermined by the system, the system will request the driver to intervene and regain control of the vehicle.

Since the Drive Pilot system can perform vehicle driving tasks, the driver can have time and energy for secondary tasks. The S-Class provides drivers with a variety of secondary tasks including working and recreation. For example, they could communicate with colleagues online via In-Car Office, answer emails, surf the Internet, or read the news. The tasks are mainly completed through the media display.

As the Mercedes-Benz's S-Class car has been put on the market, its autonomous driving scenarios and driving mode switching methods can provide a reference for our project. Since this project is to design a steering wheel screen for L3 self-driving cars, it does not specify which car it is designed for, so the existing L3 self-driving cars are considered to be the most reasonable reference targets. Some parts of this project that do not need to be redesigned will refer to the car's design and standards.

2.2.3 Human Factors For Driver-Vehicle Interfaces

A key element of vehicle automation is the driver-vehicle interface (DVI). DVI is the vehicle display that provides information to the driver and allows the driver to control the entire vehicle and various vehicle components and subsystems status control device. The safe and efficient operation of any motor vehicle requires that the DVI be designed in a way that is consistent with the driver's constraints, capabilities, and expectations. This document is intended to help DVI developers of Level 2 (L2) and Level 3 (L3) autonomous vehicles achieve these results from a human factors perspective.

The reason we chose to study this document was that it provided design guidance on the aspects of automotive ergonomics, which complemented our knowledge. At the same time, it can pave the way for further learning UX and UI design guidelines. Only by understanding the background For reasons from the perspective of human factors, we can better learn and apply design specifications.

Below is the information in this document that we think will be helpful to our project, and our thoughts on how that information relates to our project.

General Design Guidance for Level 3 Automation

This part of the document highlights Designing Messages for Driver Comprehension. For L2 and L3 autonomous vehicles, developing and presenting messages that support accurate and timely comprehension by the driver are considered to be the design goals. The document proposes a design guideline for the comprehension process of drivers. Figure 6 shows what the documentation suggests to be considered at various stages of the driver's comprehension process.

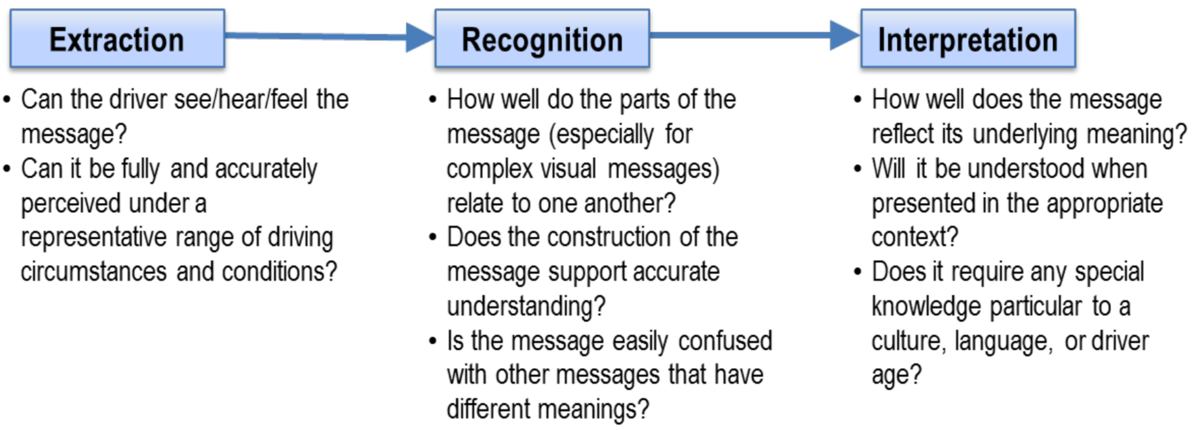


Figure 6： Questions should be considered when designing messages from Campbell et al.(2018)

This document then discusses driver needs related to message complexity and identifies the characteristics of visual, auditory, and haptic messages that affect message complexity. Message complexity refers to the number and types of basic information elements contained in a message, as well as the relationship between these elements. Overly complex messages may not be properly perceived, understood or acted upon by the driver. In order to design the presentation of information as simply as possible, while keeping the message accurate, the document makes the following recommendations:

A. Visual Messages consist of simple icons and fonts with only the necessary detail included. In text displays, the number of lines of text per-message is minimized.
B. Auditory Messages are simple when an immediate response is required. This could be single or grouped frequencies presented simultaneously; such as a simple tone that consists of a square wave.
C. Haptic Messages are simple and perceptible. Research relevant to the topic of haptic message complexity is limited.

Based on current industry trends, it is expected that many messages in L2 or L3 automation systems will be multisensory (presenting auditory or tactile messages accompanied by visual messages). This topic suggests matching the format of messages to the driver's tasks, needs, and expectations in order to improve driver comprehension and performance, and provides guidelines for supporting design. Visual information, for example, is best for presenting more complex information that is not safety-critical and does not require immediate action. Audible information quickly grabs the driver's attention and can be used to provide high-priority alerts and warnings. This means that the display on the steering wheel is more suitable for secondary tasks unrelated to the driving task. It is important to avoid the auditory information generated by the secondary task interfering with the driver's recognition and understanding of important driving-related alert information.

Visual Interfaces

The visual modality is of primary importance in the driving task, and can use various sensory dimensions, such as color, brightness, and contrast, as well as stimulus dimensions, such as location, size, shape, and periodicity (e.g., flickering). Semantic content that benefits from persistence are better suited to be displayed through visual form. In addition, characteristics such as color, size, spacing, and temporal characteristics (e.g., flashing or noticeable motion) can be used to maximize the prominence, legibility, and understandability of warning messages.

The document argues for the need to place the visual interface in a location that facilitates rapid extraction of information while minimizing line of sight off the road and negative impact on drivability, and gives potential visual display locations as shown in Figure 7. We believe that some of the visual displays in these examples might have a good linkage with the display on the steering wheel we are going to design.

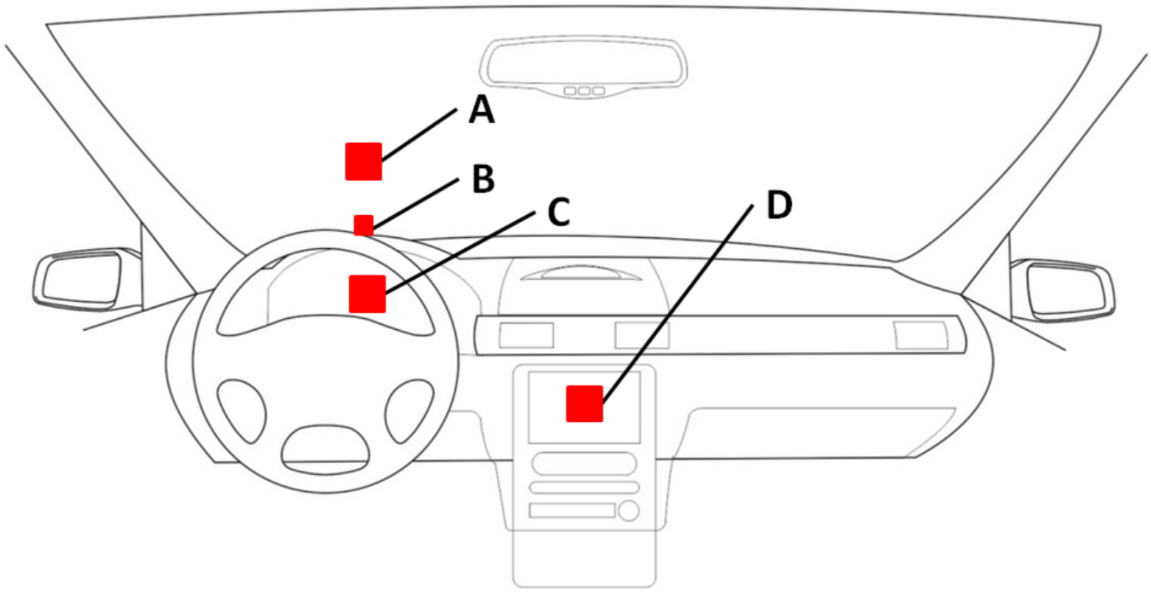


Figure 7：Examples of potential visual display locations
Display Locations in Image:
A. Head-Up Display
B. High Head-Down Display
C. Head-Down Display/Instrument Panel
D. Center Console

The document also emphasizes that when designing DVI, minimize glare, both on and from, visual displays. Glare on visual displays can originate from a variety of sources in the driving environment and can make visual displays difficult to read. In addition, the light emitted by the display can be harsh at night, causing discomfort or, in some cases, reducing the visibility of the external driving environment. The document also provides some strategies for addressing such issues. For example, mitigating glare on the display in daytime driving by providing sufficient display brightness and using high-contrast display technology to ensure sufficient contrast. Mitigating glare that emanates from the display while driving in darkness by displaying content with a dark background to minimize the amount of light emitted by the display.

In addition, the document emphasizes the application of color. Color is a characteristic of a visual display that can be used to convey the meaning or urgency of an alert signal. Compared with words and symbols, color has certain advantages in the immediacy of recognition. Here are some common relationships between color and information categories. Red is usually associated with danger or critical situations; white is usually associated with caution; green is usually associated with normal operation. One of our initial thoughts on this part is that when the interactive system switches between autonomous and non-autonomous driving modes, it may use a combination of color and other visual displays to achieve driver attention.

The Temporal Characteristics of Visual Displays are also mentioned in this document, such as flashing, blinking or apparent motion, to command visual attention. Some related design guidelines are also mentioned in the document, for example, Flashing is used for important, suddenly-occurring, situations (optimal rate is 3-4 times/s); Multiple flash mode is used for more urgent situations (this mode uses rapid pulses of flash for each flash cycle).

Driver Inputs

As autonomous driving is an emerging topic, there is limited information on driver input methods for autonomous vehicles. Therefore, the document has written this section based on basic human factors information and current interface standards. Poorly designed controls can adversely affect or impair the operation of primary driving controls. It is important for designers to carefully consider the placement and operation of various types of controls (Pomerleau et al, 1999; Stevens et al., 2005). Controls that are easy to understand and operate can minimize the distraction during the transition from manual to autonomous driving. Here are some examples of relevant design guidelines given by the document. Controls should provide timely and clear feedback (visual, tactile or auditory) (AAM, 2006; Bhise, 2011). Have identifiable labels (symbols or text) that are visible and located close to the control (Bhise, 2011). The location of the controls should not adversely affect the control of the primary driving system controls. Usage of controls must not hinder the driver's choice to keep at least one hand on the steering wheel at all times.

Control Placement is a point in this topic that deserves a separate discussion. Designers should ensure that control placement and operation do not interfere with driving tasks or use other driving controls. Here are some examples of accompanying design guidelines. The placement of controls should be easy to reach and find, and controls should be in a visible area or be able to be found blindly (Bhise, 2011).

2.2.4 UX guidelines of Android for cars

The car screens involved in this project are all developed based on the Android system. In order to design a user interface that meets the specifications, we need to understand and learn the design specifications of UI and UX for the DVI of the car. Google Design for Driving is a design hub that provides design guidelines for developers working with the two Android for Cars systems:

- Android Auto: Phone-based infotainment system that's projected onto the screens of compatible cars
- Android Automotive OS (AAOS): Infotainment platform that car makers can customize, build into their vehicles, and (if they're GAS partners) integrate with Google Automotive Services (GAS)

Design for Driving foundations

At present, there is a lack of interaction design specifications for autonomous vehicles in the market, thus it should be noted that the design principles mentioned in this part are mainly for manual driving cars. We learned the conventional driving interaction design specifications and extended them to apply to the user interface design of autonomous driving reasonably. At the same time, since the L3 autonomous driving technology requires the role of users to switch driver and the fall-back ready user, the design with reference to the manual driving interaction design specification can make the user switch the driving role faster and safer.

Interaction principles

The interaction between the driver and the screen must be simple, non-distracting and easily interrupted so that the driver's attention can quickly return to the road.

Keep information current and glanceable: To ensure that the information and status presented in the interface are clear at a glance, the driver needs to quickly understand the task or real-time updated system status by a glance at the screen. They should be able to finish reading in 2 seconds and turn their attention to the road. Also ensure that the system response time after user input does not exceed 0.25 seconds. If the content takes longer than 2 seconds to load, a spinner or similar UI change should indicate that the device is responding.

Encourage hands-on driving: Achieving safer driving requires keeping the driver's hands on the steering wheel as much as possible. For example, avoid designing interactions that require two hands, and design one-hand gesture interactions when necessary to ensure that the driver has one hand to control the steering wheel and respond in time in an emergency. A hands-free speech interface and simple voice interactions are recommended with minimal visual and manual requirements for the driver to minimize driver distraction and help the driver focus on the road.

Prioritize driving tasks and avoid pulling the driver's attention away from the road for non-essential reasons. The most important tasks a driver performs are those related to driving – everything else must be secondary. Although we need to design the steering wheel user interface to achieve the completion of the secondary task in the autonomous driving process, we need to take into account the priority of the driving task, and the secondary task needs to make compromises for the driving task at all times. And considering the position of the touch screen on the steering wheel, it is close to the effective range of the driver's driving field of vision. Therefore, we need to combine ergonomics and cognitive theory to study carefully about the degree of how the screen occupies the driver's cognitive load in different driving stages.

Visual principles

Make content easy to read: Content designed for car screens must be clear and easy to read, with a consistent UI and large touch targets that drivers can identify in all viewing conditions (day, night, bright light, etc.).

Text legibility in a driving environment can be affected by many factors, such as lighting, time of day, font scale (thin, medium, bold) and contrast. Highly legible text helps drivers reduce browsing time and decision-making time, thereby reducing cognitive and visual distractions. First of all, the key information and long paragraphs should avoid using bold font, the minimum title type characters should be 32dp, the auxiliary text size should be at least 24dp, and the number of Roman characters per line should not exceed 120, otherwise it will seriously increase the visual burden of the driver. In order to ensure the readability of the text, the contrast ratios for text, icons & background should be guaranteed to be 4.5:1, besides, the night mode is necessary and the above contrast ratio needs to be changed appropriately. Generally, the contrast ratio is reduced in the night mode to avoid glare. It is worth mentioning that the black background is recommended as it is suitable for both day and night, because it is consistent with most car interior colors, and does not occupy visual resources to cause visual disturbances during driving, at the same time, can clearly display text and icons.

Make targets easy to touch: The smallest touch targets should be 76dp*76dp and the minimum distance between two touchable targets should be 23dp. This prevents drivers from being easily distracted or making mistakes when trying to touch objects that are too small or too close to the screen.

Keep UI elements consistent: To help drivers quickly understand their screen options, the user interface must be clear and consistent. First of all, using a consistent icon in the user interface, the color and interaction characteristics of the same category of information can reduce the time and cognitive effort required by the driver and makes decision-making easier. Color is a powerful cue for reinforcing memory and recognition, such as when dialing on the phone interface, green means initiating a call, red means hanging up, and the corresponding green and red colors should be used in the notification window to ensure the color consistency of the same interactive content. Users can quickly judge and react by color.

Google Design for Driving presents basic in-car interaction principles and visual design principles in understandable language, each of which needs to be kept in mind in our project advancement, which is related to the safety of the people in the car. As at-a-glance information and simple interactions are required, while self-driving cars can allow drivers to be distracted for a while, using design to keep distraction to a minimum is what L3 self-driving technology hopes for.

Android Auto

As the user interface of the mobile phone is connected to the vehicle, the user can control the app in the mobile phone by operating the car screen. *Google Design for Driving* gives strict design specifications in the *System Design* section, including color, layout, dynamic effects, various sizes and fonts. First of all, in terms of color, the contrast in the two modes of day and night proposed in the Visual principles above is emphasized again, and specific values are given for reference. In addition, the consistency of color usage is also mentioned. The Layout section introduces the layout, pedding space and specific values for different screen sizes, and the *Sizing* section specifies different button and icon sizes and bleeding values.

Different page logic relationships should use different dynamic switching effects. The specification divides different motion effects into

- Switching between apps
- Switching between peer views
- Extending an existing action
- Minimizing and expanding an action
- Disrupting an action

Each interactive operation needs to be supplemented with specific dynamic effects to express the logical relationship of the pages, so that users can understand their operation feedback more clearly. For example, in music playback software, the shared axis motion pattern when switching from song to song in a media app reinforces that both songs are in the same playlist.

Different user input methods are also added to the design specification. The design of various components of the UI interface of different types of apps (media app, messaging app, navigation app, etc.) has also been standardized. For example, the UI principle includes how to design a standard-compliant music playback soft armor upper navigation column.

Automotive OS

Automotive OS is the advanced planted native user interfraction system, which was built into the car itself that can be used without additional connectivity. Its design specification is similar to that of Android Auto. However, as it is not restricted by the Android phone system, a lot of detailed content has been added to its design specification, such as the design principles of the dial keyboard and scrollbar.

Conclusion

Google Design for Driving places special emphasis on interaction principles and visual principles, and is a good resource library for learning and evaluating automotive UI & UX. The touch screen user interface on the steering wheel has many possibilities, its shape, size and interaction method are very uncertain at the current stage. However, it cannot be designed without any design specifications, therefore the principles of interaction & vision still need to be considered. Most of the design norms can be used for reference and application, these design norms may need to be further developed and thought deeply by ourselves to practice and evaluate in our design results. While some design norms are not applicable, we need to study and evaluate more deeply then select what we need after understanding the guidelines.

2.3 Discussion

In the above part of the article, numerous literatures helped us understand the possible benefits of designing a touch screen on the steering wheel, and also provided us with design guidance from the aspects of domain background knowledge, ergonomics and interaction design. But they all have their own limitations due to the lack of solid experiments and data.

For the steering wheel screen, although we believe that it has potential advantages in reducing driver distraction caused by mobile phone use, helping drivers maintain a better holding gesture and providing a better location for information and control, but there is no relevant experiment to prove that Level 3 autonomous vehicles can achieve such a purpose with a steering wheel screen. We can't verify the reality of these potential advantages until we have a Level 3 self-driving car and a matching steering wheel screen. But these potential advantages can serve as the direction for our in-depth study in the follow-up research. Our design goal is to design an interactive system that provides secondary tasks for level 3 autonomous vehicles. After our design is complete, we can use this system to design experiments to test the potential benefits of previous assumptions. In addition to the advantages, there may be potential disadvantages of using the steering wheel screen, such as whether the position of the steering wheel screen is suitable for long-term viewing, and whether the steering wheel screen and other in-vehicle displays will interfere with each other and affect the driver's judgment? These questions are also the directions that can be explored using the results of the project.

The background study on Autonomous Vehicles mainly helps us understand how a Level 3 autonomous vehicle works and how it differs from manual driving. We understand that ADSs of level 3 can perform DDT only after meeting a certain ODD, but the document does not propose what specific ODD is. This is because different ADSs have different ODD limits, and different Level 3 autonomous vehicles may perform DDT in different environments and for different durations. In the literature review section we cannot clearly describe the use environment of a Level 3 autonomous vehicle, so this is of limited help in defining the use scenarios of our product. In the subsequent definition of the use scenarios, we can only select some common situations as the use scenarios of the product.

As for the relevant design guidelines, although they provide us with very useful design guidelines and specifications, most of them are based on ordinary manually driven cars. While the document from NHTSA is designed for Level 2 and Level 3 autonomous vehicles, as is often described in the document, due to the lack of relevant experiments, more guidance is based on experiments with manually driven vehicles. The design guidance provided by Google also faces the same limitations, because Google provides design guidance for the interaction system of ordinary manually-driven vehicles, so the specifications in it, such as character size and other visual principles, are not for level 3 autonomous vehicles. Considering that our design is more specific to the state of the user when not performing DDT, design guidelines to reduce user distraction while driving will not needed to be followed or only partially followed. There is no clear judgment standard to help us decide which specifications need to be followed, so all the design guidance must be considered in the design process, and judgments and decisions should be made according to the actual situation.

As a conclusion, the biggest limitation of the literature in this field is the lack of recent experiments to provide analysis and design guidance for the interactive systems and steering wheel screens of autonomous vehicles. Therefore, our project is of great importance in this field. After the design results are obtained in this design project, the follow-up research can be carried out using the design results.

2.4 Conclusion

The use of mobile phones during driving is the main factor causing traffic accidents. This behavior combines manual, cognitive and visual forms of distraction and consumes a lot of cognitive resources of drivers. For L3 cars and below, more frequent distractions are more dangerous, but it's hard for people to avoid making calls or doing other secondary tasks while driving. Level 3 self-driving technology allows the car to drive by itself under certain conditions, giving the driver an indeterminate period of time to perform secondary tasks. According to the definition of SAE International, the driver as a fallback-ready user needs to take over at any time, and failure to take over in time will lead to an accident or the termination of the journey. Therefore, the closer the driver's visual center is to the road ahead when completing secondary tasks, the safer it will be. This is a limitation to how users accomplish secondary tasks, and one of the technical drawbacks of L3 self-driving cars. Level 3 autonomous vehicles require a secondary task interaction system that can quickly disengage the driver from task content or keep the drivers’ status close to manual driving.

The original intention of the steering wheel screen is that for the driver, the position of the steering wheel has the best visibility and reachability. If an interactive screen is provided in this position instead of the mobile phone for the driver to complete the secondary tasks during automatic driving, it can reduce the impact of the distraction of using mobiles, keep the driver's attention and vision as close to the road ahead as possible, and keep hands close to the steering wheel. When the system asks the driver to take over the car again, they can go back to manual driving in time. Considering the structure of steering wheels and how to hold them, our design should encourage or guide the driver to use both hands to hold the steering wheel on L9 R3, which contributes to airbag deployment and physical fitness.

In the design stage, we need to define the secondary task according to the user's requirements. It is necessary to consider which can be solved by the steering wheel user interface, and which design specifications need to be referred to to design the user interface. This is one of the difficulties of this project. Because the project involves a wide range of fields and there is no corresponding reference basis, it has considerable freedom and possibilities.

3 Benchmarking

Anand, G., & Kodali, R. (2008) summarize benchmarking as a continuous analysis of strategies, functions, processes, products or services, performances, etc. compared within or between best-in-class organizations by obtaining information through appropriate data collection method, with the intention of assessing an organization's current standards and thereby carry out self-improvement by implementing changes to scale or exceed those standards. Due to the possibilities of the project and the uncertainty of the future, we need to learn from the relevant in-vehicle interaction interface and functions of the vehicle. Since users cannot currently experience L3 autonomous vehicles, we hardly have the possibility to get the real experience of the completion of related secondary tasks from the user's point of view. In the absence of corresponding real user data, studying the relevant behaviors of users and the products that have appeared in the market or product concepts can help us gain insight into the development direction of related technologies in the current market. Therefore, in this project, we need to benchmark as many related vehicle interfaces and functions as possible. For the general direction, the content we study in benchmarking is divided into three directions, which may affect the design goals:

1. Steering wheel screen product or concept in the market
2. Functions of multifunction steering wheels in the market
3. Functions of the vehicle center display in the market

First of all, investigating the steering wheel screen concepts that are similar to this project in the current market is required. In order to better analyze the current enterprises' unique understanding of the given direction and different solution concepts, the following aspects are summarized:

- Steering wheel screen size
- Location
- Interactive mode
- Connection with other screens
- Functional group
- The meaning of the screen
- Whether/what kind of self-driving car

Due to the limited number of announced and actual products currently in the market, it is difficult to discover the design motivation and design trend of the corresponding concepts, so we need to find possibilities in the human-machine interface of all cars. Therefore, benchmarking in related fields is also necessary. For example, in the design phase, it is necessary to consider which functions of the steering wheel can be integrated into the screen; if the steering wheel screen has a subordinate relationship with other car screens, then what kind of functions of other car displays can be controlled by the steering wheel screen. Therefore, the market research on the necessary functions and the second task functions of the steering wheel is the second part of benchmarking, and the research on the functions of the current mainstream vehicle center control screen is the third part.

3.1 Ethical

The ethical factors that need to be considered in benchmarking is the confidentiality of the information, so illegal channels are not applicable to obtain the confidential information of the company. Protection of business secrets is an ethical aspect that needs to be considered during the benchmarking. Therefore, in the process of benchmarking, the source of information should be considered, and information that is authentic and credible and does not affect business secrets should be obtained from formal channels such as the official website of the enterprise as much as possible.

3.2 Process

3.2.1 Steering wheel screen product or concept in the market

At present, there are no related steering wheel screen products that have been released in the market, but their various functions can be studied logically and reasonably through a wide range of related concepts released by well-known companies in the automotive field. First, we started from different companies, inquired about the latest product releases, and summarized the concepts of the steering wheel screen into a table. The following information in table 1 was found from the official introduction websites of the relevant companies.

	BYTON m-byte	Lixiang L9	Hyundai
			
Scale	Rectangle 7’	Rectangle unknown	2 rectangles unknown
Position	Steering wheel upper center	Middle top edge of steering wheel	Where the thumbs are
How to interact	Touch & gesture	Touch	Touch Press hard for activating
Connection between other screens	The steering wheel screen and the center armrest screen are used as the controller of the central large screen, Affect the big screen by interacting on these two	Unknown	Unknown

	screens		
Function groups	Main menu is customizable. Music, maps, air conditioning, seats, games, photos, meditation mode.	Touch Bar: Quickly operate vehicle functions	All functions in the car – from radio volume to seat heating
Purpose of the screen	Apps and functions selection, use as a pad	Quickly operate basic car functions	Basic car functions
Is there an ADS?	L3+	L4	Unknown

Table 1: Benchmarking of steering wheel screen concepts and products in the market

3.2.2 Functions of steering wheels in the market

Considering the comprehensive and valuable information in the market, it is valuable to summarize the steering wheel functions of various vehicles from many brands. In this benchmarking process, the main research object is the multi-function steering wheel. The following content in table 2 comes from the official websites of the corresponding companies.

	Left function group	Right function group	Form
	Basic driving functions Keep distance, speed limit Volume adjustment slider	Media controller Voice control switch Heat steering wheel	Bump sensation with panels that move ever so slightly so that certain features actually feel like a button being pushed
	Basic driving functions Speed limit, Keep distance Home, direction, back	Phone call Media controller Customize function Voice control switch Home, direction, back	Button feedback display
	Phone call Media controller Customize function Voice control switch	Basic driving functions Speed limit, Keep distance	Physical buttons Small roller

	Left function group	Right function group	Form
	Keep distance, speed limit	Media controller Voice control switch	Pressing panel buttons
	Turn-signal headlight button Scroll：volume (up and down), changes the audio track (left and right)	Car horn, wiper, voice control switch Scroll："Autopilot" (press) Pilot speed (up and down)	Touch-sensitive buttons and two scroll wheels

Table 2: Benchmarking of functions that the steering wheels have in the market

3.2.3 Functions of the vehicle center display in the market

Finally, we took the Tesla Model 3 as an example to study the functions of the in-vehicle central display (figure 8). It is a unique industry benchmark in the current market as the screen in Tesla has the most abundant functions and the best visual effects. Tesla Model 3 center screen includes basic vehicle function controllers that control the vehicle itself through user-friendly visualization operations, such as the air-conditioning wind direction. Other functions like Vehicle Assistance, Navigation, Music, Tricky Entertainment, Music, and Send Messages, are also provided by the center display.

The implanted system's interface first displays the content related to safe driving by default, and other functional content is displayed in the form of modal windows and drawers. The level of the operation interface is reduced as much as possible, and the content is put away after use to significantly improve the use efficiency. The most important and most frequently used function buttons are as close as possible to the driver's side of the display. In the bottom function bar, the one closest to the driver's side is the Model 3 model icon. Clicking it will call up the vehicle's detailed settings page. Because the capacity of the bottom function bar is not enough, Tesla specially designed an application drawer and placed it in the position of the third icon. Drivers can click it to use applications in the drawer, such as browser, contact list, energy consumption curve, and so on.

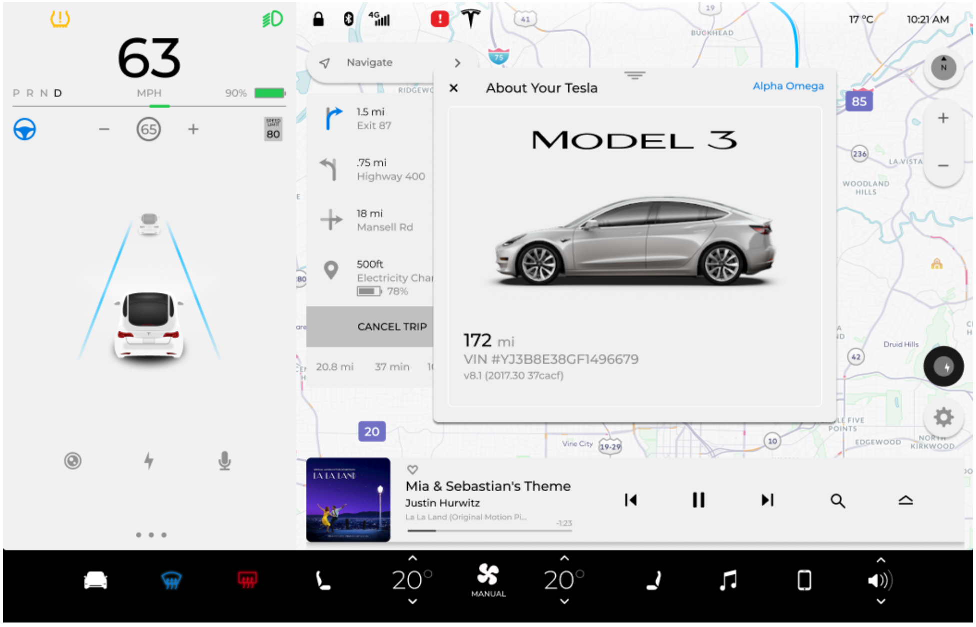


Figure 8: Interface of Tesla Model 3 center screen

3.3 Result and conclusion

Through benchmarking in the current market, it can be seen that the steering wheel screen appears in the form of concepts, and the number of related concepts is still small. First of all, some companies in the industry tend to use the screen instead of the traditional physical buttons on the steering wheel, so as to achieve the purpose of simplicity and full customization to allow users to define their own steering wheel. This type of screen is mainly responsible for quick vehicle setup on a smaller scale.

In Hyundai's concept, there are two rectangle screens on the spokes where the thumbs are when a driver is holding the steering wheel with both hands. The screen on the left shows the basic function settings of the vehicle. The right screen acts as a controller for the selected function on the left. The concept first guarantees the position of the user's hands on the steering wheel when performing the corresponding operation, making the transition process for the user to take over the driving task shorter and the deployment of the airbag safer. At the same time, the screen is located at the position of the index fingers of both hands (Meschtscherjakov, 2017). In order to prevent accidental touches, the function triggering method of the screen is also different from ordinary clicks. It needs to be pressed hard within a short period of time to trigger the corresponding function. Although this may reduce the operating efficiency of the driver, from the perspective of user-centered design thinking, preventing misoperations also greatly reduces the risk of accident, so similar triggering methods can be considered . Hyundai's concept is not specifically designed for self-driving cars, because more attention is paid to the possibility of using a touch screen to replace the previous physical buttons on the steering wheel.

Lixiang L9 is also a recently released car product, as for the steering wheel screen, the physical buttons are replaced by the touch bar above the airbag cover. In this touchbar, the basic control functions of the vehicle are provided. At the same time, since the vehicle adopts the form of HUD to replace the traditional instrument panel, the steering wheel screen also undertakes the display function of some vehicle information. On the whole, the steering wheel screen does not help users complete the second task, but it serves as a replacement for some physical buttons and instrument panels. However, due to the small size of the screen, it is not conducive to the display of information, so it appears on the steering wheel as a functional touchbar.

BYTON gave a different answer to the market. A larger screen that is not rotated with the steering wheel is placed in the upper center of the steering wheel area. First, the screen is used more like a tablet, with plenty of secondary task apps. The steering wheel screen also has a frequent connection with other screens in the car. For example, during automatic driving, the driver can project the video selected on the steering wheel screen to the center screen and watch it together with the occupants in the car. Although the screen is fully functional, BYTON still retains the relevant physical buttons arranged on both sides of the screen. During automatic driving, the driver’s hands can leave the steering wheel to complete a variety of secondary tasks by operating the steering wheel screen and the center screen. Compared with the other two concepts, BYTON gives a more complete and effective answer to the user's secondary task requirements during autonomous driving, giving the driver a lot of freedom to use both hands when the vehicle is driving automatically. However, it prevents the user from quickly taking over the driving task and increases the possibility of injury to the user in the event of an emergency.

The three steering wheel screen concepts currently released in the market propose three distinct solutions. The current market is not prepared enough to adapt to autonomous vehicles. It will be difficult to find a balance between encouraging users to perform rich secondary tasks and safer autonomous driving. Safer autonomous driving encourages the driver to keep both hands on the steering wheel during autonomous driving, which has obvious benefits both in terms of the speed at which it takes over the driving task and the secondary injury of airbag deployment (Meschtscherjakov, 2017).

The steering wheel functions configured in most automotive products have obvious design commonalities. The function groups of the latest steering wheel products are mainly divided into two types. The first function group is responsible for setting the basic functions of vehicle driving, including distance maintenance, automatic cruise switch, light switch, and so on. This part of the function group is set on the left steering wheel spoke of the thumb position held by the left hand in 4 of the 5 brands of vehicles investigated, and most of them appear in the form of physical buttons. Another type of function group is responsible for the secondary tasks, which generally include answering calls, voice control, volume adjustment, and other media control functions. This type of function group appears in the form of physical buttons on the right-hand steering wheel spoke. As a highly integrated steering wheel, Tesla adopts a form of multi-function buttons, through the driver's pressing and rolling in different directions, it can play different control functions. Besides, the left side function button is responsible for the basic driving functions of the vehicle, and the right one controls the media functions, which is similar to the market trend.

At present, cars in the market have made a clear distinction between the functions of the left and right-hand controllers, so as to avoid confusion between the secondary task functions and the driving functions. When considering the functions of the steering wheel screen, it is also necessary to follow the general regulations of distinguishing the function groups for the two hands. The function buttons are mainly in the form of physical buttons, which can be operated by the driver without vision, which greatly reduces the cognitive burden of the driver. The button feedback display, which is partially reused in the currently launched cars, makes the entire steering wheel integrated. At the same time, in order to achieve the same effect of reducing cognitive load and driving distraction as physical buttons. Interactive feedback is important to this type of button, they should give users a similar experience through realistic pressing effects and vibrations. Various interactive feedback effects need to be considered, especially when the user uses a screen to perform corresponding operations.

4 User Study

Through literature reading and benchmarking, the corresponding design specifications and related design concepts in the market are introduced. Then a user study is considered to be needed, and it is one of the important design processes used to discover user needs. The steering wheel, a product that is closely related to the user, needs a user-centered design method to obtain the user's needs and usage problems. However, the design objective of this project, the L3 autonomous vehicle, is at the conceptual stage in the current market, so we cannot obtain the actual user experience and problems of users. Therefore, it is considered to cut into the problem from the side. Although the results of user study cannot directly reflect the needs of users, regulations can be discovered.

The user study was mainly divided into four parts (as shown in figure 9). First, reading papers and meetings with Autoliv were used to determine the target user group for this project. Second, interviews were used for the target group to obtain the corresponding mobile phone and driving habits information, and discover the needs for secondary tasks. Thirdly, through the practice of the Bodystorming method, we studied the relationship between the user's preferences of display position and the secondary task interface. Finally, after obtaining the results of two user studies, potential secondary task requirements were discovered and analyzed.

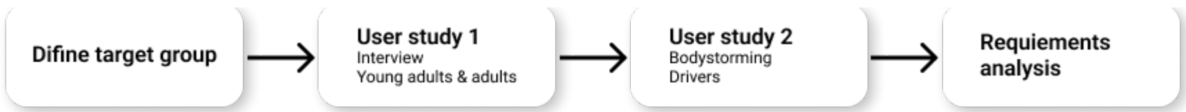


Figure 9: Process of the user study

4.1 Define target group

According to literature, compared with higher and lower level autonomous vehicles, under certain conditions and imperfect autonomous driving will significantly increase the cognitive burden of drivers（Seppelt & Victor, 2016) because the driver needs to be the fallback-ready user, who needs to pay attention to the dynamic driving task frequently. This shows that L3 autonomous vehicles have high requirements for the driver's cognitive ability and other related abilities. In addition, Günthner, T., & Proff, H. (2021) studied the acceptance of autonomous driving technology by users of different ages. It was found that most people start to feel a decline in their physical ability and cognitive response-ability from the age of 50. Usually, the elderly will avoid participating in secondary tasks as much as possible for their own driving safety due to their physical decline. Although self-driving technology is beneficial to the elderly with declining physical ability, let them make up for the lack of physical ability through the self-driving system. But for the market, this result means that the usser group of older drivers, in particular, can be persuaded to use advanced driver assistance systems by means of a suitable and user-focused value proposition. For the elderly, higher-level and more perfect self-driving systems are needed. Besides, trust is equally important to all user groups for the usefulness and ease of use of autonomous driving technology, but tends to be slightly higher among younger users and is more willing to engage in secondary tasks.

So in this project, young adults (20-35 years old) and adults (36-50 years old) with driving skills are our primary target group, they can quickly adapt to new technology while participating in secondary tasks with more willingness. The occupations and lifestyles of the two target groups are different. Young adults are more willing to use mobile phones, and their needs for secondary tasks are more youthful and trendy. Adults, as employees, have a higher demand for information input. Therefore, the results need to be counted separately in the following interviews.

4.2 Ethics

In order to obtain the requirements of users, it is necessary to study the daily behavior of users, which will inevitably involve corresponding personal privacy issues, and some issues may include the daily behavior habits of respondents. Especially for the study of driving habits, due to the current lack of self-driving cars, it is not entirely legal for some drivers to complete secondary tasks while driving. As legal and safe driving is admired and distracting from driving to secondary tasks is not recommended, we need to avoid tying users' actions to the name and identity of the individual. The interviewee's name and address information should not be interviewed and recorded when recording the interview results, and the interview materials should not be screen-recorded during online video interviews. Because the protection of the personal privacy of respondents in the user research stage is one of the ethical factors that need to be paid attention to. On the other hand, it is necessary to avoid the description and guidance in the questions that are contrary to the laws of the country, so as to reduce the guidance of the interview questions to the respondents on unsafe driving habits. This helps promote safe and responsible driving. Finally, gender equality and occupational equality also need to be considered.

4.3 User study 1

4.3.1 Method and purpose

In order to more effectively analyze the user requirements we need from other perspectives, we need to use a long time to communicate with users. Only by communicating as deeply as possible, we can discover potential needs from the behavior of users. Therefore, it is particularly important to guide interviewees to fully recall their daily behaviors and think deeply. Through the most suitable form of interviews, we help the interviewees to open up their hearts and speak freely through progressive questions and more flexible time. We can also ask follow-up questions and discuss with interviewees to further explore the needs of users. In order to more comprehensively analyze the corresponding secondary task requirements from other perspectives, we need to start with the mobile phone that is currently used to complete secondary tasks to study the corresponding mobile using behavior, including daily use and the use during driving. In addition, we also enriched the research on user expectations in the interview, so that the interviewed drivers can first mobilize their thinking in the form of recalling what they did this morning, then transitioned to daily behavior, and finally imagine future scenarios. Therefore, the purpose of this interview is mainly to obtain the user's requirements for using mobile phones, the needs of users for using mobile phones during driving, and the user's imagined preferences and requirements for secondary tasks during autonomous driving.

4.3.2 Process

First, we developed step-by-step interview questions, starting with the user's travel experience that day, asking the user to recall how they used their phone during their commute, and why. The interviewees were interviewed on their recent long and short trips and asked about the purpose and method of their travel, as well as how and why they used their mobile phones on the road. Then, the questions were directed to the respondents' daily driving habits, including the corresponding driving experience, steering wheel grip, common functions of the vehicle center display they usually use, and the need to use mobile phones in daily driving. Respondents were finally asked to imagine various tasks they would like to accomplish under hypothetical autonomous driving conditions. The questions of the interview are in Appendix B. In order to better explore user needs from the side, additional questions will be added for different respondents and answers, which will not be included in it.

Since the target driving user groups are divided into two types: young adults (20-35 years old) and adults (35-50 years old), we found 5 young adult drivers for interviews and then interviewed 6 adult drivers. The results of all interview sites will be summarized after the interview. At the same time, we ensured the gender ratio and occupational diversity of respondents when looking for respondents. The interviews lasted an average of 15 minutes and were conducted in the form of an online video conference. One of the panelists is responsible for asking questions from the list of questions, with additional questions for deep requirements, the other panelist is responsible for recording the interview and the answers. The interview is divided into the following steps:

1. Introduction of project background
2. Emphasize the protection of respondents' privacy
3. Formal interview
4. Follow-up questions
5. Feedback time and emphasize the protection of personal privacy again

Everyone's answers are included in Appendix C. In each person's answer, there is a need for using a specific mobile app. For different secondary task requirements, we separately counted the types of secondary tasks in different situations mentioned by the respondents of the two target groups, and the number of times the secondary tasks were mentioned by different respondents. Statistics on secondary tasks are included in Appendix D.

4.3.3 Results

Young adults (20-35 years old) target user groups are mainly students and young practitioners. On the way to study and work, their main requirements for mobile phones are navigation (including bus route apps, and map navigation), enjoying music and podcasts, followed by news and current affairs. The use of social media software is also a raised user requirement. This group of users has the most obvious need for music and podcasts, although the need for navigation is the most cited. In non-work and study situations, the respondents' needs for mobile phones are also reflected in their needs for navigation and music/podcast. In addition, in this relaxed atmosphere, they communicate more with their friends or use social applications to send texts. In addition, listening to audiobooks is also an option for some young respondents.

For driving purposes, the answers given by the respondents did not show a certain pattern, but in general, carrying items that cannot be carried on public transportation is a relatively common reason. Most of the respondents hold the steering wheel with both hands, and more than half of the respondents hold the steering wheel at a position higher than L9 and R3. Their main needs for mobile phones during driving are to listen to music and radio, use navigation, and perform control operations within the software.

Among the secondary task requirements proposed by young adult drivers in a hypothetical autonomous driving environment, watching Youtube and playing games are two novel secondary task requirements, while music and podcasts are still relatively basic secondary task requirements. In addition, sending text messages, checking and replying to emails, and using a browser to surf the Internet are also the requirements raised twice by the respondents. Overall, Young adult respondents believe that some secondary tasks that require high cognitive resource consumption can be completed during autonomous driving, and current daily secondary tasks will not be replaced.

Similarly, adults have the most prominent need for mobile phone navigation during their daily work trips, followed by music, audiobooks, and news reading. In addition, due to interpersonal and family requirements, they frequently use their mobile phones to send and receive text messages and make phone calls. While driving, listening to audiobooks was one of the most mentioned secondary tasks, texting and listening to music were two other important secondary tasks.

Adults drive mostly for vacation trips and family trips, followed by carrying goods. Regarding the steering wheel holding position, the most concentrated on the L10R2. Compared with young adults, they are more inclined to drive seriously and safely and to hold the steering wheel more safely. They have a requirement for active input of daily information, which is reflected in their love for reading and listening to books. Among their expected secondary tasks, reading and podcasts remained the most prominent choices, followed by watching videos, sending messages and emails, and listening to music and news.

In general, the two types of user groups have certain similarities in the choice of secondary tasks in daily mobile phone use and driving. Listening to music or audiobooks is the secondary task that occupies less cognitive resources, and was also the most mentioned task. Whereas young people tend to appreciate music, adults tend to read. Regarding the imagination of the two target groups for the secondary task, watching videos is the common choice of the two target groups, and answering emails was also proposed by the two groups. Video media and text input were the most easily associated kind of tasks among users. Therefore, they are the secondary tasks that we decided to develop in-depth.

4.4 User study 2

4.4.1 Purpose

After obtaining the possibility of user needs for various secondary tasks from user study 1, some questions and follow-up research directions appeared. First, the possible secondary task requirements were estimated based on the user's mobile phone usage and the user's speculations. So we need some way to verify which secondary tasks are actually required by the user in an autonomous driving environment. Second, as drivers need more information while driving, and as the car wants to provide more secondary tasks, Level 3 autonomous vehicles will likely offer many displays. For example,the Head-Up Display ,the High Head-Down Display, Instrument Panel and Center Console Display may exist in the field of vision of a driver at the same time. In this case, the screen on the steering wheel and other displays need to be clarified in relation to secondary tasks. Display and control are considered to be the two most important relationships between secondary tasks and displays. Therefore, for vehicles with multiple displays, the responsibility of the screen on the steering wheel for secondary tasks and the relationship of secondary tasks to multiple displays needs to be defined.

In summary, the overall purpose of further user studies is to validate the results of the previous user study and explore users' thoughts on the relationship between secondary tasks and multiple displays.

4.4.2 Method

Different from other experiments that study the user experience of drivers in ordinary cars, we hope that the environment in which the experiment is located is a level 3 autonomous driving environment. This means that the user can see the driving environment outside the car while sitting on the driver's seat, but at the same time, they do not perform driving tasks for a period of time. So far, there is no widespread Level 3 autonomous vehicle on the market, nor is there a way to simulate a Level 3 autonomous driving environment. In talking with Autoliv's supervisor we learned that Autoliv has driving simulators that simulate both autonomous and manual driving scenarios. This simulator is considered to be able to help us do better research. An experiment can be designed based on the simulator. And bodystorming is considered the most suitable user research method for this experiment.

Bodystorming is an immersive innovation process that involves role-playing and physical involvement with props, prototypes, real items, and physical environments to explore ideas. Its overall aim is to comprehend the interactions between people, their physical location, and the items (e.g., tools, devices, materials) they employ in that context (Wilson, 2011).

The main implementation method of this experiment is that the simulator provides a physical environment and an electronic driving environment, and we supplement the environment details by descript, including time and tasks. We print pictures of all possible secondary tasks and their different functional components, show them to the user after simulating entering self-driving mode in the simulator, and let them choose their preferred secondary task and perform the interaction they think makes sense. We observe and record from the sidelines.

4.4.3 Process

According to the target group, we found 3 young adult drivers and 3 adults drivers for physical and online experiments. In order to keep the information of the participants confidential, we did not record and take pictures in the physical experiments and online experiments. The average duration of each experiment is 15 minutes, and the following is a simplified version of the experimental process. The full experiment procedure is attached in the appendix E.

We followed the same process for both physical experiment and online experiment. First is the introduction of the project and the experiment. After that, we described a detailed scenario for users helping them immerse themselves in the scenario and make decisions. Figure 10 shows how we create scenarios through Miro. They were told to imagine they are driving a Level 3 self-driving car with many screens, including a touch screen on the steering wheel. Then they were required to choose three secondary tasks they want to perform during autonomous driving from the secondary tasks we provide. For each secondary task,they were asked to place different functional components where they see fit. Take email as an example, a reading email page, a writing email page, and a keyboard were provided. Users may believe a bigger screen is more suitable for reading email, and the steering wheel screen is more suitable for a keyboard. And they were asked what kind of touch screen on the steering wheel they would like to have. At the end of the experiment, we invited respondents to ask us questions and give feedback.

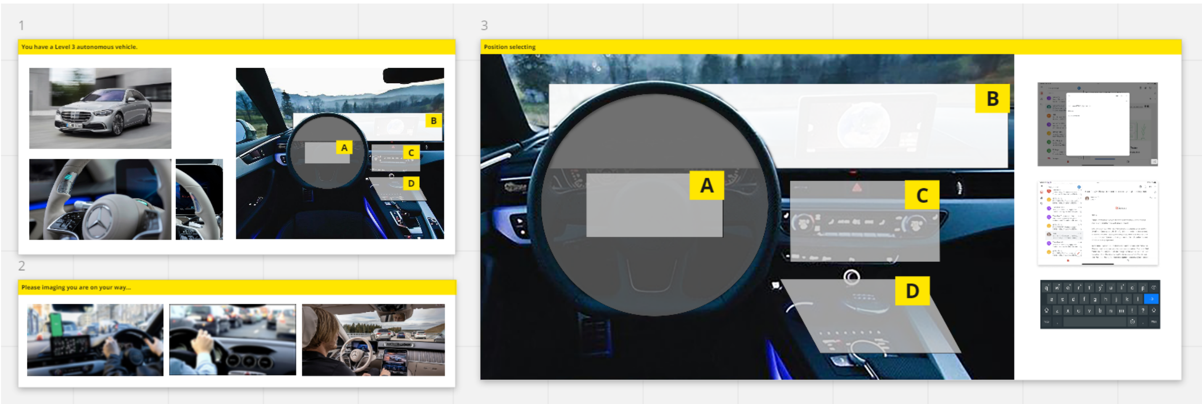


Figure 10: Scenario created by Miro

4.4.4 Result

Although we used onsite and online experiment, because we have the same purpose and process for these two methods, we comprehensively analyze all the results of the two methods. The complete record of this study is attached in Apendix F.

Combining the experimental results of the two target groups, some useful conclusions are found. First, we wanted to see if the experimental results showed that some secondary tasks were mentioned significantly more than others. Combining the responses of all participants, we found that Spotify, Messenger, Youtube, and Gmail were mentioned the most. But due to our small number of participants, this result does not indicate that some secondary tasks are especially valued and favored in the self-driving scene. Larger and longer studies may be required to obtain data on secondary task selection. Then for our design, the conclusions of user study 1 are more worth considering when deciding which secondary task should be provided.

Regarding the placement of different functional components in the application, although participants chose different types of applications, we found some commonalities. Figure 11 shows the components that we concluded were the most frequently selected by the participants to be placed on the steering wheel screen. Among them, the play function buttons and keyboard are considered to be the most suitable components to be placed on the steering wheel screen. We believe that users tend to place components with control functions on the steering wheel screen, such as the play and pause buttons in playing video. Components with reading or watching attribute are more placed on other larger screens, such as video or email content. In addition, users believe that some content can be displayed on the steering wheel screen and other screens at the same time, which will give users more freedom. This inspired us to think about the relationship between multiple displays in the car. Different alternatives can be proposed later in the design phase to explore multiple possibilities.

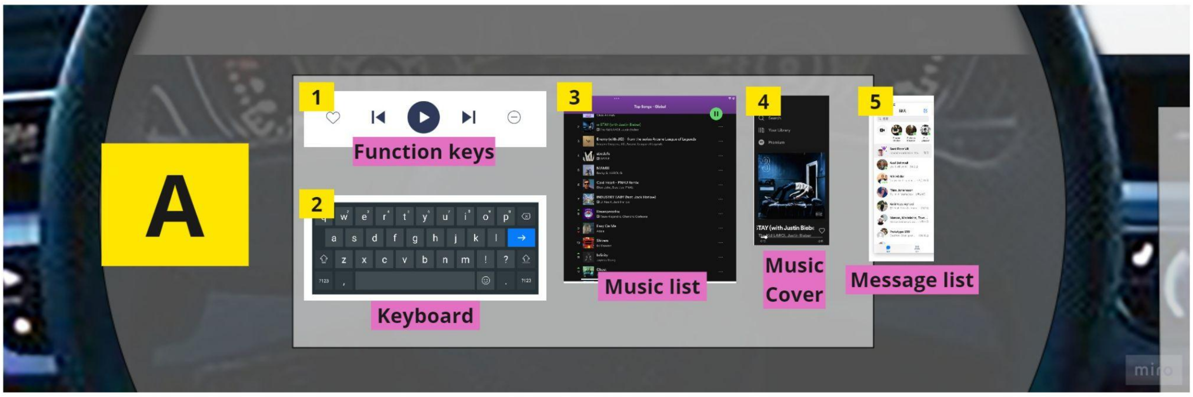


Figure 11: Components that most frequently selected by the participants to be placed on the steering wheel screen.

Additionally, no more consistent preferences were found in the user's perception of the position of the steering wheel screen. But some concerns of users were found. For example, users are more concerned about whether the position of the steering wheel screen provides a comfortable operation and whether they need to keep their heads down to observe the screen. What this inspired us is that users believe comfort and ease of use come first, and we should focus on exploring good controls.

5 Use scenario

5.1 Purpose

After obtaining a lot of user behavior and preference information, we hope to use a more vivid way to summarize and analyze the obtained information, and to help us better predict the user's intention and performance when using the products we provide. Persona and use scenarios are considered to be a good way to help us translate user needs into product concepts. Since we have two target user groups, we want to create two persona and their use scenarios according to their respective typical needs, in order to simulate and explore common use scenarios of all target user groups.

Persona is a fictional character created from research to represent possible different types of users. Creating personas will help users understand their needs, experiences, behaviors, and goals. (Dam & Siang, 2022). Nielsen (2013) proposed a method “Ten steps to personas” to construct persona, as shown in Figure 12. This process model contains four different main parts: data collection and analysis, persona descriptions, scenarios for problem analysis and idea development, acceptance from the organisation. Nielsen (2013) argues that a project does not need to follow all steps. In this project, the sixth step “defining situations” is considered to be the most efficient approach and we call it creating use scenarios. We want to create some virtual characters and usage scenarios that describe the user's scenario when using our product, including the user's vision and behavior, possible feedback and performance of the product.

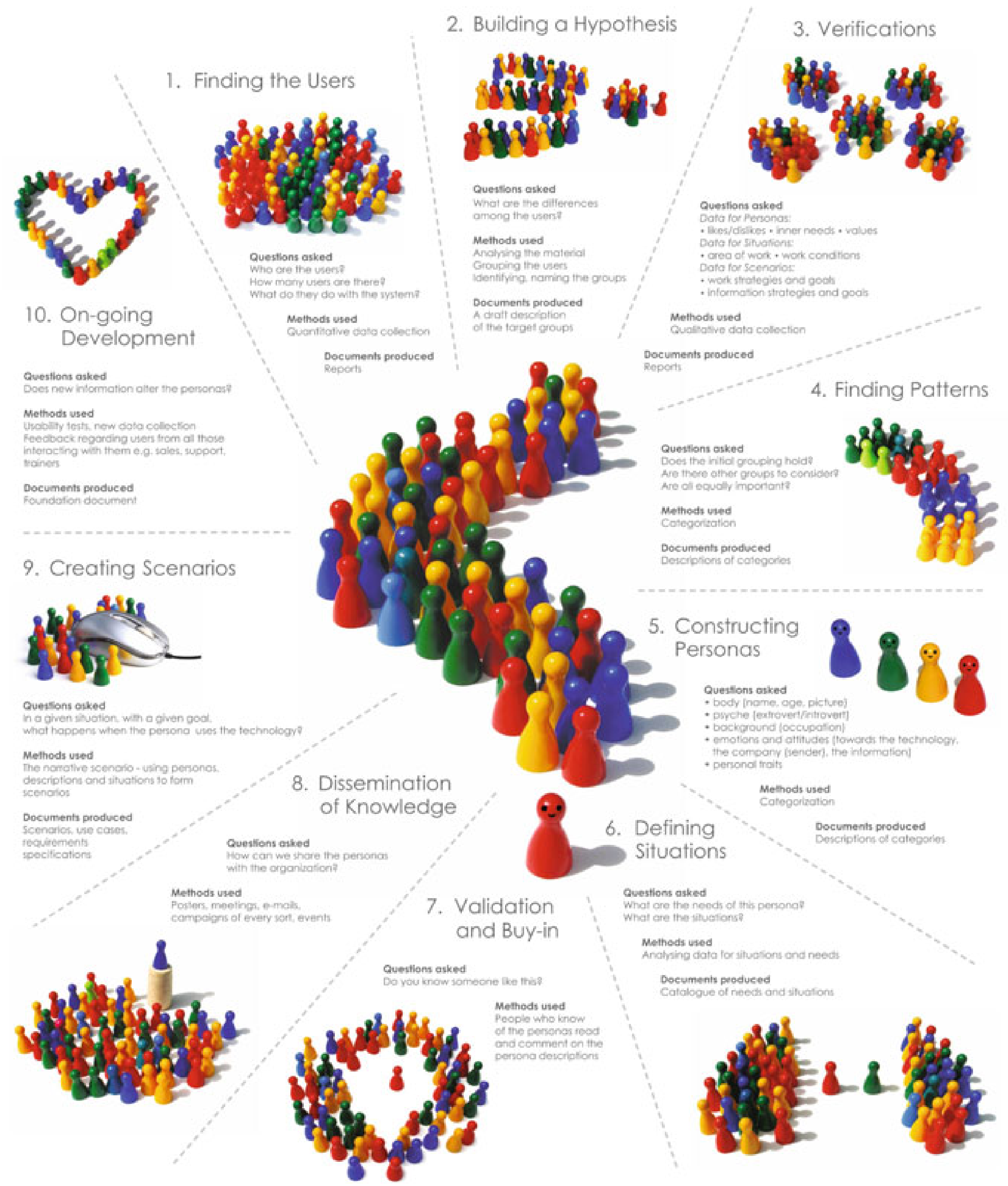


Figure 12: “Ten steps to personas” to construct persona by Nielsen (2013)

We believe this is critical step in the project, because the creation of the use scenario is based on the results of the user research, which represents the patterns of user behavior and needs found in the user research, and is the summary and presentation of the data in the user research phase. At the same time, the use scenario is also the beginning of the product concept generation. In this step, we define the use environment of the product in more detail, the scope of the design, and the results we want to achieve.

In the user research stage, we found that media and text input are the most desirable secondary tasks for users, and they are also the two types of secondary tasks that we decided to develop in depth. Therefore, when creating use scenarios, these two types of applications are integrated into the story, and the email application and video application are highlighted.

Another reason to choose these two types of apps is that video apps are more of an entertainment and relaxation attribute, while email apps are more of a business attribute. Reflecting on the secondary tasks that users frequently mentioned in the user research they wanted to perform in a Level 3 autonomous vehicle, some of them were more for entertainment purposes, and some were more for office purposes. This gave us the hint to create a relaxation scene and an office scene when creating the use scenario. Therefore, reading and replying emails, and watching videos, respectively, match the two usage scenarios that users expect from a Level 3 autonomous vehicle. According to the results of user research, young adults use more entertainment and relaxation apps on a daily basis, so we designed a scene that is biased towards relaxation for young adults. Adults, on the other hand, showed preferences for self-improvement and work in user research, so we designed an office scenario for adults.

To make the story seem more real and specific, we substitute each type of app with a specific product that is most widely used in that type of app. For example in Young adults' use scenario, we use Youtube instead of "video app".

5.2 Scenarios

For young adults, we created a couple's persona and a situation where they drive to IKEA to shop.

Carl (26 years old) and Anna (25 years old) are students at Chalmers University of Technology and live in the city centre of Gothenburg. On a weekend in April, Carl and Anna decide to go to IKEA to buy some furniture and decorations for their home . Since IKEA is so far away from their home and they probably need to buy a lot of things, they decide to drive to IKEA instead of taking public transportation.

According to Google Map, they will spend 40 minutes driving. They set off at 9 am and get into the car with their belongings, including their mobile phones. The car has Level 3 ADS, which means they don't need to perform driving tasks at some time, but can instead devote themselves to other tasks.

Once in the car, they connect Carl’s phone to the car's system so they could receive calls and messages from the phone. Today they choose to play soft music to relax. Since they are unfamiliar with the way to IKEA, they use the car's navigation software to navigate. When they are on the road, the car's system informs them that self-driving mode can be turned on. They turn on the self-driving mode with a button on the steering wheel. They think it's a good time to watch videos, and since they don't have enough time to watch a movie or an episode of a TV series, they choose to use the big screen to watch videos on YouTube. They open up youtube and happen to see an IKEA shopping sharing video while browsing the video list, which is exactly what they need. So they clicked on the video and the soft music stopped automatically. While watching the video, a friend sent a message inviting them to a party on Sunday, and they reply their friend while watching the video.

After 10 minutes, the car reminds them through sound and light that they need to regain control of the car and perform the driving task within 10 seconds. With the information, they quickly adjust their status, refocus on the road, and take over driving tasks. At this time, the secondary task interface such as the video is hidden, the light music is replayed, and Carl is able to devote himself to driving.

Finally, they get to IKEA and spend 3 hours buying what they want and loading them into the car. It is almost 1pm and they do not have lunch at IKEA, so they are a little hungry. They decide to look up a nearby restaurant on the drive home. On the way home, when in self-driving mode, Carl opens the browser, looks for nearby restaurants, and chooses one for lunch. During the day's driving activities, the secondary tasks that the car offers meet Carl’s and Anna’s needs well.

For adults, we created a scenario where Maria drives to meet clients.

Maria, 38, is starting her own company, not only to work in the company, but also to meet customers in different places frequently. She has very little free time and every minute is precious to her.

On this day, Maria have to drive an hour from the company to Kungsbacka to meet customers. First, she turned on the navigation, because she was not familiar with the way to this place. Before she started driving, she opened the audiobook app “Audible” and listened to the startup-related book, The Lean Startup. Five minutes later, she was on the road and the car informed her that self-driving mode could be activated. She activated it by pressing a button on the steering wheel. At this point, she stopped the audio book and opened Gmail to read and reply to the emails that needed to be processed. It took her about half an hour to read and reply to emails. She was asked to take over the dynamic driving task several times during this period of time, but the self-driving mode was reactivated after a while.

After replying to the email, Maria found that she had about 10 minutes to reach her destination. So she decided not to do other work tasks, but to open Audible to continue listening to the book and prepare for meeting with customers.

Maria thinks that the secondary tasks provided by the car on this trip are a good fit for her needs of having a light-duty office environment.

5.3 Analysis

When writing the stories, we try to include all possible situations, so we can fully consider the product function and usage process when designing. Some unique scenarios in the two use scenarios are considered to have strong guiding and normative effects on the design.

First, switching between manual and automatic modes is common in stories and in actual use, so the information displayed and the functions provided by the steering wheel screen in different modes need to be considered. When users are asked to regain control of the car within 10 seconds, their attention needs to quickly shift from secondary tasks to the driving environment and the driving task. Therefore some questions that should be considered during the design phase. Could the system help users shift their attention faster? Could it help users better distinguish between manual mode and automatic driving mode from a design point of view and so on.

Second, the use scenario mentions that people are accustomed to connecting their mobile phones with car systems in order to recieve messages and calls. Therefore it will be common to receive messages and calls while the user is performing a secondary task. In view of this situation, when the screen displays other applications, how to prompt the user that there is new notifications from other applications are factors that need to be seriously considered.

In addition, it is also relatively common for users to switch between multiple secondary task applications. So the use flow of switching between multiple secondary tasks needs to be considered. At the same time, we also need to consider whether to provide a way to quickly switch applications.

In summary, the various situations mentioned in the use scenario provide guidance for our next design, and it is a very effective method for guiding design based on the results of user research.

6 Design goals

Our design goal is to design a touchscreen on the steering wheel of an L3 self-driving car, providing the driver with secondary tasks that are safe, enriched, and highly usable. The specific goals include:

A. Improve the driving safety of users through the location of the screen, how the content is displayed and controlled.

B. Satisfies the needs of most users for secondary tasks by providing a variety of secondary tasks including entertainment and work.

C. Provide an intuitive and highly usable use experience through reasonable screen position, control method, UI design, etc.

After obtaining the design results, we expect to verify that the design goals have been achieved through user testing. However, due to the current limitations of our technology and our own disciplinary background, a fully usable physical and digital prototype could not be produced and tested within the scope of the master thesis project. Therefore, within the project, some goals may not be verified. But we will try to test as many design targets as possible with limited conditions, and propose some possible test methods for other targets.

7 Physical Concept Generation

After developing use scenarios based on the user study that helped us understand the design task, the specific form of the screen was considered. However, there were many possibilities for projects, which may lead to problems of loss in generating concepts. We need to find several design directions to guide the design so that the concepts we conceive can be more traceable. To generate multiple conceptual directions in a short period of time, we chose to use the Crazy 8 method. The Crazy 8 method requires team members to record one thought per minute for eight minutes, which is a solution related to what was discussed (Jones, Nabil & Girouard, 2021). Each of us folded a piece of A4 paper into eight equal parts, set an alarm for one minute, and recorded the concept in the form of text or sketch on the space of the paper within the next eight minutes. We had a discussion after four concepts were conceived to verify that the concepts were as expected. After 8 minutes, we aggregated and merged identical or similar solutions for the resulting 16 concepts. Through the classification and summary of concepts, we got several directions that can help us conceive the concept: the position of the screen, the control method of the screen, how to control it, the linkage relationship with the center display, etc.

After getting these design directions, we started with two shapes: round steering wheels and square steering wheels (figure 13). The proposals in the Initial concept generation focused on how the use of the screen was designed to encourage users to hold the steering wheel with both hands, as Meschtscherjakov (2017) illustrates the benefits of two-handed holding. We found in benchmarking that the current steering wheel in the market has a very clear distinction between the functional areas of the left and right hands. The left hand generally controls driving-related functions and the right-hand controls the secondary task function buttons. In order to avoid confusion between the driving functional area and the secondary task functional area, we improved the design concept that distinguishes the primary and secondary functional areas for left and right hands. At the same time, we also considered whether the steering wheel screen turns with the steering wheel. After communicating with Autoliv, we finally decided to focus on the square steering wheels because of the following reasons. Firstly, square steering wheels provide more space room for legs and vision. Secondly, it also provides a psychological cue to the driver, allowing the user to naturally place their hands in the L9R3 direction, which is a safer steering wheel holding position (Meschtscherjakov, 2017), and also in line with Hruška (2018) that using this posture to hold the steering wheel has health benefits.

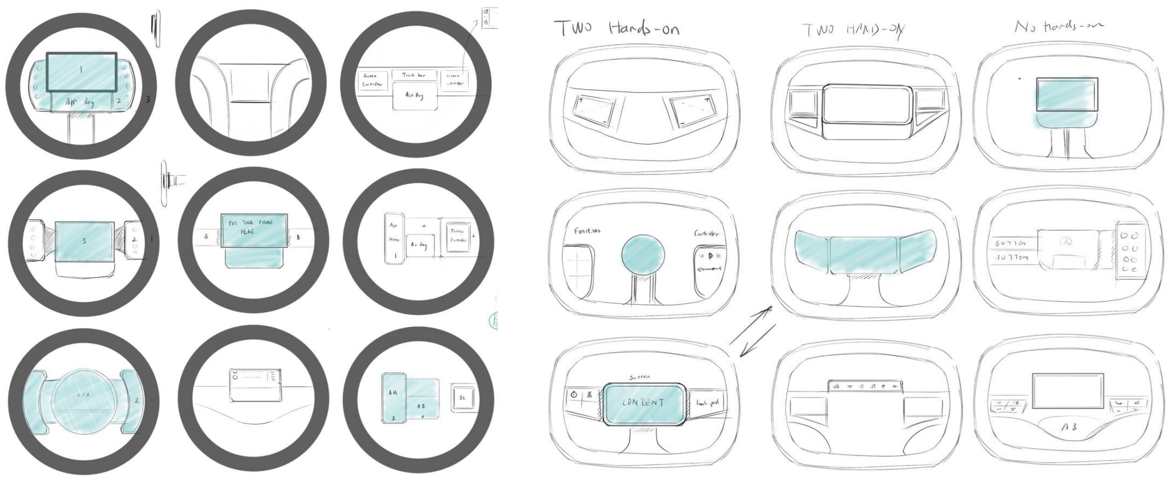


Figure 13: Initial concept generation

After the first few rounds of concept generation, we got two directions (1 & 2 in figure 14). These two solutions best meet the design goals among many concepts and can provide users with a better and more intuitive experience, while also more in line with the design structure of the steering wheel. Concept 1 in figure 14 is to install the mobile phone on the steering wheel, which can reduce the use of mobile phones while driving, and the mobile phone acts as a steering wheel screen. Concept 2 in the lower part of the figure 14 is to use a screen that can be turned into a touchpad in specific situations to control the center screen. In this concept, the touchpad screen displays the main menu for all secondary tasks, and after the driver touches to select one of the apps, it turns into a touchpad, just like the one on a laptop, to control the center screen.The interface for all apps are displayed by the center screen.

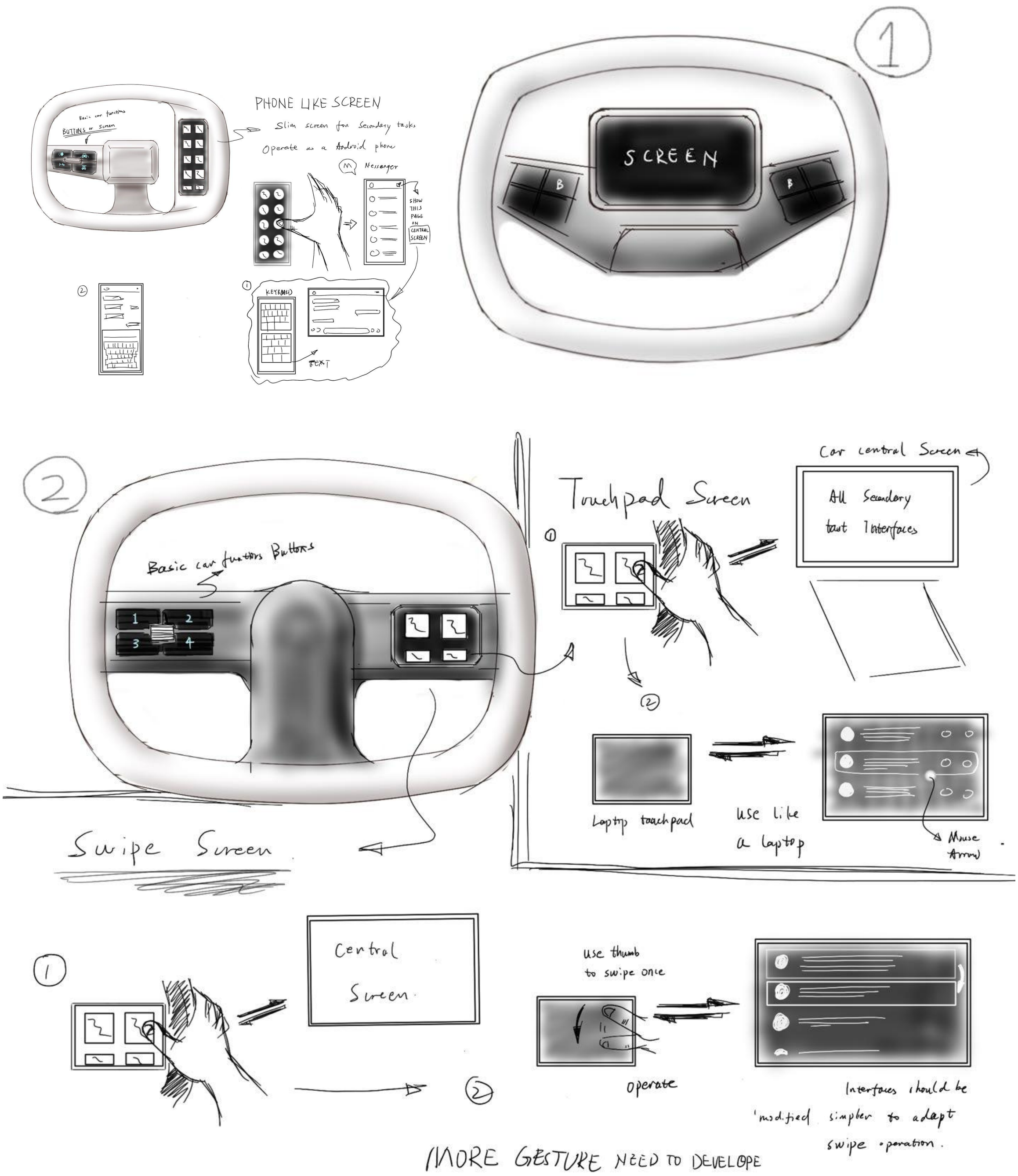


Figure 14: Second concept generation

More alternatives were developed according to the two concepts selected in figure 14. Based on previous research in the Literature review on reducing distraction while driving, and the user study 2, which concluded that users tend to place components with controls in secondary tasks on the steering wheel screen, in order to bring users a better second task completion experience, we were more inclined to use the steering wheel screen as the controller or auxiliary screen of the center screen. Unlike low-level autonomous driving technology, L3 technology can provide the driver with a longer time to complete the second task. Considering the steering wheel space and position are limited, and the possible illness caused by the driver watching the screen on the steering wheel for a long time, it is a better choice to use the in-vehicle center screen as the main screen for presenting the information.

The position of the steering wheel has the best visibility and reachability in the car. In our solution, we built a relatively smooth driving mode switching and attention transfer process:

When the driver activates the autopilot function, the user's attention shifts from the road conditions ahead during manual driving to the autopilot button, which often appears on the steering wheel. After the autopilot function is activated, the driver's attention shifts from the steering wheel to the center screen to watch the interfaces.

We believe that the steering wheel screen as a transition platform for starting the secondary task, together with the center screen, can help the driver to achieve a more natural and smooth transition between different driving modes. For example, the steering wheel screen displays a menu containing different applications in the manual driving mode and the automatic driving mode. After the user selects the secondary task app, the center screen is the main screen for presenting information and the driver's viewing, and the steering wheel screen provides necessary function buttons to control the center screen.

We filtered the solutions for the third concept generation by conceiving the complete usage process of the driver and finally got three alternatives as shown in figure 15. From top to bottom are Concept 1, Concept 2, and Concept 3. Concept 1 is a combination of a mobile phone and a touchpad, users can use the touchpad and the phone to control the center screen. The touchpad itself can be pressed as physical buttons on the corners which are responsible for four different functions. Concept 2 is about inserting a mobile on the steering wheel while using a gamepad stick to control the center screen. Generally, the content that the center screen and the phone screen displays in this concept are the same. But in some situations, the content displayed on the two screens can be different, which depends on the kind of secondary tasks. Concept 3 is the previous touchpad concept which does not require a mobile was selected as an alternative. It is also the most intuitive concept for operating processes and methods.

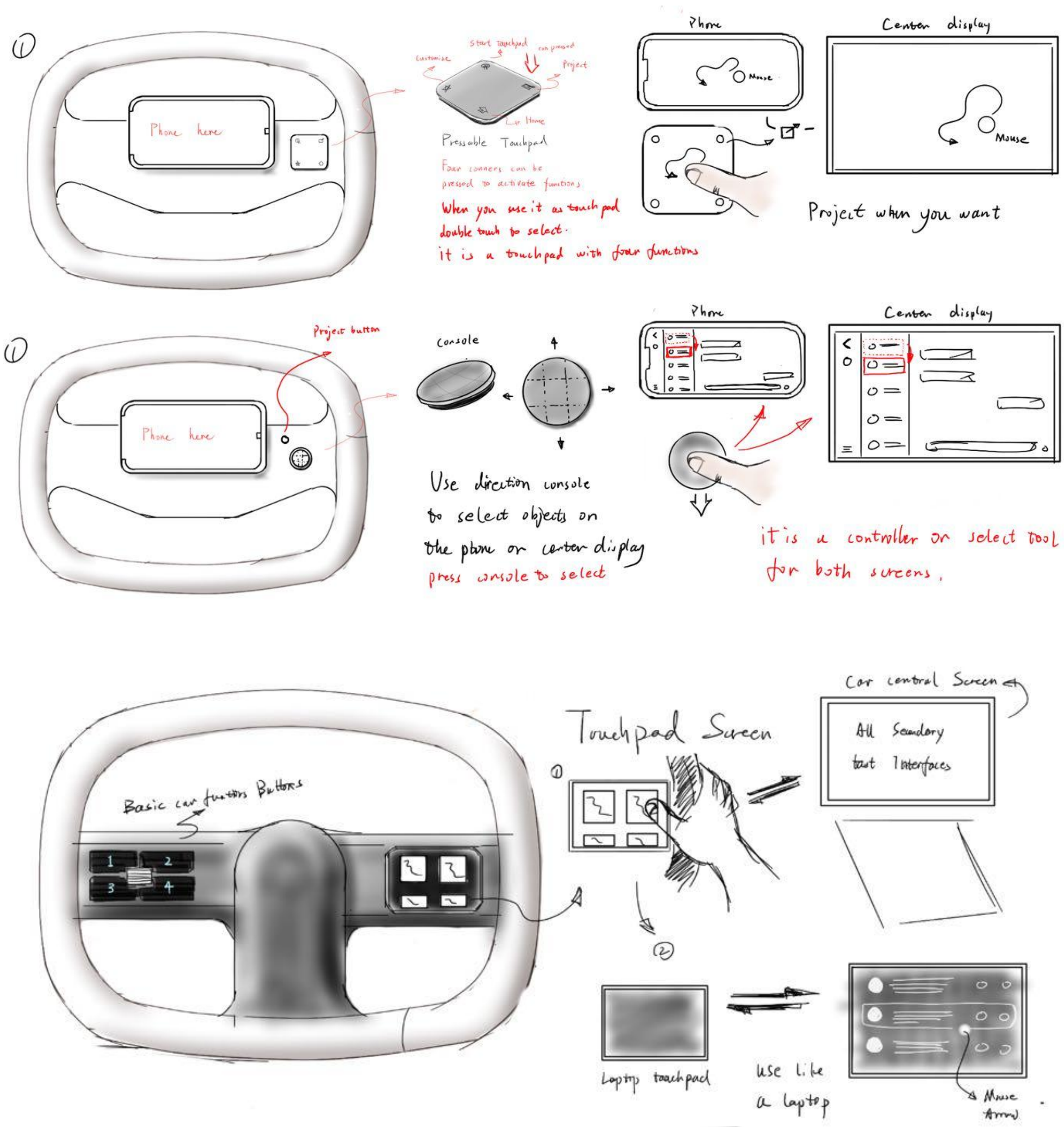


Figure 15: Third concept generation

After getting three alternatives, in order to systematic screening concepts, a test with physical prototypes is needed. Prototypes help us demonstrate the ergonomics and feasibility of concepts. We made the touchpad with the cardboard, and also made the stick and other physical buttons, and then fixed the phone to the 3D printed steering wheel through a phone bracket. As shown in figure 16, we evaluated their requirements of operation accuracy, visual distraction, etc., and used the Kesselring matrix to score them(table 3). When making the Kesselring matrix, we summarized and extracted some specifications from the design goals, and determined the weight of each specification through discussion, trying to filter out the best solution by weighted scoring.

Figure 16: Concept 1 (left); Concept 2 (middle); Concept 3 (right)

Legend			Weight Factor (w) 5 = Highest importance 1 = Lesser important		Rating scale (v): 10= Most preferred 1 = Least preferred			
Sl.No.	**Criterion**		**Solution alternative**					
			Phone + Touchpad		**Phone + Stick**		**Touchpad screen**	
		w	**v**	**t**	**v**	**t**	**v**	**t**
Safety	Limits hands position for safety	**2**	6	12	6	12	8	16
	Less visual distraction	**5**	7	35	7	35	7	35
	Minimize the influence of mobile phone	**2**	9	18	9	18	5	10
Control	Compatible with finger range of motion	**4**	9	36	10	40	6	24
	Ergonomic operation with finger dexterity	**4**	6	24	9	36	7	28
	Less chance of accidental mistouch	**3**	5	15	9	27	6	18
	Low operational complexity (mainly for both hands)		8		8		9	
	Operational efficiency		7		6		7	
	Understandable interaction	**3**	9	27	9	27	8	24
	Low requirements for user operation accuracy	**4**	6	24	9	36	6	24
	Low difficulty in developing interactive systems	**2**	9	18	5	10	9	18
	T=sum (tj)		209		241			197

Table 3: Kesselring matrix

From the testing of the physical prototypes we found a number of ergonomic issues that could affect the driver's efficient operation. First of all, for concept 1, we found that when the driver is holding and turning the steering wheel, there is a high probability of accidental touch, because the driver will inadvertently press the button on the corner of the touchpad. Since this solution uses a touchpad for control, the driver's operation accuracy is required to be high. Meanwhile, in order to realize the gesture operation of a specific touchpad, one hand of the driver may need to leave the steering wheel to operate with more than two fingers of the right hand, or directly operate the screen of the mobile phone by touch. This will increase the occupancy of the driver's cognitive resources, and under certain circumstances, there will be situations where both hands are not held at the same time. In these aspects, the solution still needs to be further optimized.

When evaluating concept 2, we clearly felt the impact of the stick's height on the driving operation. The height of the stick can significantly interfere with the driver's steering. Due to the obstruction of the steering wheel caused by the stick, it is easy for the driver to accidentally touch the stick while driving, which will lead to various risks. Regarding the height, we referenced the height and pattern of the lowest stick on the market when making the prototype, and set its height very low. At the same time, different from the protruding top stick in the market, we adopt a concave design with a lower height, which can also achieve a good control effect. In the evaluation, we found that such a stick has the least disturbance to the driver, and can maintain the integrity and smoothness of the steering wheel interface to a certain extent. But in order to adapt to stick's unique operation and input methods, we need to make a more particular design for the user interface. At present, the vehicle user interfaces in the market are interacted by touch. Therefore, concept 2 needs to make great changes to the system interface in the design to allow the driver to quickly and efficiently select any element on the interface through the stick to achieve the same function as the touch screen. This requires more effort from us and from the system developers.

Concept 3 has a significant difference compared with the other two concepts. Since the touchpad screen has both display and control functions on the steering wheel, it has a more integrated operation logic. Compared to the other two which require additional methods for control, this concept is simpler and more straightforward. When prototyping, we took into account the impact of the size of the screen on the operation. In order to allow users to use their thumbs to reach every corner of the touchpad screen, after several experiments, we finally decided to design the screen size to meet the 360*270dp ratio for the lower part of common Android phones. In this way, the touchpad screen can be fully controlled by the thumb like a mobile phone. In addition, in the user study, we found the driver's requirements for the secondary task of the text input, so the usage of the keyboardwe is also needed to consider. Designing the screen as the size of the bottom of the mobile phone can meet the touch control requirements of the thumb, and at the same time, this position is also the position where the virtual keyboard on the mobile phone appears. At this size, the user can use the keyboard and enter text with a single thumb.

Concept 3 was retained in order to ensure the existence of different alternatives to the project. Through the Kesselring matrix, we found that Concept 2 has obvious advantages in terms of operational safety and requirements for operational precision. High operational safety includes the probability of accidental touches and the requirement for the position of the hand to hold the steering wheel. Concept 2 can significantly reduce distractions and system problems caused by false touches, reducing the chance of danger. In addition, the low requirement for operation accuracy makes the cognitive resources required to complete the operation less occupied, and the driver can pay more attention to the information presented by the center screen instead of shifting between the controller and the center screen. Although the driver can use more time and more cognitive resources to complete secondary tasks in L3 autonomous driving mode, L3 technology still requires the driver to take over the driving task as a fallback-ready user at any time. If the design of the system can quickly detach driver's attention from secondary tasks, it will significantly reduce the risk of the driver not being able to quickly take over the driving task. So in comparison, concept 2 can better accomplish our design goals, helping the driver to complete secondary tasks more safely.

Next, we will call Concept 2 as Concept I and Concept 3 as Concept II. A more detailed and specific design of the two concepts is needed before digital concept generation. Other important factors, for example, the size of the screen, the composition of the functional area and the surrounding physical buttons are also should be considerd.

8 Concept I

The biggest feature of this concept is that the user's mobile phone is integrated into the DVI system of the car. From the perspective of improving driving safety, this design can greatly reduce the distraction of the user due to the use of the mobile phone when driving. When the car is in manual driving mode, the functions that can be used by the mobile phone are limited, which means that the user is forced to limit the use of the mobile phone when driving manually.

The adaptation of software to hardware is considered to be an important part. We need to consider the relationship between hardware and software design at the same time. That is to say, the design of the user interface needs to take into account the use characteristics of the physical product. And the hardware design of the product needs to be adapted by software. Software and hardware are two design factors that interact with each other, and this opens up a plethora of possibilities. De Michell, G., & Gupta, R. K. (1997) define hardware and software co-design as exploiting the synergy of hardware and software through concurrent design to achieve system-level goals. Level-of-detail design performed by humans is often a time-consuming and error-prone task. In addition, the amount of information involved in collaborative design problems is large, and it is impossible for human designers to optimize all objectives, resulting in product value lower than potential value. In order to achieve the corresponding design goals and minimize the impact of non-co-design, we cannot think of the physical product alone and ignore the software problems, which can lead to many problems in the digital design process. Therefore, we did not complete the concept design in the physical concept generation stage, but combined with the user interface design in the initial stage and conceived and perfected the software and hardware design at the same time. It is necessary to consider the possibilities of the combinations of software and hardware as much as possible, and it is necessary to find the best solution from them.

The concept wants to use a joystick similar to the stick on a gamepad as a controller. By investigating the common joysticks on the market, we found that the functions that the joystick can achieve are limited. Generally speaking, the joystick can only complete the direction control and selection. So whether the stick can be used as the only physical controller to complete all the control of the system, and whether all the function keys in the interactive system can be selected and controlled by the joystick have become the key issues to be noticed and discussed in this concept.

The original purpose of proposing this concept is to provide a control method, which the user can control the display by operating the controller while looking at the display when the center display cannot be directly controlled. Since our intention is to design a controller that can be manipulated blindly, the haptic properties of the controller should be carefully considered. It should have enough tactile features for people to recognize blindly, and its composition should be as simple as possible to simplify the process of blind recognition. Based on these two points, we believe that if the functions provided by the joystick itself cannot meet all the needs of the system, we can add a few physical buttons, but the number of them should be limited and should also have enough tactile characteristics to be blindly recognized.

After considering the controller, the relationship of the phone screen to the other displays in the car has also been reconsiderd. Although the size of a phone screen is capable of displaying most types of information and doing most of the things we need today, its small size and the position on the steering wheel are not suitable for wathcing and using for periods of time in a Level 3 self-driving car. Therefore, this solution proposes that the mobile phone placed on the steering wheel is not used as a main display for the secondary tasks, but is used as an auxiliary screen for other in-vihicle displays.

After comprehensive consideration of the above requirements and system requirements, the concept was refined. As shown in figure 17, the basic concept of Concept I is to install the mobile phone on the steering wheel after the user enters the Level 3 self-driving car. The mobile phone itself will be charged, and at the same time, the mobile phone will participate in the display of driving task information and secondary task information as a small display screen. On the right-hand side of the steering wheel, there are two physical buttons that act as controllers for this secondary task system. They're placed close to the edge of the steering wheel. Users won't accidentally touch them when they're in the normal grip, but can easily control them by moving their thumbs when they need to be used. The larger button is a joystick, just like the joystick on a gamepad (figure 18), this joystick can be moved slightly in four directions to control the selectied part in the system, and it also has the function of “selection” when it is pressed. In addition to the joystick, there is a small physical button with voice assistance. We believe that voice assistance has a huge role in enhancing the overall experience of using a self-driving car, and its role is not only reflected in the completion of secondary tasks. For the system we designed, its role is voice input. Users have a great demand for text input. Due to various restrictions on the screen size and position of the mobile phone, the speed and comfort of text input through the keyboard may be affected, so voice input is a better alternative. When users want to reply to an email, but don't want to use the phone screen to type, they can press the voice assist button for voice input. We did not set any other physical buttons besides these two. Other commonly used buttons including the home button and return button have been designed as virtual buttons on the screen, and be placed in the best position for selection through the joystick. Physical buttons and virtual buttons will be explained in more detail in the wireframe section.

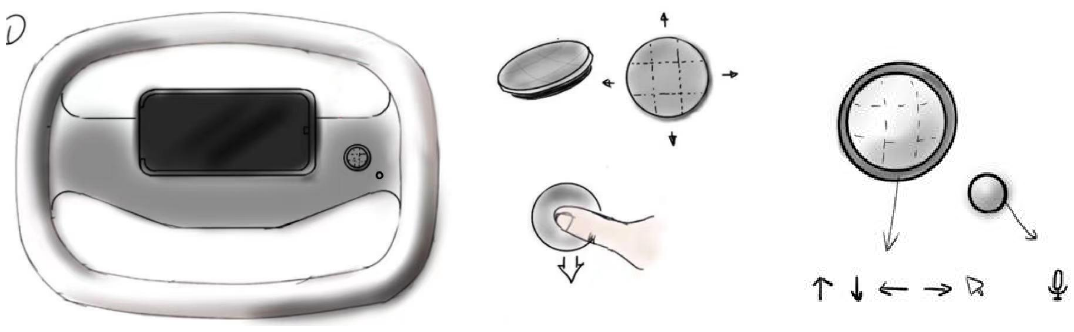


Figure 17: Basic concept of Concept I

Figure 18: A gamepad with two joysticks

We believe that in order to provide a better experience for secondary tasks, Level 3 self-driving cars will be equipped with larger in-vehicle center displays. Therefore, in Concept I, we use the mobile phone screen (screen A in figure 19) as an auxiliary screen for the car's central display (screen B in figure 19), which is mainly used for control and input functions. Specifically, in most cases, screen A and screen B will display the same content, and the user's main behavior is to look at screen B to obtain information, and to control screen B through the joystick. Of course, we also retain the control method of the touch operation on the screen A, and the user can also control screen A by touch to achieve the purpose of controlling the screen B. However, in some cases, screen A and screen B will also display different but related content. For example, screen A will display a keyboard to facilitate user input operations, but screen B will not display the keyboard but show the content the users are typing at this time.

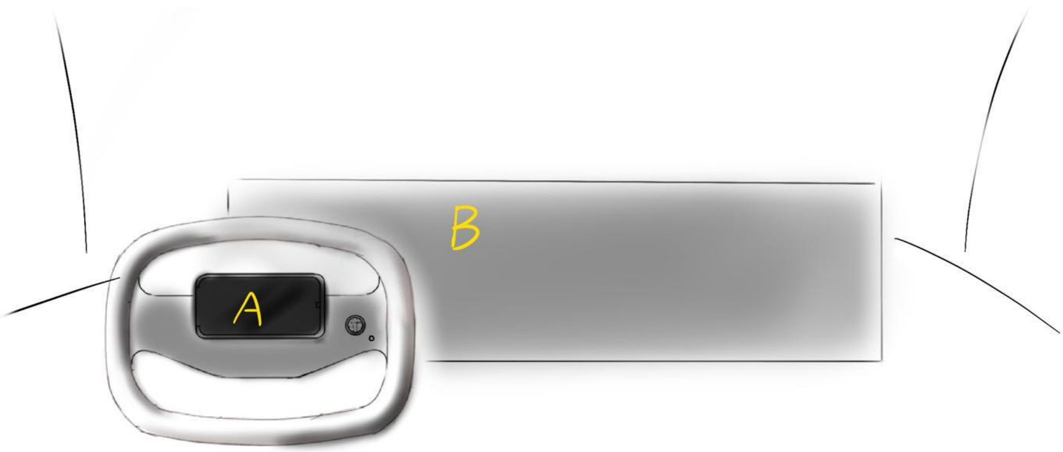


Figure 19: Two important displays in Concept I

8.1 Wireframe

As mentioned above, the matching of the interaction system and the hardware is particularly important for this concept. Therefore, while further refining and changing the concept, we simultaneously drew wireframes for this concept to determine the basic interactive system architecture.

In the process of designing the wireframe, we summarized some commonly used function buttons, such as voice assistant, home button, back button, etc., and also discussed their location. As mentioned in the section describing the physical buttons of this concept, we believe that the fewer physical buttons the better, so which function buttons are suitable for physical and which ones are suitable for virtual becomes the key point to be decided at this time. Wireframes can help us better sort out relationships of pages and functional components. In the process of drawing, we found that the “back” button and the “home” button are the buttons that almost every page will need, but voice assistance is not the case, it is only particularly important when input is required. More importantly, the location of the voice input function seems to be adjacent to the text feild, which means that for every text feild there is a voice input button next to it, which leads to too many elements on the page. And, if designed according to this logic, the voice assistant function lacks the many intelligent functions it could carry. Considering the above reasons, we believe that the voice assist button must be designed as a physical button. In contrast, the back button and the home button can be arranged in the navigation bar as virtual buttons, which is in line with the habits of users using mobile phones and tablet applications.

Then, we sorted out the entire process of using the secondary task system by drawing wireframes, including the list of secondary task applications provided by the system after the vehicle enters the autonomous driving mode and the basic process of users using Gmail and Youtube. Drawing wireframes is an exploratory process, as you can see from the figure 20, we have made a lot of trials and changes when drawing wireframes. We believe wireframe is a means of exploring better solutions, not a means of showing design.

Figure 20: First round of wireframing

Finally, we redrew the selected and improved wireframe, as shown in figure 21, including the most important pages of the designed system. The system structure and user flow as determined by the wireframes provide the structural foundation for our low-fidelity prototypes.

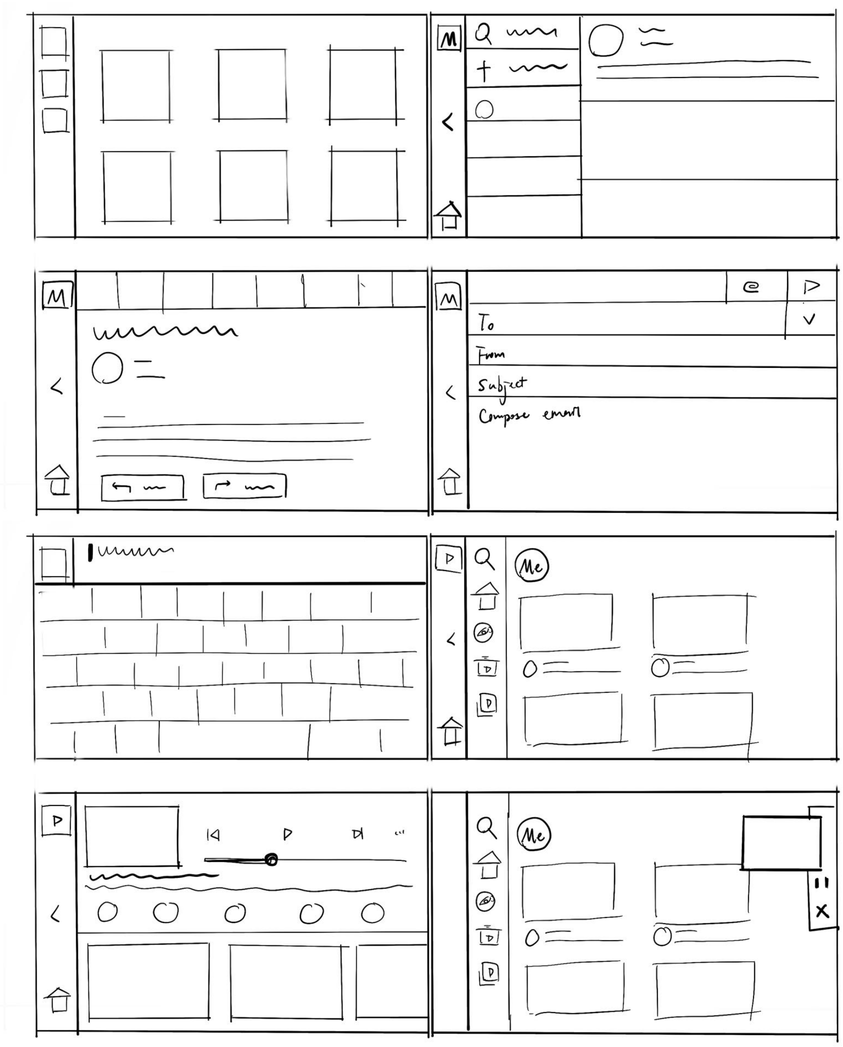


Figure 21: Final wireframe

8.2 Low fidelity prototype 1

We used Figma to make the low-fidelity prototype. We first designed the structure and homepage of the system. After that, we analyzed the pages and functions of Gmail and Youtube on different platforms, in order to extract specific functions suitable for secondary tasks of Level 3 autonomous vehicles, and design pages suitable for interactive control using joysticks.

8.2.1 Home page

The Home page is the beginning of the user flow. As shown in figure 22, the home page is divided into two parts, the right part shows all the secondary tasks available to the user, displayed in a 4-column grid structure, and the user can browse and select in the list. According to our analysis of user requirements, users have the need to use an application multiple times and switch between different applications. Therefore, the area on the left is designed to display the applications used in this trip, which can be understood as "recently used" or "background apps", which is convenient for users to quickly switch between various applications.

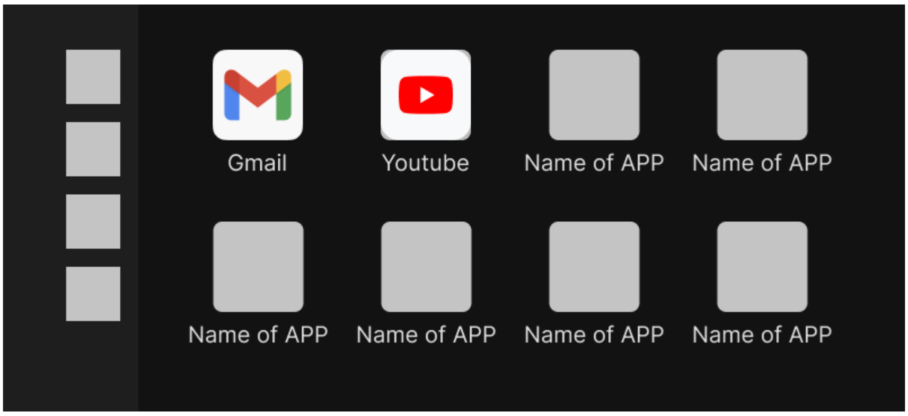


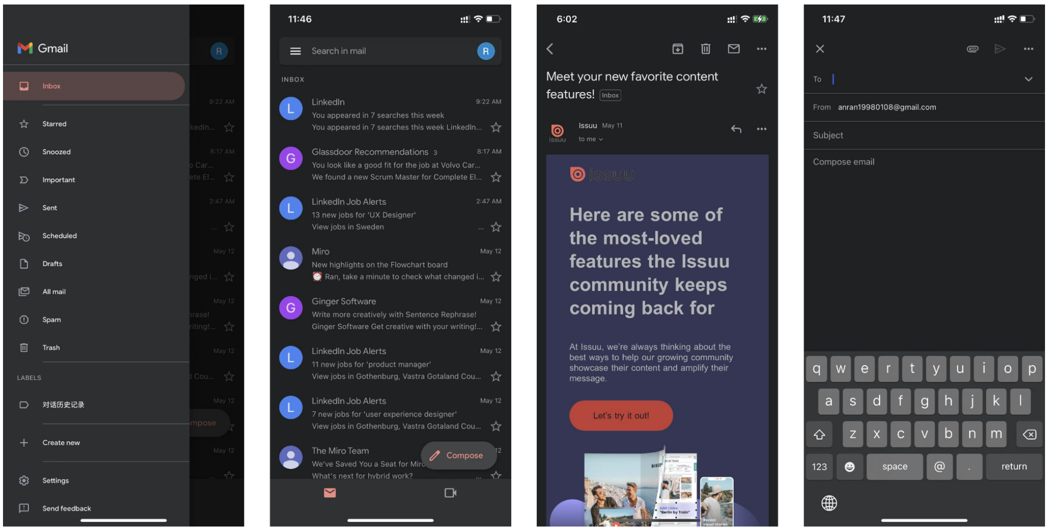
Figure 22: Concept I's low fidelity prototype of homepage

From the perspective of interaction, the design of the column on the home page meets the requirements of joystick operation. For example, the user can move in the application list (the right area) to browse and select the target. When the user wants to select the background application, he only needs to push the joystick to the left for several times, and the selection area will come to the background column (area on the left), then just move up and down to select. In addition to the home page, we have also designed other interfaces in this way of dividing functional areas, in order to ensure the consistency of the system and also facilitate the operation of the joystick.

8.2.2 Gmail

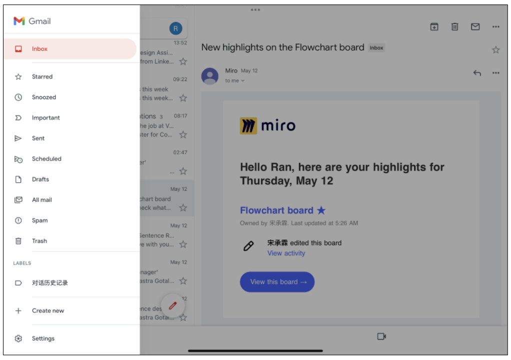
In the Use scenario section, we mentioned that Gmail was chosen to be designed as an application representative of the text reading and input type of app. An analysis of Gmail's application interface on tablets and phones was deemed necessary before starting to design low-fidelity prototypes. Obviously, the environment of using Gmail in the car is quite different from that at home or in the office, which is considered a light-office scenario due to the shorter time and higher likelihood of being interrupted. Therefore, not all the functions provided by Gmail need to be integrated into the in-vehicle Gmail system. We want to get the most suitable function combination and layout for the light office environment in the car by analyzing the functions and layout of Gmail's interactive interface on different platforms.

Figure 23 shows some more important interfaces in Gmail's mobile phone application, including Navigation Drawer, Landing page and Writing email page. The Navigation drawer mainly includes different tags, which can be said to be a classification of all emails. Users can quickly enter the mailing list more relevant to their own purposes through these tags. The Landing page contains more functional components, including the searching function, email list, composing email button, meeting function and so on. The Reading email page includes more functions for the email itself in addition to the body of the email. As for the Writing email page, an important component of it is the keyboard. Figure 24 shows the interface of Gmail on the tablet. Compared with the interface on the mobile phone, the interface on the tablet may be different in layout, but the important functional components have no great difference.

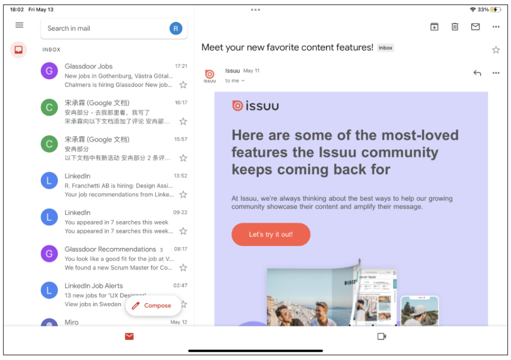


Navigation drawer　　Landing page　　Reading email page　　Writing email page

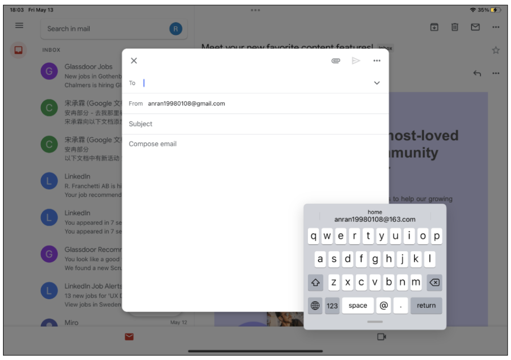
Figure 23: Important interface of Gmail's mobile phone application



Navigation drawer



Landing page



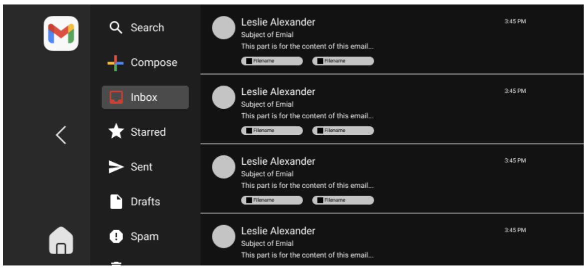
Writing email page

Figure 24: Important interface of Gmail's tablet application

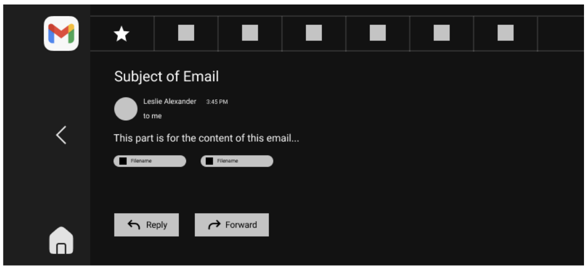
The tabs in Navigation Drawer were considered too many for a light office environment, so we only selected some of the more important ones. At the same time, considering the light office environment, we have not added the Meeting function in our in-vehicle Gmail system.

Figure 25 shows a low-fidelity prototype of our design for key pages within Gmail. We still continue the columnar method of the system homepage, and separate a column on the left as the Navigation rail, which displays the logo of the application the user is using at this time, the back button, and the Home button that can return to the Home page.

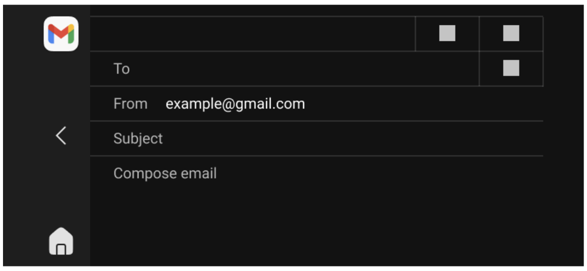
In addition to the Navigation rail on the left of the Landing page (Figure 25-A), the rest of the space is also divided into two columns. The middle column includes some important functions like searching function, composing emails, and simplified tabs. On the right is a list of emails belonging to a specific label. The functionality within the Reading email page (Figure 25-B) is similar to the mobile interface, but we have integrated Icon buttons scattered throughout the page to the top of the page. Writing email page (Figure 25-C) is basically the same as the interface on the phone as well. When the user wants to enter text in the text feild on the Writing email page, the keyboard will appear on the screen of the mobile phone as shown in Figure 25-D, and the keyboard will not appear on the central screen, but the text information being entered will be displayed.



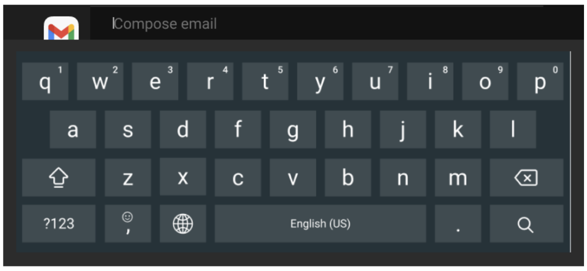
A. Gmail landing page



B. Gmail reading email page



C. Gmail writing email page

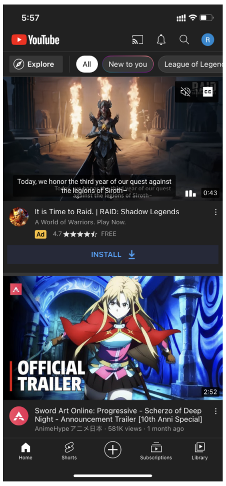


D. Gmail writing with keyboard-phone

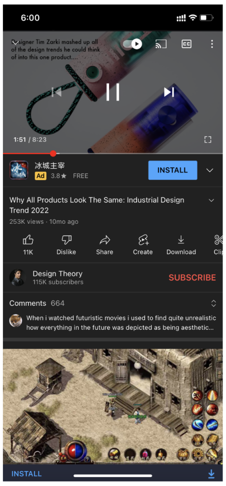
Figure 25: Low-fidelity prototype for key pages within Gmail

8.2.3 Youtube

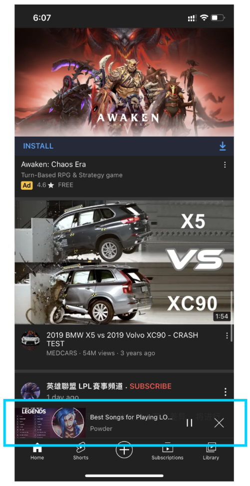
Similarly, we also analyzed Youtube, the representative of media applications. In the mobile version (figure 26) and tablet version (figure 27) of Youtube, the functional components contained in each page are similar. Important components of the Landing page include the Icon buttons at the top of the page, the video list in the middle, and the Navigation bar at the bottom. The functions within the Navigation bar can be briefly divided into watching videos and uploading videos. When clicking on a video, it jumps to a video detail interface, which also has a lot of video-related icon buttons, and a list of video recommendations. When we click on the full-screen icon, it will jump to the full-screen play interface, including many function buttons such as the pause button. In addition, Youtube also has a small window play interface. When we exit from the video detail interface, the video will not be closed, but will be played as an overlay on the video list in a small window that does not affect browsing the video list. The position of this overlay on the phone screen is on the bottom (the position of the blue rectangle in the figure 26), and the small window on the tablet is in the lower right corner (the position of the blue rectangle in the figure 27).



Landing page



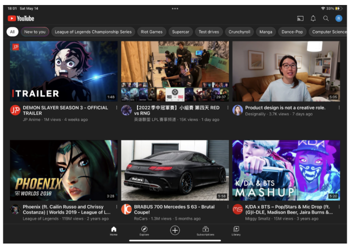
Video with more functions



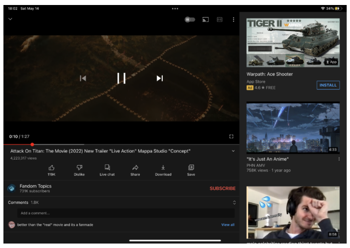
Video list with small window

Fullscreen play

Figure 26: Key interfaces of Youtube in mobile phone

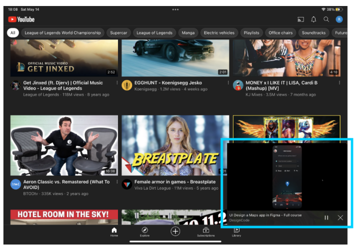


Landing page



Video with more functions

Fullscreen play



Video list with small window

Figure 27: Key interfaces of Youtube in tablet

After analyzing Youtube's interface, we believe that Youtube's overall logic is simple and clear, and we can follow its interface jump logic. But at the same time, many functions that exist in its own interface need to be simplified. According to the user research results, users would like to watch videos, and no one mentioned that they want to create and upload videos on any platform. Therefore, the upload function was removed. In addition, some classified tags in the landing page take up a lot of screen space, and they are also considered unimportant features and are removed. According to the above analysis results, we have designed several important interfaces of the in-vehicle Youtube system, as shown in figure 28.

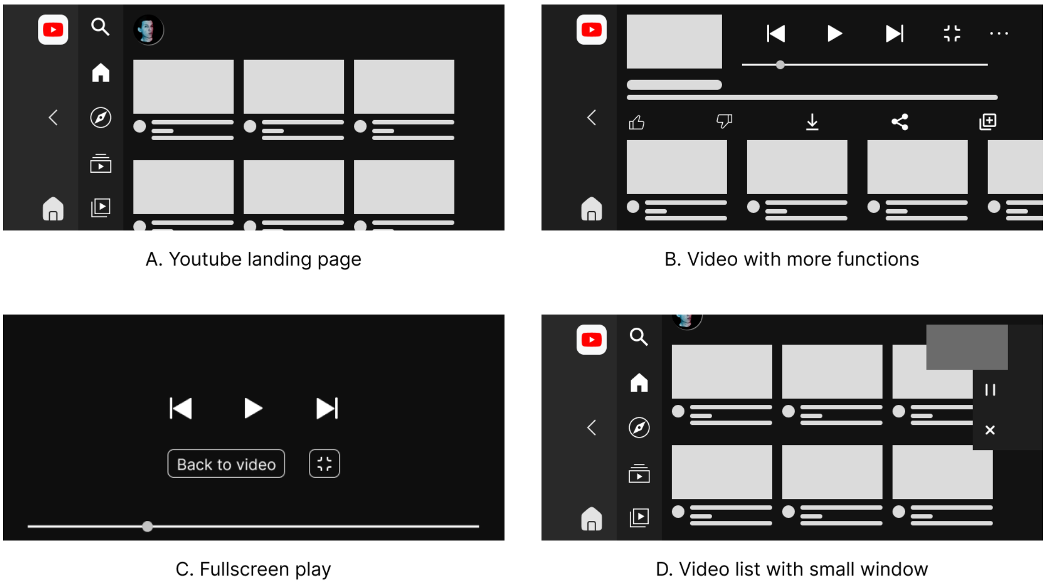


Figure 28: Low-fi prototype of Youtube in concept I

In the Landing page, as shown in figure 28 A, the left area is the Navigation rail at the system level, and the middle is the switching tabs of Youtube's internal locations, including Searching, Home, Explore, Subscriptions and Library. On the right side of the screen is the video list, and users can use the joystick to select the video they want to watch. When the user presses the joystick to select a specific video, the content displayed on the mobile phone screen and the car's central display will be different. Figure 28 B shows what the phone will display, including the video being played, some function buttons, and the recommended video at the bottom of the screen. Figure 28 C shows the state of the car center display at this time, which will play the selected video in full screen. This mode of displaying different but related content on the two screens is considered to be the most suitable way for the multi-display collaborative in-vehicle display environment. When the user wants to return to Youtube's video list, the user can touch the back button on the Navigation rail of the mobile phone screen, or select the back button on the large screen with the joystick, both of which will make the interface enter figure 28 D state, that is, returning to the video list, but the video continues to play in the upper right corner in the form of a small window.

8.3 Low fidelity prototype 2

After designing the first low-fidelity prototype, we tested the logic and functionality of the prototype within the team and found some issues. After discussions with Autoliv, we got more requests from our client.

First, we think the system lacks a Status bar, which shows time and weather information, along with system status details such as connectivity and battery level (Google Design for Driving). Therefore, we added a Status bar on the basis of the original system interface, as shown in figure 29.

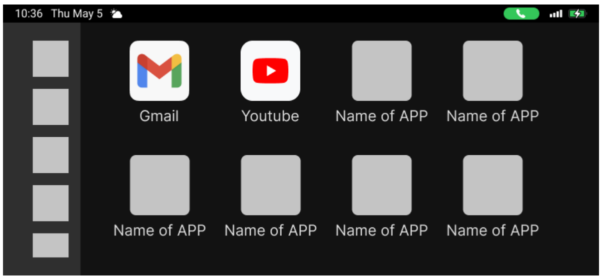
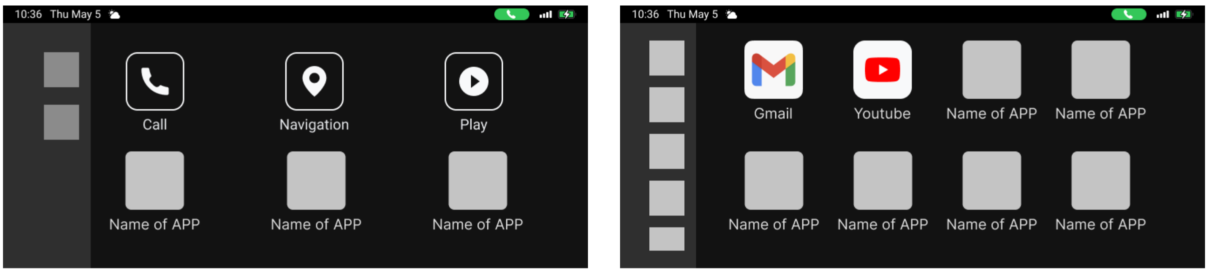


FIgure 29: Home page with a status bar

In addition, the client wanted us to think more about the complete use flow of secondary tasks, including how the system interface changes when the car transitions from manual to autonomous driving mode. In the low-fidelity prototype of the last stage, we only considered and designed the interface when the vehicle enters the automatic driving mode, so we reconsidered the design of this part and supplemented the interface when the car is in manual driving mode, as shown in the figure 30. When the car is in manual mode, the screen shows some basic secondary tasks like phone calls, navigation, etc. The left side of the screen shows the apps that users have open during this trip, but when the car is in manual mode, the logos of those apps turn grey to indicate that they are unavailable. When the car enters self-driving mode, more secondary tasks are offered, and the background apps on the left become selectable.

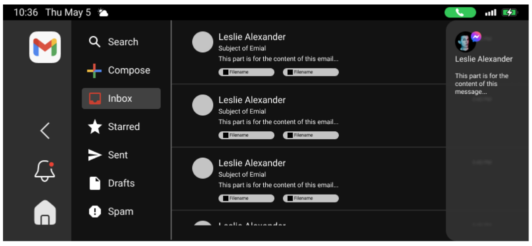


Manual mode

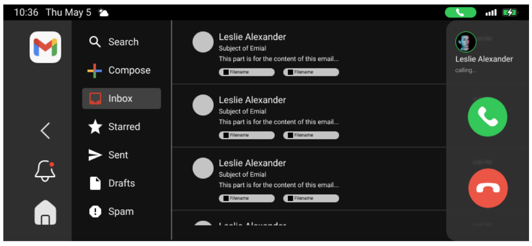
Self-driving mode

Figure 30: Home page interface when in manual mode and self-driving mode

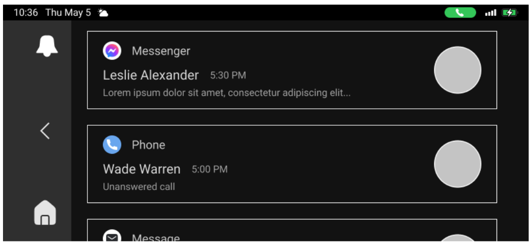
Additionally, the use scenarios have the situation where the driver receives notifications while performing a secondary task. The first round of the low-fidelity prototype did not present the notification interface. Notifications provide succinct and timely information about relevant events, such as phone calls or messages, along with actions the user can take in response (Google Design for Driving). Users can respond to notifications when they first arrive or access them later, in the Notification Center. Therefore, we need to design two related interfaces, one is the pop-up notification card and the other is the Notification Center.



Message notification



Call notification



Nofitication Center

Figure 31: Low fidelity prototype of notification related pages

As shown in figure 31, we designed message notification card, call notification card and Notification Center. In the Message notification interface in figure 31, you can see that a notification icon has been added to the left Navigation rail to display new unread notifications. If this icon is selected, it will enter the Notification Center interface to view all notifications. New messages from the Messenger app are displayed on the right side of the interface, and the Notification card briefly describes the name of the sender and the content of the message. Users can move the stick to the right and select this card to enter the Messenger app to view messages. Call notification is the same principle. When a call comes in, a card will appear on the right side of the screen, and the user can push the joystick to choose to answer or hang up the call.

8.4 High fidelity prototype

After two rounds of low-fidelity prototypes and tests, we have a more comprehensive idea of the usage process and interface of the system. This section will first introduce the designed high-fidelity interface, and then show the use flow of this concept through a flow chart.

Proposed in Google Design for Driving, The foundation of the color strategy is the idea of “building from black.” Basing interface colors on black makes for a more consistent user experience, with no drastic change between day and night themes. Building from black also ensures better alignment with hardware, since dark materials are often used in car interiors and dashboards. This black-based interface theme is called the Dark theme. A dark theme interface of this concept was designed according to the relevant design specifications in Google Design for Driving.

Before starting to design the details, we specified the overall layout of the interface to ensure the consistency of layout between each interface. Figure 32 shows our specification for all interface layouts. The left column of the interface is divided into the positions of Background apps or Navigation rail. The top part of the interface is the Status bar, which displays system status information that users may care about.

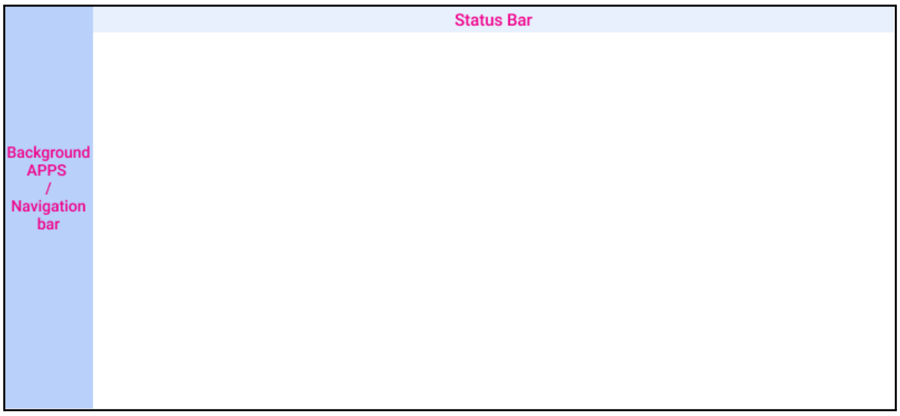
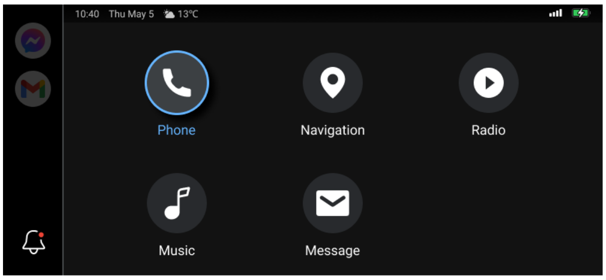
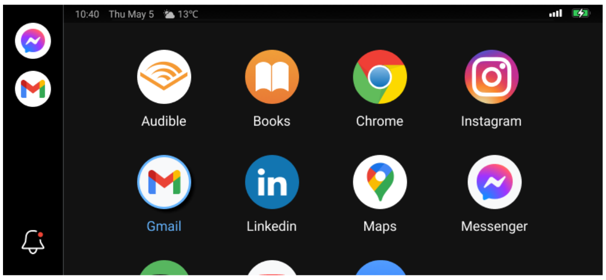


Figure 32: Layout for Concept I

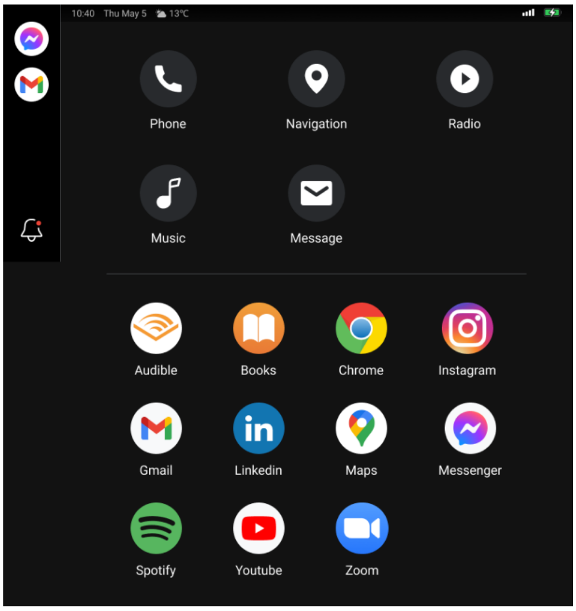
Figure 33 shows the home page of the mobile phone screen and the car's central display in manual and automatic driving modes. Whether the car is in manual driving mode or automatic driving mode, the left column of the interface is Background apps. The difference is that in manual mode, in order to avoid distraction, Background apps are not selectable, and the driver can only choose some secondary tasks that consume less cognitive and attention resources, such as making calls, listening music etc. App lauchers of this type are arranged in a 3-column grid structure. When the vehicle enters automatic mode, the system provides more secondary tasks, arranged in a 4-column grid structure to highlight the difference from manual mode. At the same time Background apps are also in a selectable state. When the automatic mode is activated, the interface will preferentially display complex secondary tasks, of course, users can also select basic secondary tasks by pushing the joystick up. In addition, we use Google official accent color, a shade of blue referred to in the support library as "car accent" as the accent color of the system to display the position selected by the joystick, such as Phone in Home Page - Manual mode in figure 33.



Home Page - Manual mode



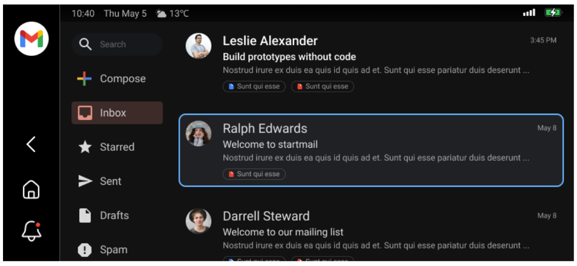
Home Page - Self driving mode



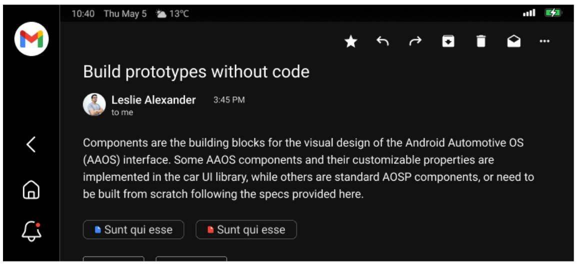
Home Page - Self driving mode - Complete interface

Figure 33: Home page in Concept I

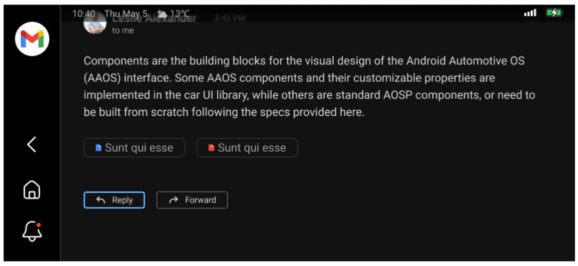
The following will take Gmail as an example to show how text reading and input applications adapt to this interactive system. Figure 34 shows the design of the key interface in Gmail. After users click the Gmail logo on the homepage, they will first enter the Gmail landing page, which displays the messages in the Inbox by default. On the left of the page is the Navigation bar, the top of which displays the application the user is in, and the three icon buttons below are the return button, the Home button and the notification button. The blue border in the interface shows that the user has selected this email, but has not yet entered the reading page. When the user presses the joystick to select this email, the page will jump to the Reading email page, and the user can view the complete email content by moving the joystick up and down. The interface for replying emails is basically the same as the interface for writing emails. Here is an example of the interface for writing emails. The user can select the position to be entered by moving the joystick up and down, and then press the joystick to input in this text field. At this time, the screen of the mobile phone will display a keyboard. In addition to keyboard input, the driver can also perform voice input by pressing the voice assistant physical button. The keyboard will not appear on the central display of the car at this time, but will only display the information currently being entered.



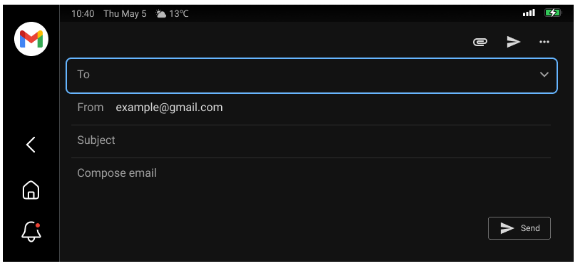
Gmail landing page



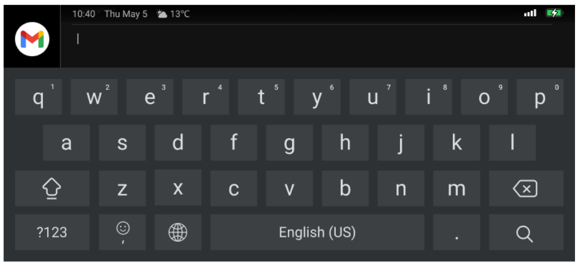
Gmail Reading email page 1



Gmail Reading email page 2



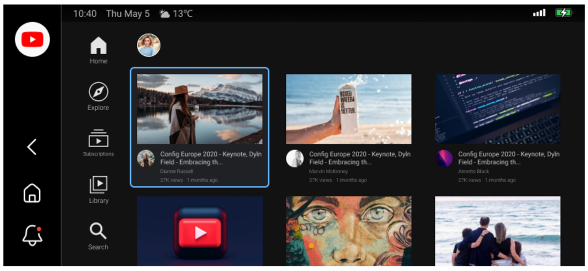
Gmail Writing Email page



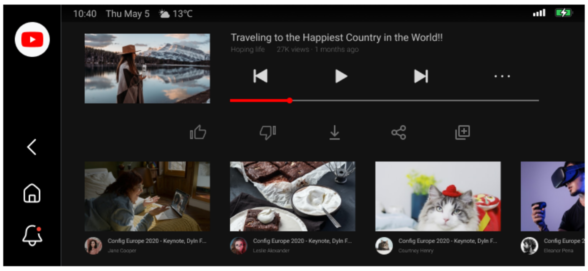
Gmail Writing Email with keyboard

Figure 34: Gmail interfaces in Concept I

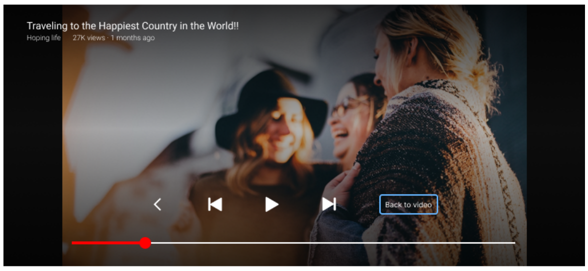
We also take Youtube as an example to show how video play applications adapt to this interactive system. Figure 35 shows the design of the key interface in Youtube. After the user clicks the Youtube logo on the home page, the user will first enter the Youtube landing page. By default, it is on the Home interface in Youtube, displaying a list of videos recommended by the system. When the user selects a video by controlling the joystick and presses the joystick, the interface will be switched to the video play page, and the content displayed on the mobile phone screen and the central display are different. On the phone screen, the video is played in a small window, with multiple function buttons, and a list of recommended videos. The user can control the components in the mobile phone through the touch operation. The video is played in full screen on the car's central display. The user controls the central display with the stick. While watching a video, some function keys will appear on the central display once the user pushes the joystick. The adjustment of the video state by controlling the mobile phone and controlling the central display through the joystick are synchronized, that is to say, if the user clicks the pause button on the mobile phone screen, the video on the central display will also be paused. When the user performs the return operation through the mobile phone screen or through the joystick, the content displayed on the mobile phone screen and the central display will be re-consistent, that is, the homepage video list is accompanied by a small window to play the video.



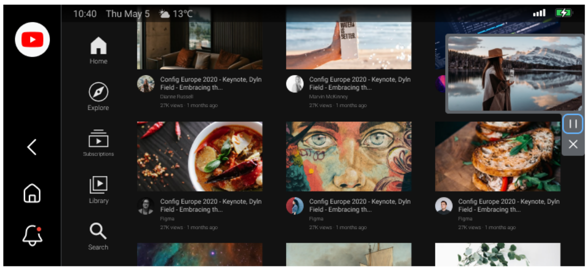
Youtube landing page



Youtube - video - phone



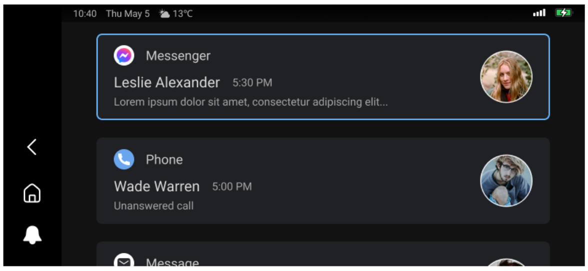
Fullscreen play - center screen



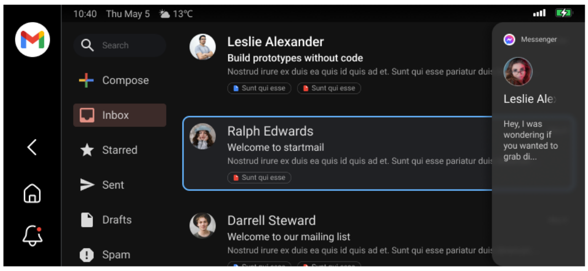
Video list with small window

Figure 35: Youtube interfaces in Concept I

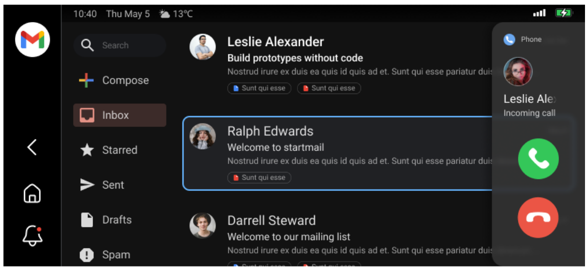
In addition to this, we also designed notification pop-up cards and the notification center, as shown in figure 36. On the navigation rail of each previous page, the bottom icon button is the notification icon. When the user clicks the notification icon button, they will enter the Notification center, where all unanswered messages are displayed. When a new notification arrives, the new notification will appear on the right side of the interface in the form of a pop-up card. The user can push the joystick to the right to select the notification pop-up window and click to view the new message.



Notification center



Message notification



Call notification

Figure 36: Notification cards and Notification center

To better explain the use flow of Gmail and Youtube, and to show what exactly the relationship of phone screen and the center screen, a flow chart of using Gmail and Youtube has been made. As shown in figure 37, it present the use flow and the information displayed in each screen.

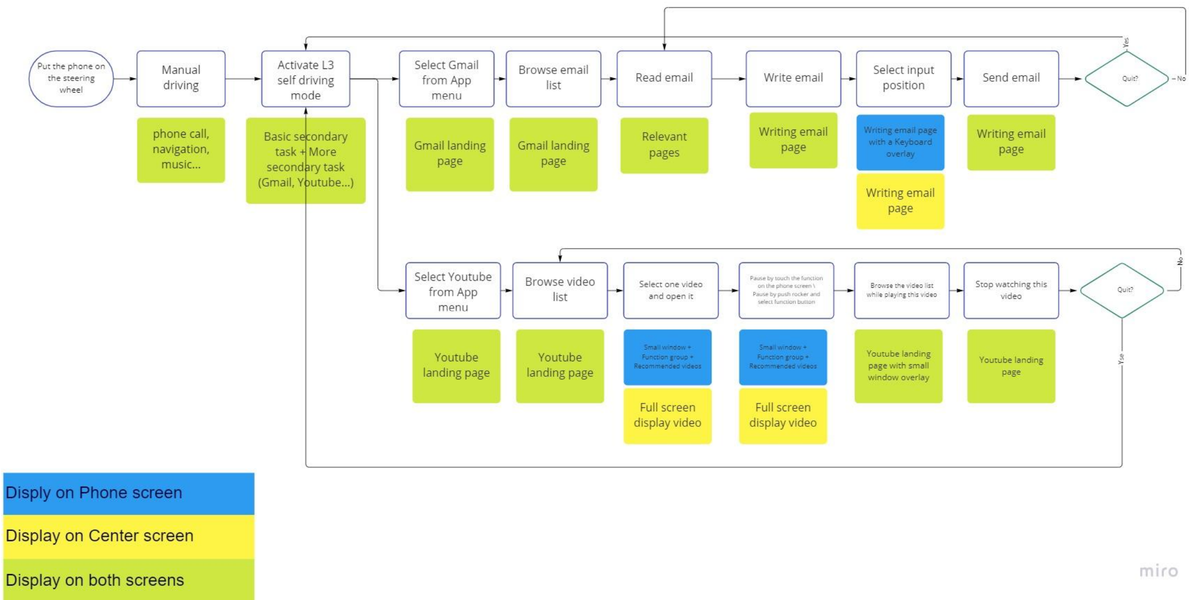


Figure 37: Use flow of Gmail and Youtube in Concept I

9 Concept II

For Concept II, three physical buttons are designed at the bottom of the screen (figure 38), responsible for Voice assistance, Home, and Back respectively. The three physical buttons are similar to touchscreen phones from a few years ago, providing basic and intuitive fallback and input functionality. And as shown in the upper part of figure 38, these buttons, which are frequently used by users in the system, are designed as trigger buttons with a certain angle of inclination, which is in line with the way the thumb moves when holding the steering wheel in ergonomics. With gaps between buttons and different button shapes and sizes, drivers can accurately select and activate the appropriate function without having to see what the buttons are. This reduces the cognitive resources required for operational input, and avoids the frequent shifting of attention, making the experience of using the interactive system smoother.

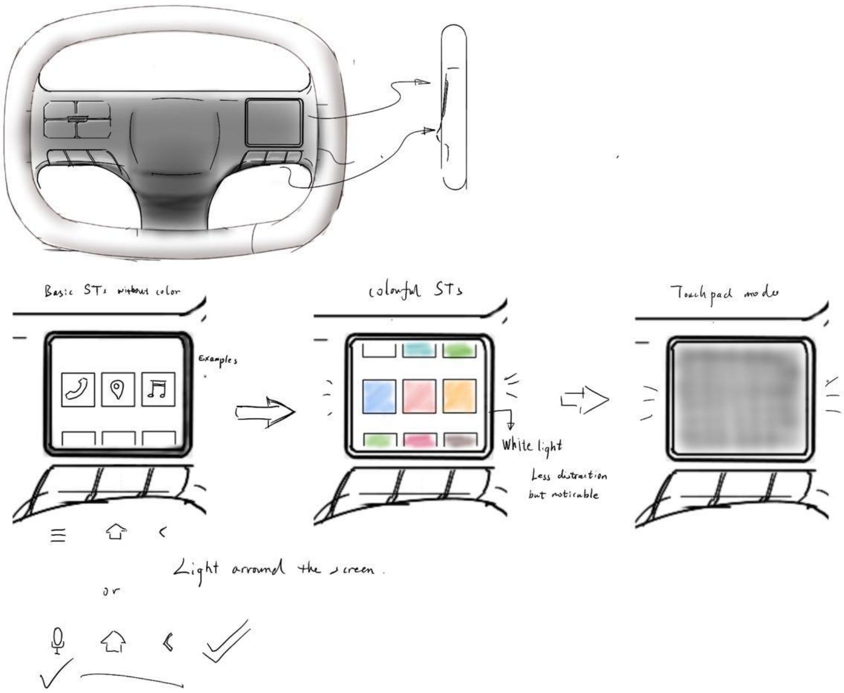


Figure 38：Concept II development

9.1 Wireframe

While adding further details to concept II, we also studied UI design in concept by sketching wireframes. As shown in figure 39, we selected several user interfaces in Gmail and Youtube to generate the concepts in the form of sketch wireframes.

Figure 39: Wireframe study of user interfaces

Combining the hardware and software design sketches in figures 38 and 39, we studied the overall usage flow of the steering wheel screen. When driving manually, the touchpad screen displays the most commonly used secondary tasks, such as making calls, navigation, and music, in black and white. Other secondary tasks icons have been de-saturated to show unusability, and the main app menu displayed on the touchpad screen will not be scrollable to other apps that are not allowed to be used while driving manually. When self-driving mode is activated, the border of the touchpad screen will light up, and apps that can be used while automatic driving will restore color saturation and can be selected. Whether in manual driving mode or in automatic driving mode, when the driver selects an app by touching the touchpad screen, the touchpad screen will become a touchpad that does not display any information. The driver can use the touchpad to control a selection tool as the mouse arrow on the center screen, to select an element presented on the center screen by different ways of clicking the touchpad (for example: single click, double click). When the user needs to go back level by level or close the application, he/she can use the “Home” and “Back” buttons below the touchpad screen to achieve faster "exit" and "return" operations instead of selecting the back button in the user interface. In the study of wireframes, we also did not add a corresponding function button representing the meaning of "return" in the application interfaces, because the physical buttons are efficient and intuitive enough.

Through wireframing study, we found many possibilities of user interface, and selected user interfaces from a large number of alternatives that conforms to the concept II interactive system. The next step is to use low-fidelity prototypes to study the feasibility of the concept and the impact of the basic elements in the page on the interaction. We use Figma software for low-fidelity prototype design, including all the user interfaces of Gmail and YouTube that need to be rendered on touchpad screen and center screen.

9.2 Low fidelity prototype 1

9.2.1 Touchpad screen

Before building a prototype, a brief analysis of the existing product pages is required. Issues such as streamlining functions, page layout changes, etc. need to be taken into account to accommodate touchpad operations. So for the touchpad screen (figure 40), the functions presented in manual driving mode are presented in a monotone color, and the secondary task app launchers that cannot be used are presented in a low-saturation form (figure 40 top left). The app launchers in the main menu of the touchpad screen are displayed in 3 columns. At the same time, the screen can display up to 9 app launchers, and at most 6 app launchers can be fully displayed. In order to highlight the launchers in the middle row under the premise that the user knows which apps are in the upper and lower rows, only the content of one row is highlighted at a time to reduce the cognitive load of using the main menu. When the touchpad screen does not fully display 9 apps (figure 40 top right), the upper and lower rows of launchers will not be fully displayed, and will be covered by the inner shadow that comes with the screen. Three app launchers in one row help drivers quickly understand which apps are displayed on the touchpad screen at a glance.

When the driver clicks to select an app launcher , the touchpad screen will change to a touchpad that does not display any information as shown in the bottom left of figure 40. The driver controls the touchpad with his fingers, and the center screen is responsible for all user interface presentations. The driver can use the touchpad to control the center screen like a laptop.

We also considered the need for a virtual keyboard when using Gmail to send emails or other secondary tasks such as messengers that require text input. As shown in figure 40 bottom right, when the user double-clicks the touchpad when they need to input text, the virtual keyboard will be automatically activated and appear on the touchpad screen as an overlay. When the user finishes text input or needs to change the input position, the virtual keyboard can be hidden by pressing and dragging the bar indicator above the keyboard, or clicking the arrow in the upper right corner of the keyboard.

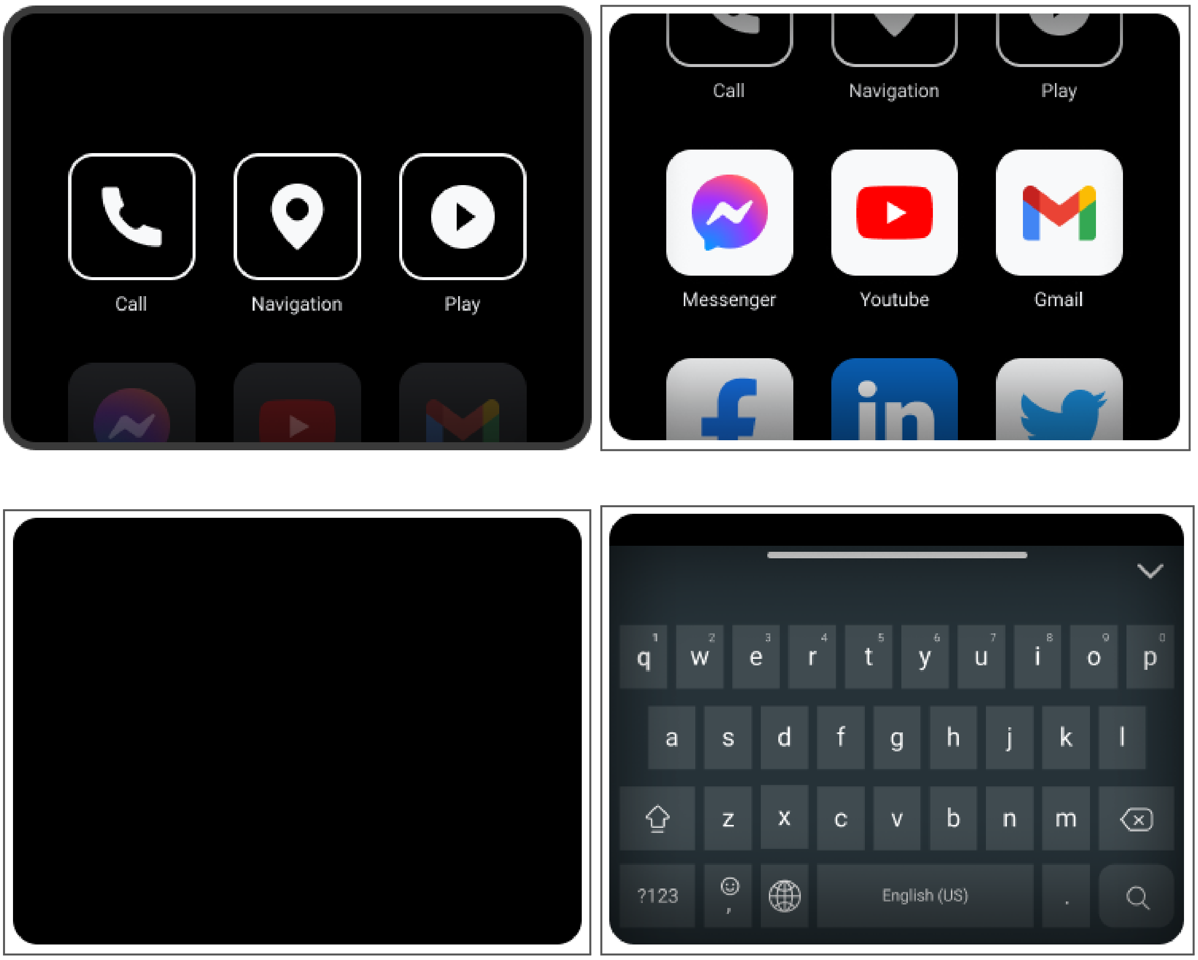


Figure 40: Manual driving mode (top left); Self-driving mode (top right); Touchpad mode (bottom left); Keyboard texting mode (bottom right)

9.2.2 Center screen

We separately researched and designed the user interfaces of the Gmail and Youtube applications displayed on the center screen. Different from concept I, the design restrictions of the user interface design in this concept are not significant, and it is necessary to consider how to enable the driver to use the touchpad to quickly select any element on the user interface. This requires simplification of the user interface of both applications. The most commonly used user interfaces that are closest to concept II are from web and tablet platforms. The user interfaces of the corresponding applications on these two platforms need to be referenced and studied.

Gmail

The Gmail page on the webpage is mainly divided into three parts. The first part is the top app bar at the top of the page, including the burger menu icon for navigation drawer, logo, search box and account setting function group. The second part is the navigation rail that contains the basic email sections. The largest part is the email list (including email filtering function, mail type classification, mail list), in which users can quickly find the email they need to check through the two-column grid design of the email list. When users click on an email, the email list will become an email page (including email content, email operation functions), and when users need to return to the email list, they need to click the return button on the email page. When the user creates a new email, they can edit the email through the new pop-up window on the right side of the screen (figure 41, left). Gmail on the web is fully functional, displaying as much content and functionality as possible on one page. As a user interface on the PC, Gmail puts very complex information into web pages, and the size of various function buttons will naturally be compressed very small, which requires a high degree of user operation accuracy. However, this project is aimed at the design of the in-vehicle user interfaces. Users cannot use the in-vehicle interactive system like a computer when driving a car. They need a lighter office environment in cars. Putting such complex information on the car display will not meet the requirements of light office work. Therefore, it is necessary to simplify the various functions of Gmail and the information displayed in one interface.

The user interface design of Gmail on the tablet platform is more inclined to light office work. The entire page is divided into three columns, and there is no top app bar compared to the web platform. From left to right, the 3 columns are: the navigation rail, the email list and the email content area. After users select one of them from the email list, the email will open in the right space. Unlike the website, the tablet user interface uses as many icons as possible to replace text descriptions to make the page look neater and cleaner. In addition, the compose email button is set as floating action buttons and hover over the email list, while the web platform's is in the navigation rail of the basic email section. Considering the touchpad operation of this concept, the processing method on the tablet platform is obviously not suitable for touchpad operation. When the user creates a new email, a new overlay is opened over the user interface (figure 42, right), and similarly when the user selects account settings, the overlay is also used to present information. It can be seen that the user interfaces of the tablet platform implements the corresponding functions with a minimum of layers, which is similar to the car user interface. And a concise user interface can help users locate information faster, which is of great benefit to safe driving.

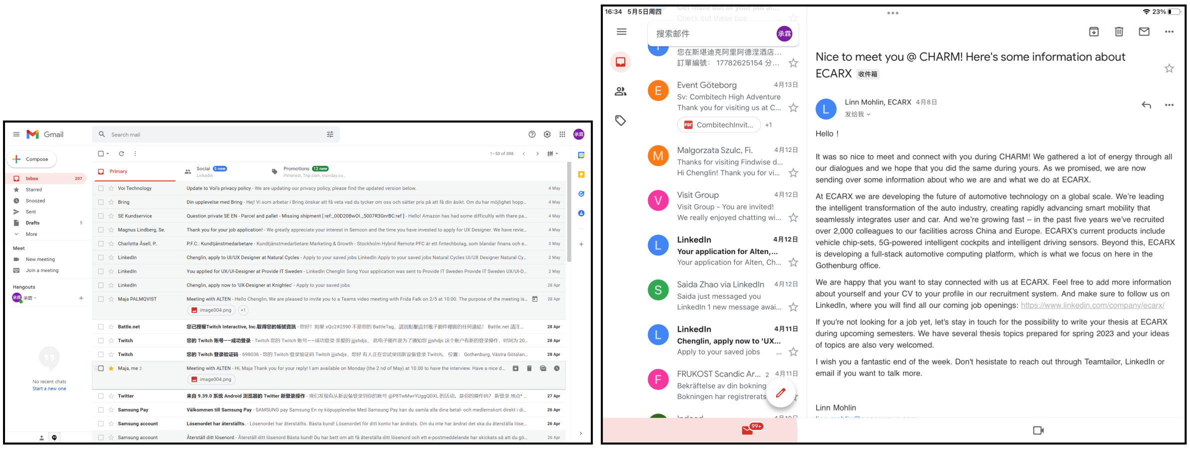


Figure 41: Gmail website (left); Gmail on tablet platform (right)

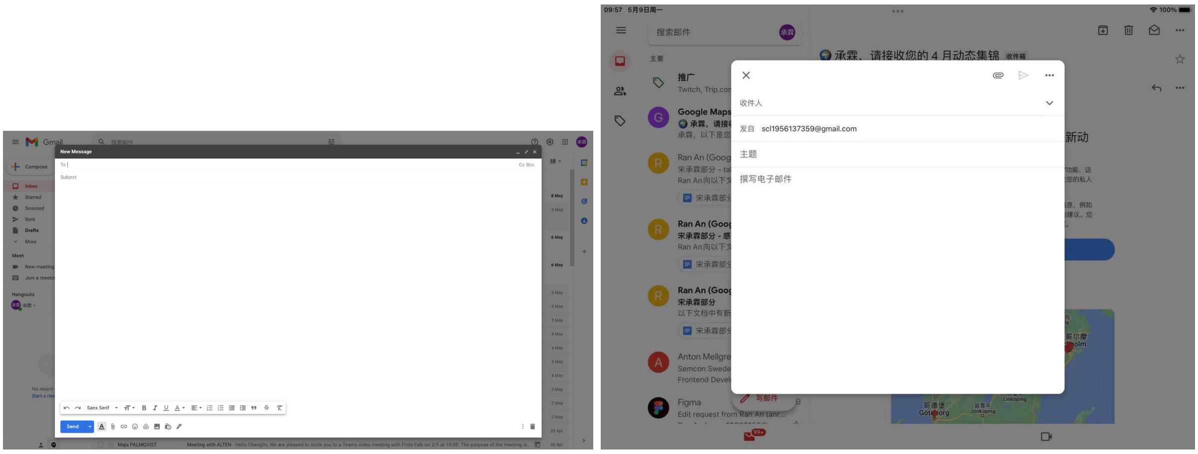


Figure 42: Email editing on Gmail website (left); email editing on Gmail tablet (right)

The Gmail landing page low-fidelity prototype uses a 3-column structure to divide the page (figure 43), and the navigation rail on the far right contains the Gmail logo, email sections, and account settings. The middle column contains search box, compose email and email list. On the right is the email reading area. The design of the low-fidelity prototype is similar to the light office application of the tablet platform, and some unimportant or infrequently used functions are removed, such as the sorting button for three types of email and most of the infrequently used functions in the basic email sections. The compose email button is designed between the email list and the search box, because the location of the "Compose" button on the tablet platform is difficult for the user to select through the touchpad. As an in-vehicle user interface, functions should be laid out so that they can be quickly operated on a two-dimensional interface. A lot of descriptive text has been omitted, making interface divisions more obvious.

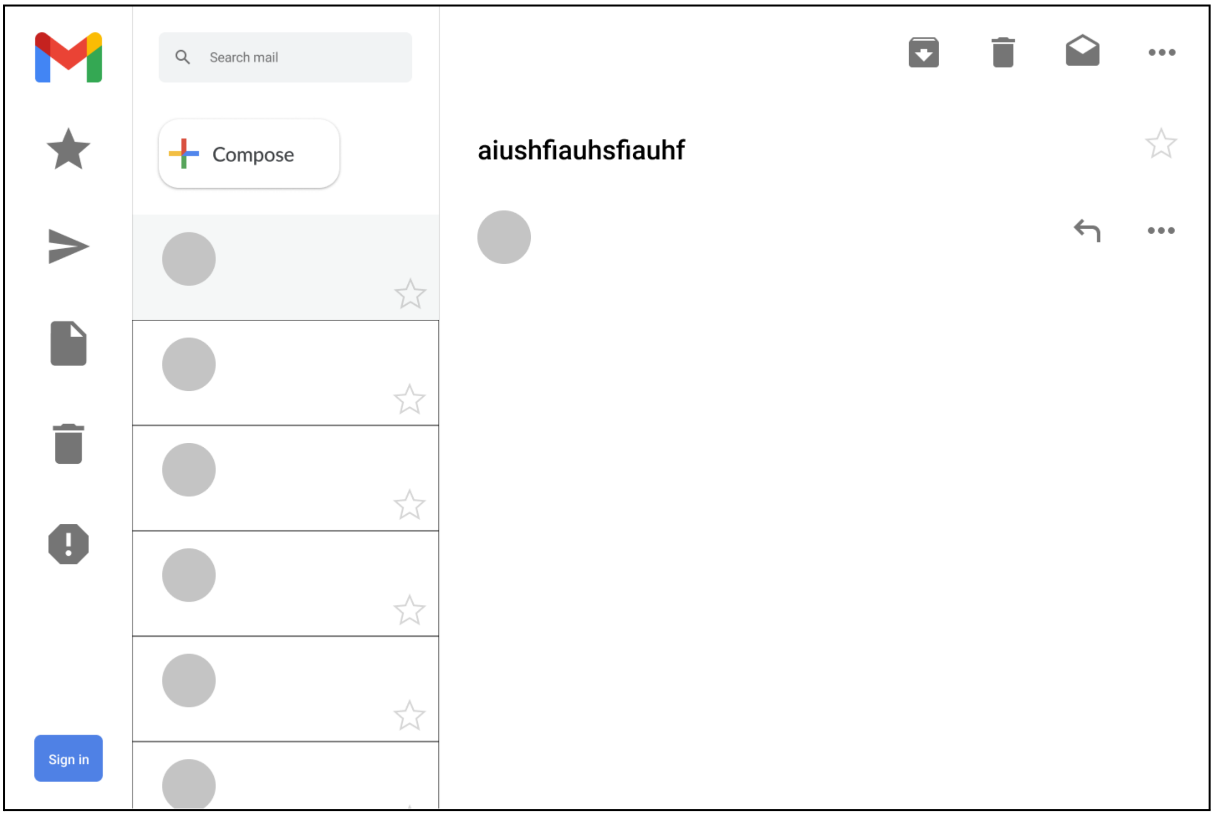


Figure 43 : Gmail landing page low fidelity prototype

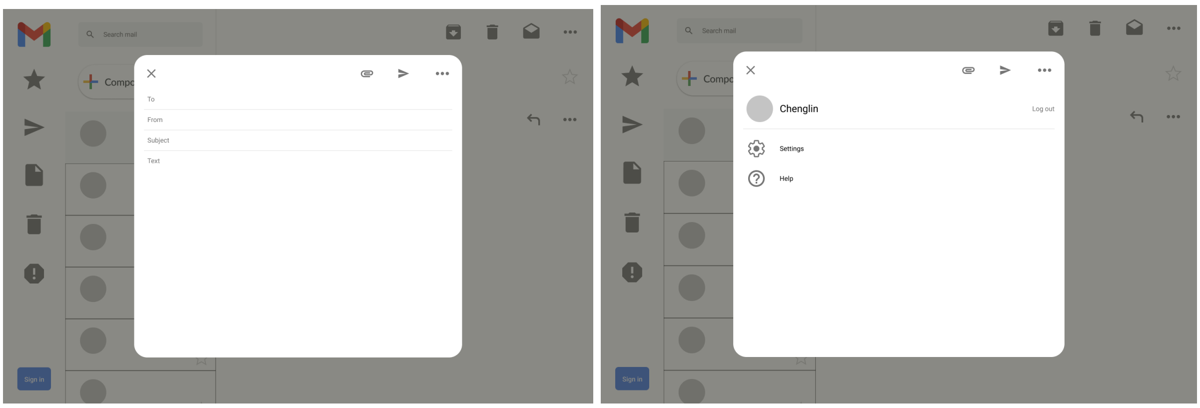


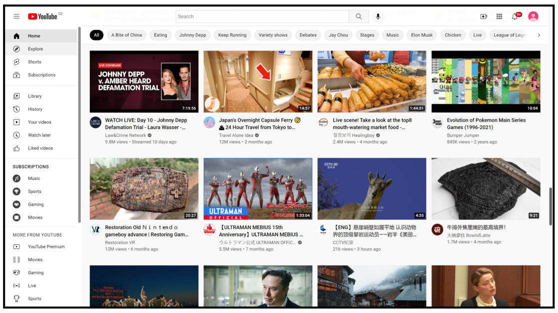
Figure 44: Gmail edit email page; Gmail profile page

As shown in figure 44, the email editing interface and the profile interface have the same design style. This overlay design can help users focus more on the information on the overlay interface without being disturbed by other information. On both interfaces, users can return to the landing page via the close button in the upper left corner or the physical back button below the steering wheel screen.

Youtube

As shown in figure 45, there is little difference between the Youtube user interface on the web and tablet platforms. The interface on the tablet platform uses a 3-column grids structure to arrange the video cover images, while the website uses 4-column grids. The structure of the web pages are roughly divided into left and right columns, while the pages on tablets are a top and bottom structure. The navigation bar on the tablet platform is at the bottom of the page, while the website is in the right navigation, and more video classification options can be expanded through the burger menu icon in the top app bar. Most of the video classification options on the tablet platform are hidden. Both platforms have a similar top app bar, which contains the logo, and four function buttons on the right that are designed for different platforms. The search box on the web side is retained, while the search function on the tablet is done by clicking the search button on the right side of the top app bar to jump to the search page. The difference in platforms allows the web pages to present more information and video covers images. Considering the size of the car screen and the readability of the information, it is necessary to present larger video covers images and less classified information. However, the user interface structure on the tablet is designed for touch screens, so its structure (the Navigation bar is below the video list, and the video list can be scrolled vertically) is not suitable for touchpad operations. Because when users are scrolling the video list, they may be disturbed by the navigation bar. Therefore, the layout structure of the web page is desirable for touchpad operations.

The video details page and video play user interfaces on the two platforms are basically the same. The web page retains the top app bar (figure 46, left) on the video details page, while the tablet Youtube does not retain (figure 46, right). The two platforms of the video details page have a two-column structure, including the video playback window on the left, the comment area below and the related video recommendation list on the right. When the user returns to the landing page from the video details page, the playing video will not be closed, but will continue to play on the landing page in the form of a small window. The user can click the close button of the small window to close the video. The purpose of this design is that users can continue to find more interesting videos without closing existing videos. Comparing the video cover image size and text font size ratio of the two platforms, the tablet Youtube hopes to display a larger video cover to help users find interesting videos through pictures. Similarly, In-vehicle user interfaces also need to allow users to quickly locate and understand information. Pictures and colors are more efficient means of expression than text (*Google Design for Driving*).



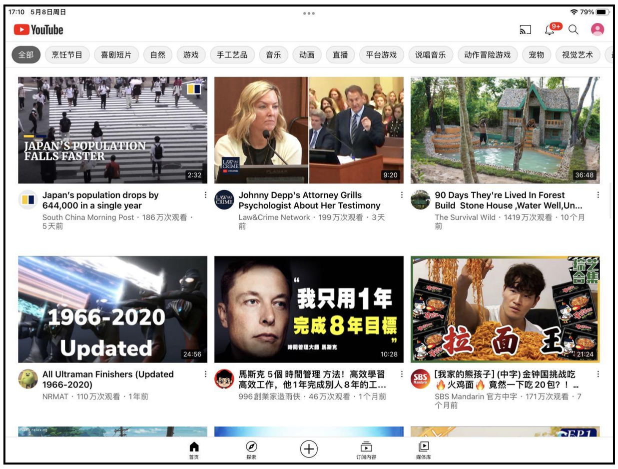
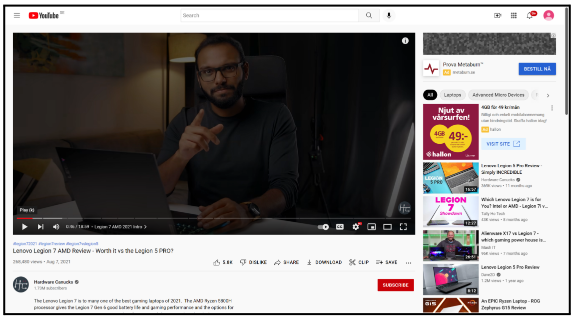


Figure 45 : Youtube on website (left); Youtube on tablet (right)



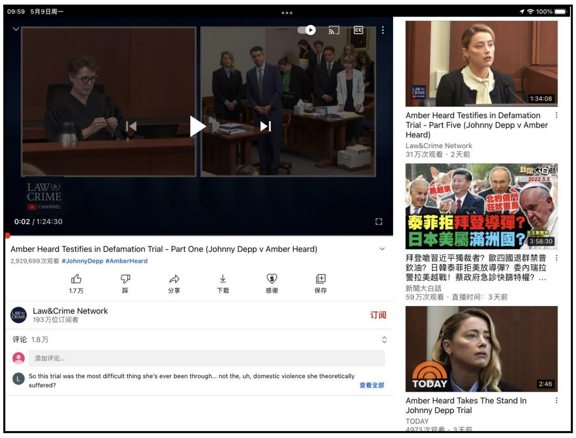


Figure 46 : Video detail page on website (left); video details page on tablet (right)

The low-fidelity prototype of the Youtube landing page uses a two-column structure (figure 47) similar to the website. The navigation rail on the left contains the logo, the video sections (similar as the website Youtube navigation rail and tablet Youtube navigation bar), and the burger menu icon. On the right is the video list, which uses a three-column grid structure to arrange the video cover images. Above the video list is the search box, notification and account settings with fixed position on the screen when scrolling the video list. Since the user interfaces exist in the vehicle implanted system, Gmail and Youtube should have the same design language, both using side navigation rail to present the main functional areas. The design of each video cover image is similar to current design, with pictures as noticeable as possible, with text as an auxiliary description.

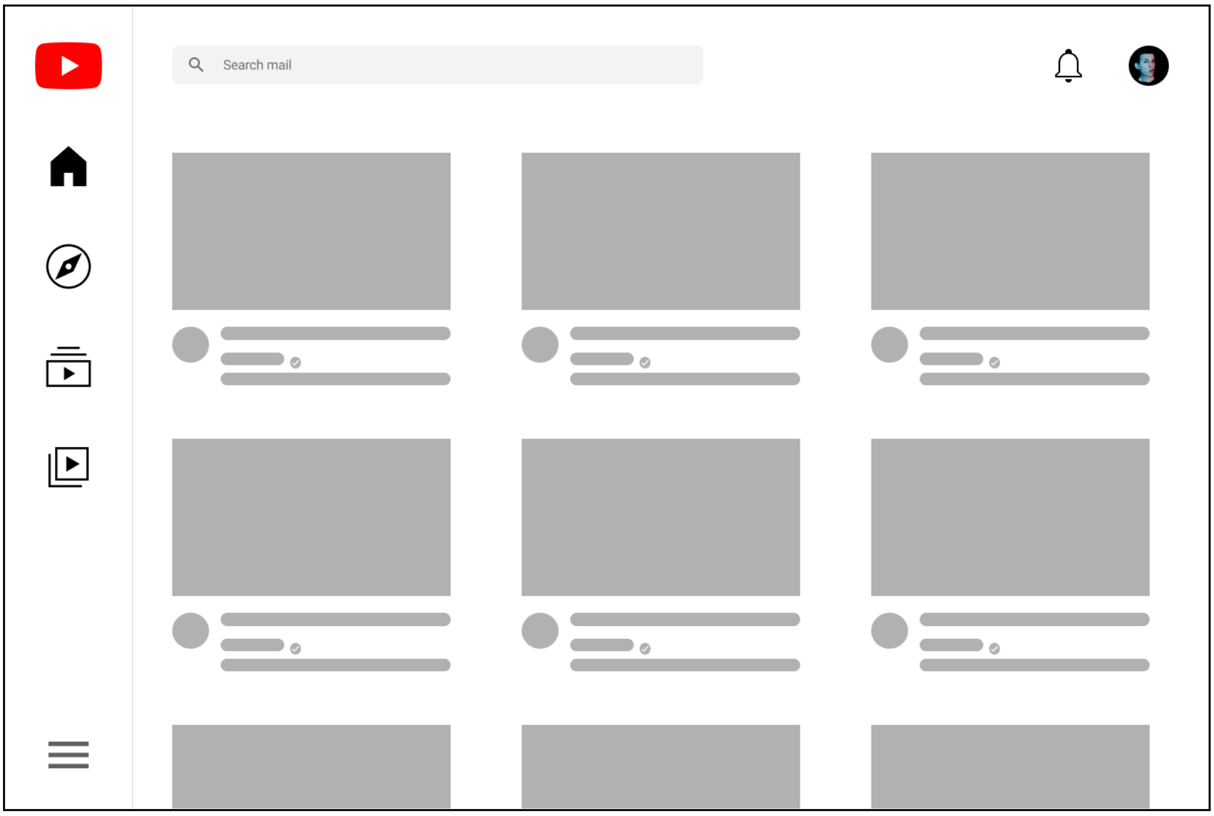


Figure 47: Youtube landing page low fidelity prototype

Figure 48 : Video detail page (left); Full screen play (right)

As shown in figure 48, the video detail page is similar to the tablet platform, but we keep the side navigation rail to allow users to quickly go back and find new videos. The basic media control buttons are displayed in the middle of the full-screen play page, the video progress bar is at the bottom, and the volume control is at the right edge. Users can also change the video volume through the vehicle's media volume adjustment method. The “Back” buttons in the upper left corner of the video details page and full screen play page can play the same role as the physical back button below the touchpad screen, they do not directly close the video. Their function is to return from the full screen play page to the video details page, or from the video details page to the landing page with the video played in a small window.

9.3 Low fidelity prototype 2

After working on the first low-fidelity prototype, we discovered many logical issues and functional gaps through internal testing and analysis. After discussions with Autoliv, we need to think about all the special user interfaces that may appear in the whole process from manual driving to autonomous driving.

According to our use scenario, the driver can receive and view received messages or notifications, but there is no location or interface for new messages in the first low-fidelity prototype. A place for users to view and manage notification messages is needed. When the user returns to the touchpad screen to display the main menu step by step, the center screen will face the problem of being idle. Similarly, when the user starts the car, the center screen will not display anything according to the previous design. So we believe it is necessary to design a landing page for the center screen. In addition, since the in-vehicle interaction system provides the user with very few user interface layers, the functions of the "Home" and the "Back" physical button are duplicated in most cases, so we think the function of these buttons should be changed.

We re-organized the operation process of the whole system, and then changed the "Home" button to a button that toggles the touchpad screen function (figure 49). The user can switch the touchpad to the touchpad screen at any time to display the main menu, so that the user can quickly switch to other apps by changing the function of the touchpad screen when using the touchpad to control an app. When users do not need to complete secondary tasks, they can switch the touchpad screen displaying the main menu to a touchpad to control the notification interface on the center screen.

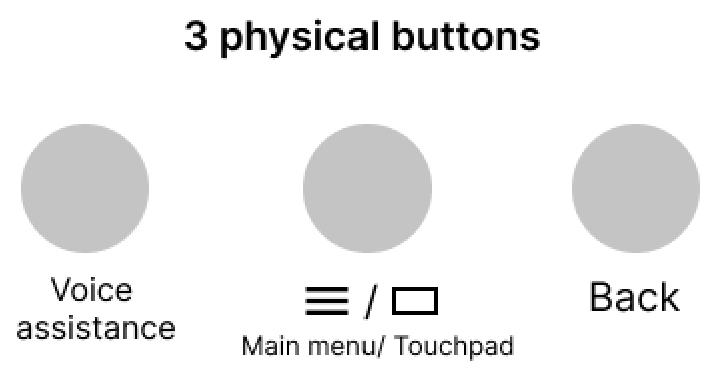


Figure 49: New functions of 3 physical buttons

We designed a landing page (figure 50 left) for the center screen. This page is displayed without selecting any app. It mainly displays time and weather information, as well as notifications and new messages received. The user can switch the touchpad screen to the touchpad function, select the corresponding new message to enter the app to view. At the top of each interface we have added a status bar to display received messages and basic time and weather information (figure 50 right). Users can also tap new messages and notifications in the status bar to quickly access. Through the redesign of physical buttons, users will be provided with a more flexible and comprehensive experience, including switching between apps and viewing notifications. The function switching of touchpad screen in any situation simplifies various operations and conforms to the user's intuition.

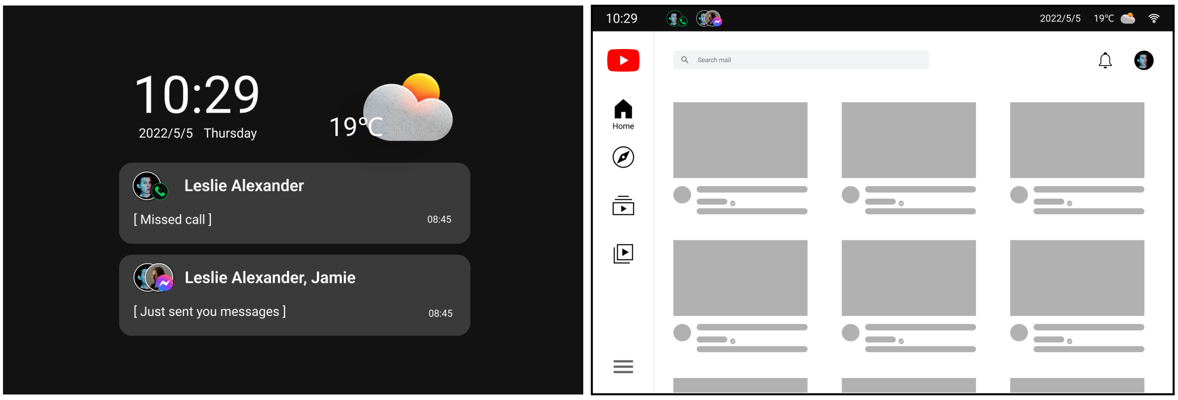


Figure 50: Center screen landing page (left); state bar on the top of each page (right)

For the touchpad screen, in addition to several screens in the first low-fidelity prototype, an incoming call notification screen was added (figure 51 bottom left). The left side of the interface displays the avatar and name of the calling user, and the right side is a swipeable virtual button responsible for answering calls. In order to make the action of picking up or hanging up the phone ergonomic, the button is designed for users to use the thumb to slide the button to the up right to answer the call, or to the bottom left to hang up the call. Alternatively, the driver can also ignore this incoming call by pressing and dragging down on the bar indicator similar to the one above the keyboard. The ignored calls will appear in the notification (landing page) interface of the center screen and the status bar above the interface. Every interaction in the in-vehicle interaction system needs to take into account the operation accuracy and efficiency as well as ergonomics, which are crucial to the user's driving safety.

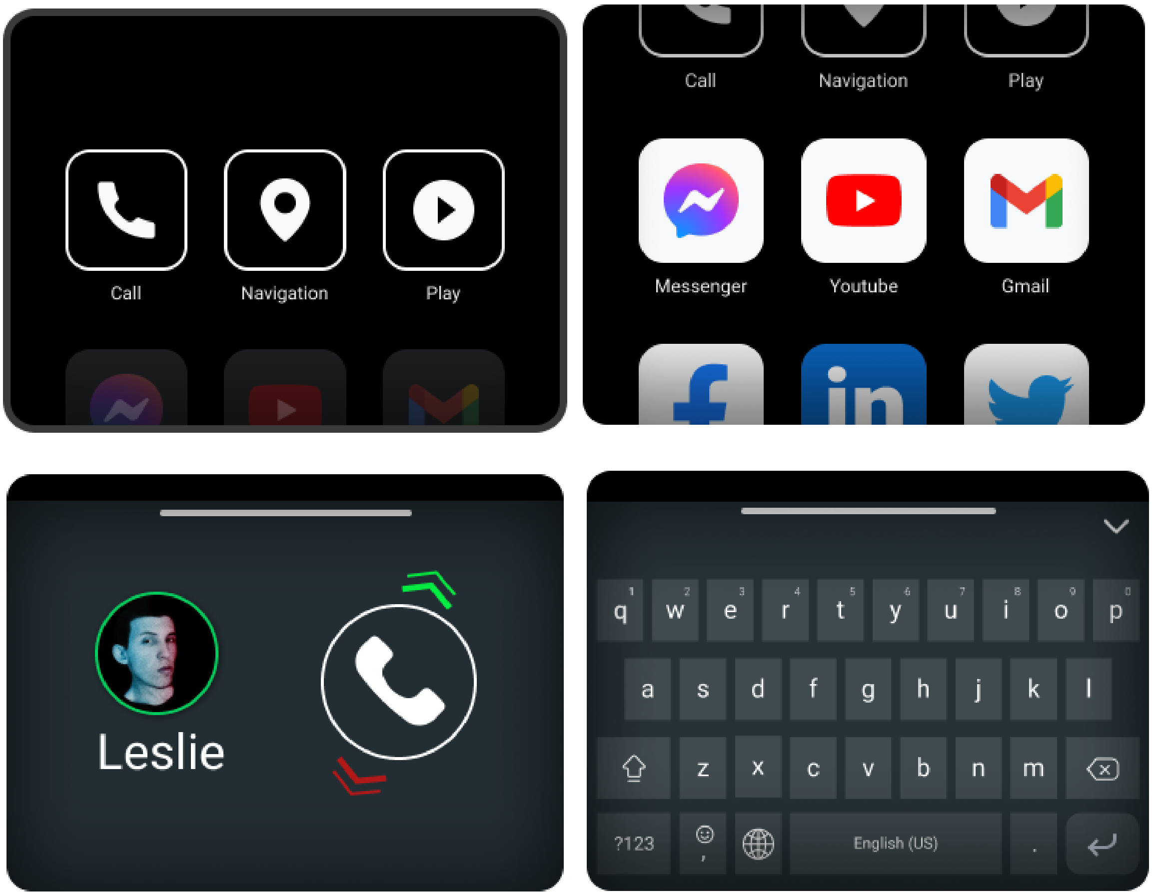


Figure 51: Second low fidelity prototype of touchpad screen

9.3.1 Gmail

The main changes are concentrated in the landing page (figure 52 top), we maintain the 3-column structure of the landing page, and add a status bar at the top. The Compose button has been moved from the top of the email list to the side navigation rail under the logo. Because of the logic problem in its original position, the Compose button should be independent of the email list and not in the same level as the emails in the list. For the side navigation rail, we distinguish the selected icon from other category icons to help users understand where they are. At the same time, each icon has three states, the unselected state, the state with the text title under the icon when the mouse is hovering, and the state with the text title after clicking. Such a design can keep the page clean, and it also provides instructions for new users to understand the function. At the end of the texts in the email reading area, we added “Reply” and “Forward” buttons to facilitate users to operate directly after reading.

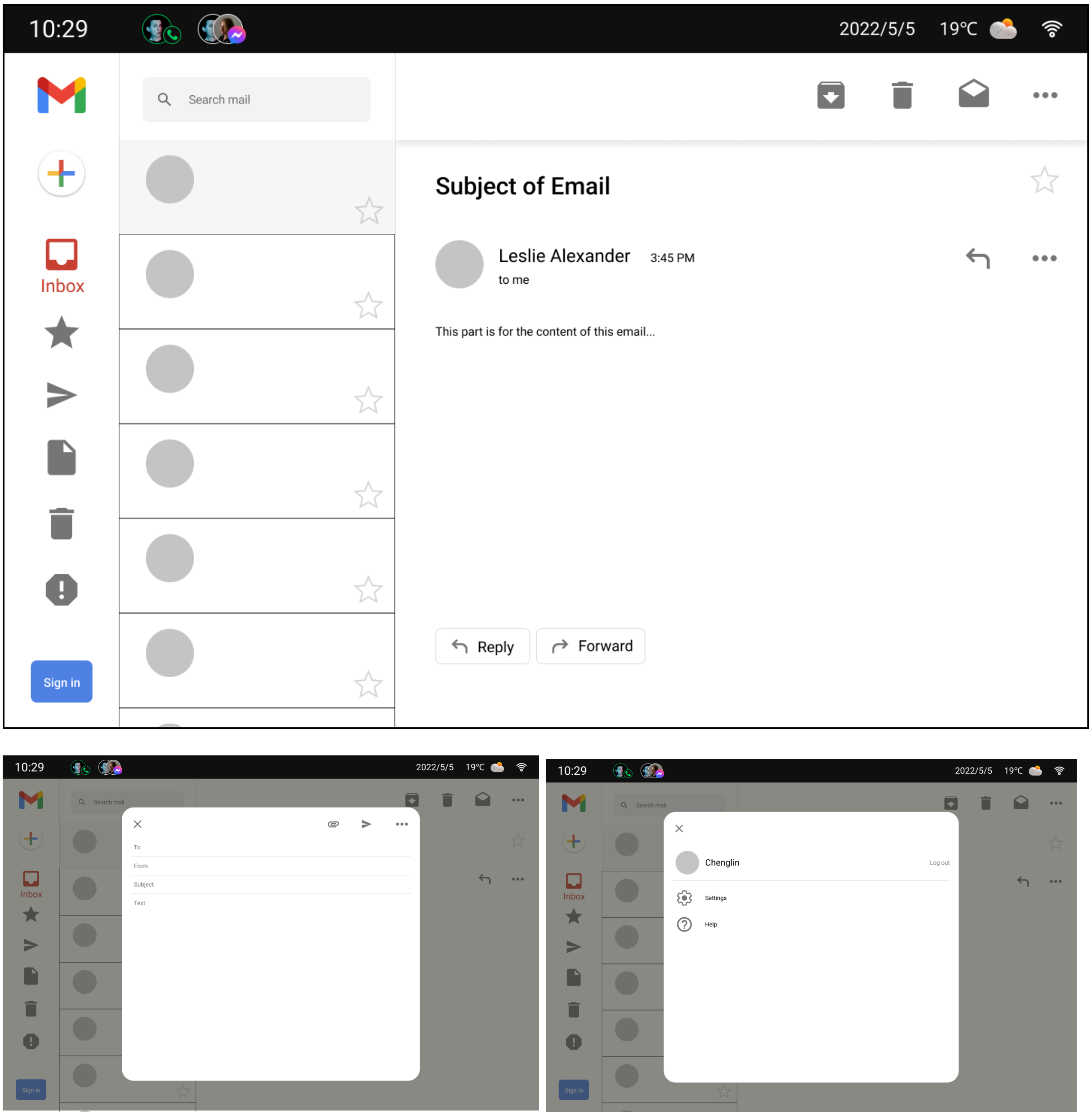


Figure 52: Second low fidelity prototype of Gmail

9.3.2 Youtube

For Youtube (figure 53) , in the side navigation rail, we add different states for icons as what we did for Gmail.

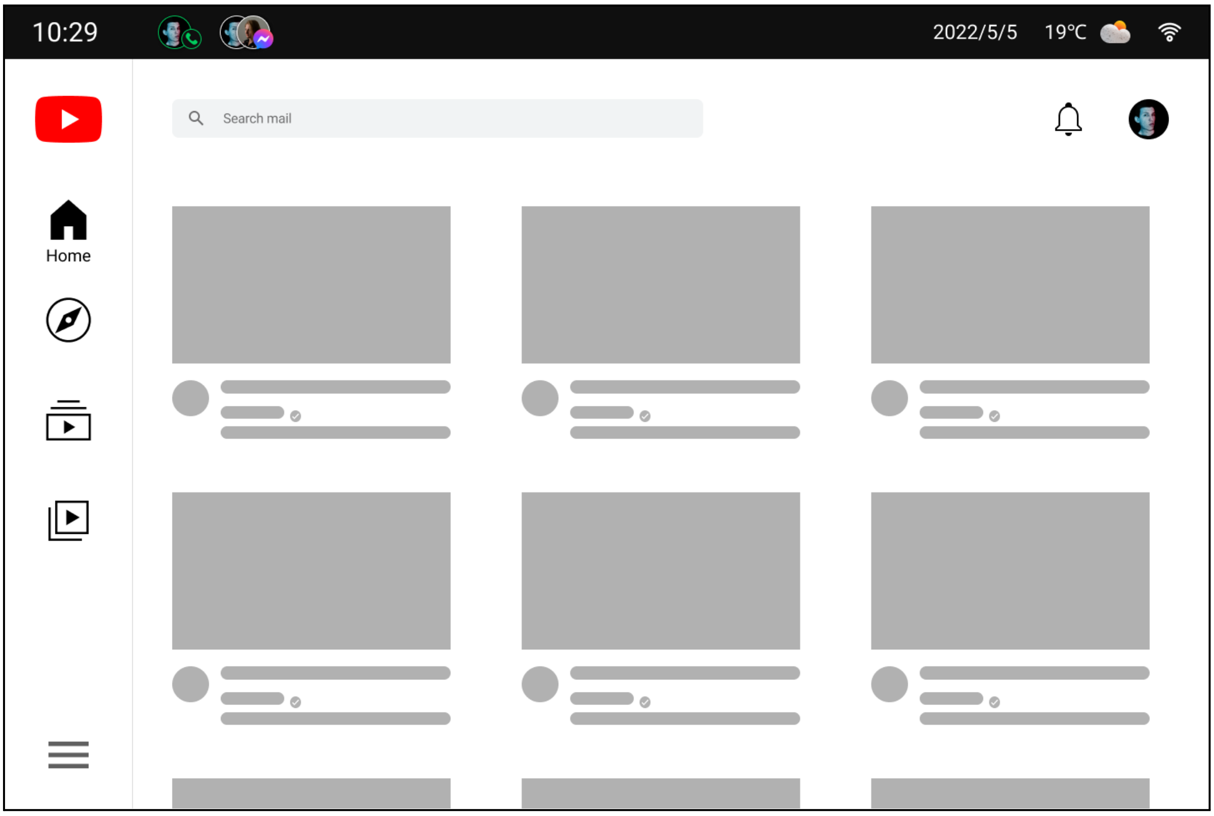


Figure 53: Second low fidelity prototype of Youtube

9.4 High fidelity prototype

Through the second low-fidelity prototype, we determined the basic content and structure of user interfaces. The high-fidelity prototype required us to practice *Google Design for Driving*, apply guidelines to the user interfaces, and standardize various elements.

For the touchpad screen, since it appears on the steering wheel, the black background color can adapt to both day and night environments, and black can also avoid distraction during driving caused by the color of the steering wheel screen being too prominent. As shown in figure 54 top left, the wireframe of the app launchers is replaced by a background color with transparency, the purpose is to help users quickly identify the scope of the button. In addition, for the overall layout, we used an 8dp grid for alignment of any elements on the interfaces. At the same time, we standardized the color and size of app launchers. In the incoming call interface, we redesigned the UI to help users quickly identify the function of components through a design that conforms to guidelines.

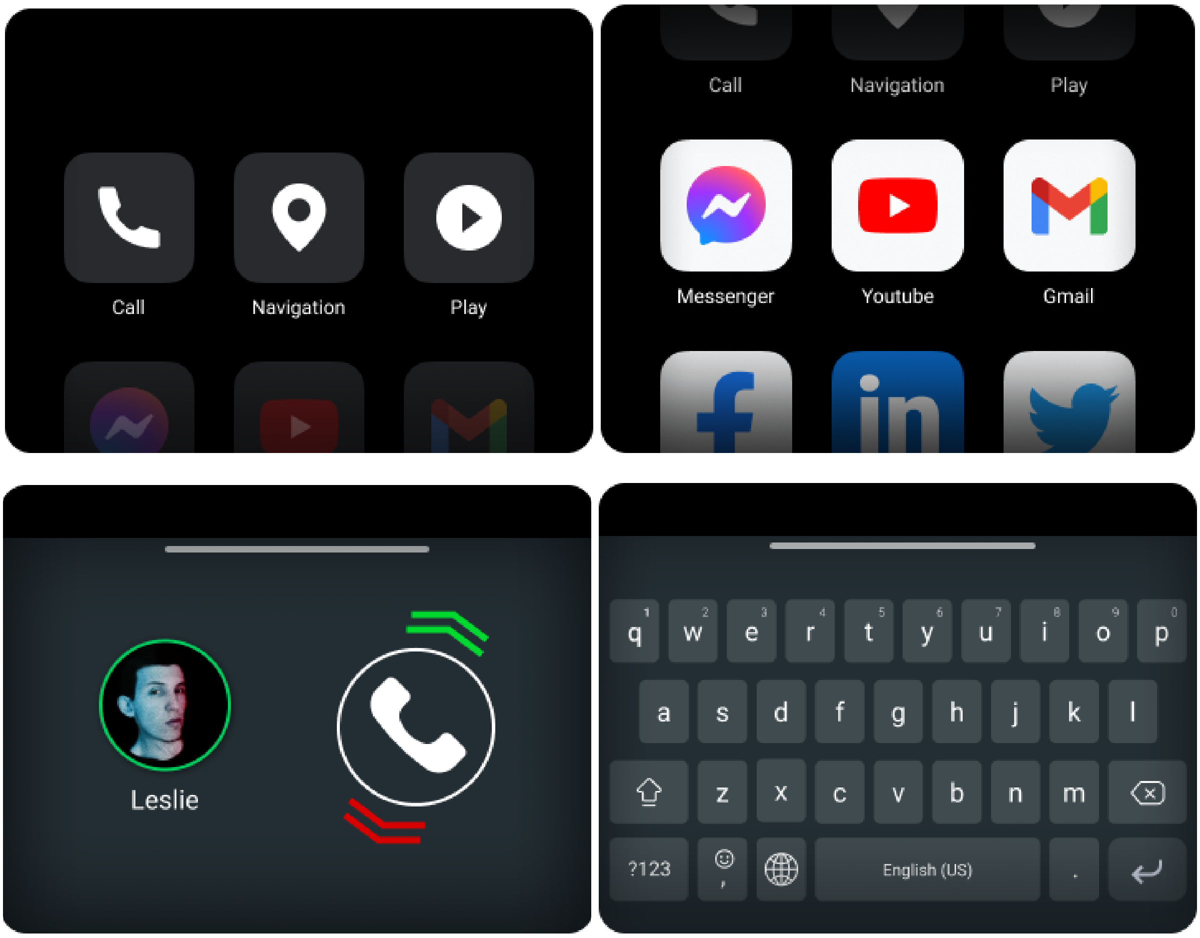


Figure 54: High fidelity prototype of touchpad screen

The Landing page of the center screen has been further detailed (figure 55), and background images have been added to make the user interface look more advanced and immersive to use. Besides, we arranged all the elements on the page strictly according to the grid system, and redesigned the notification card according to the design specification.

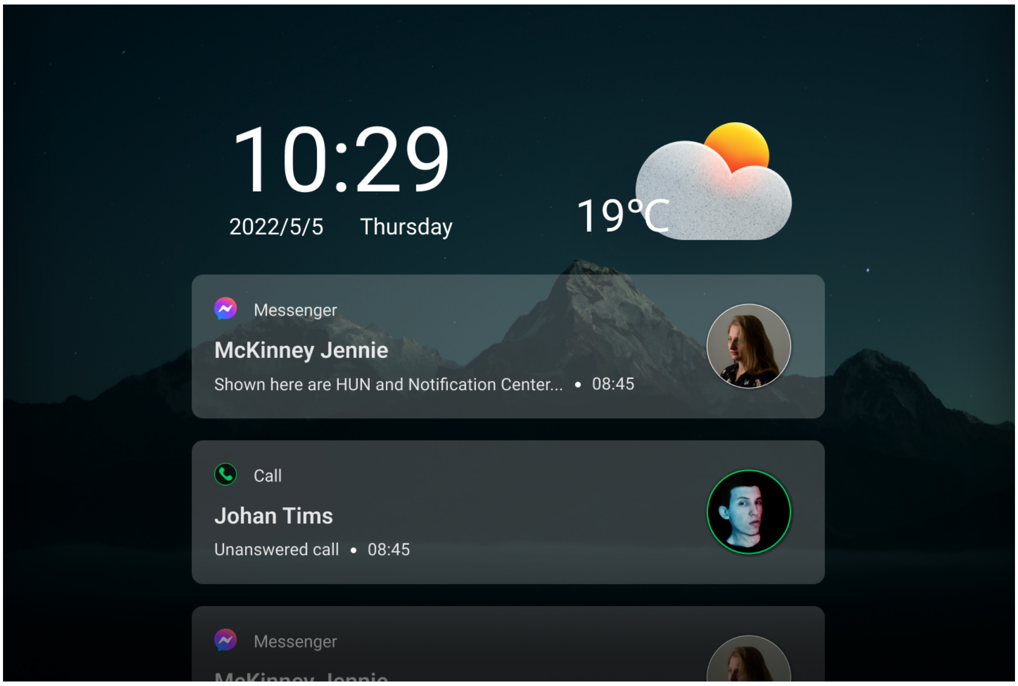


Figure 55: High fidelity prototype of center screen landing page

Considering the overall user flow, we designed the notification incoming interface, including day mode and dark mode (figure 56). The design of the notification card refers to the design and layout of notifications in *Google design for driving*. We added voice play and mute buttons to the notification card to help users perform quick operations. At the same time, the notification card uses partial scrim as the background, which helps users ignore the background information when the notification card appears to highlight the content of the card. In order to help users perform quick operations, when a notification card appears, the mouse arrow will automatically be moved to the card range. Users can tap a card to jump to the corresponding app, or tap the “Play” button to listen to incoming messages. Users can also tap the “Mute” or outside of the card to quickly hide the notification card.

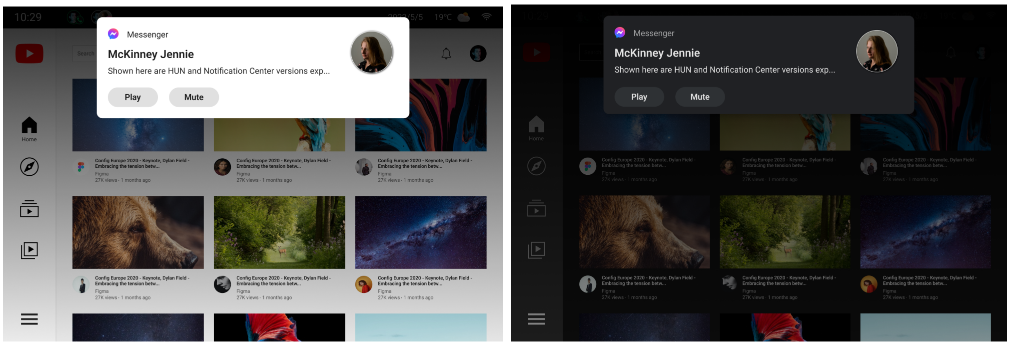


Figure 56: Recieving notification page day mode (left) and dark mode (right)

In Gmail's high-fidelity prototype (figure 57), we further emphasized selected elements in the navigation rail, using colors and background color to help users quickly identify. In addition to adjusting and designing the interface layout strictly according to the guidelines, we also use different background colors and lines to divide different functional areas. The text has also been standardized to make it meet the text display standard of the in-vehicle user interface.On the contrary, for some text with lower reading priority, we did not follow the requirements given by the guidelines, which require a minimum font size of 24dp after we analyzed the importance of the text and highlight the text with higher reading priority. We additionally designed a dark theme as shown in figure 58, which is in line with Google's requirements for in-vehicle user interfaces. According to the dark theme design guidelines, we have standardized the text color, background color of different levels, etc., so that the high-fidelity user interface meets the market and user requirements.

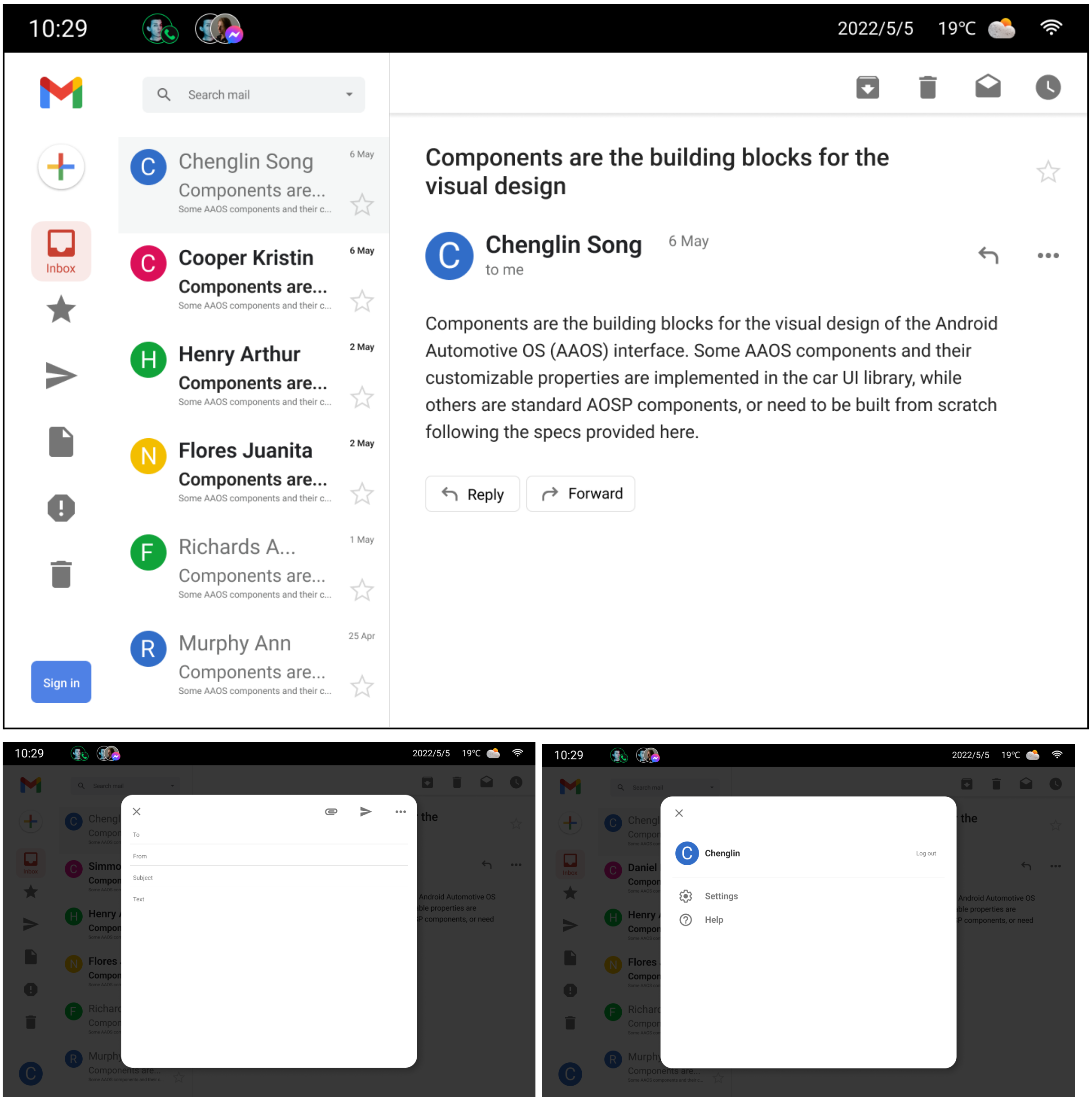


Figure 57：High fidelity prototype of Gmail day mode

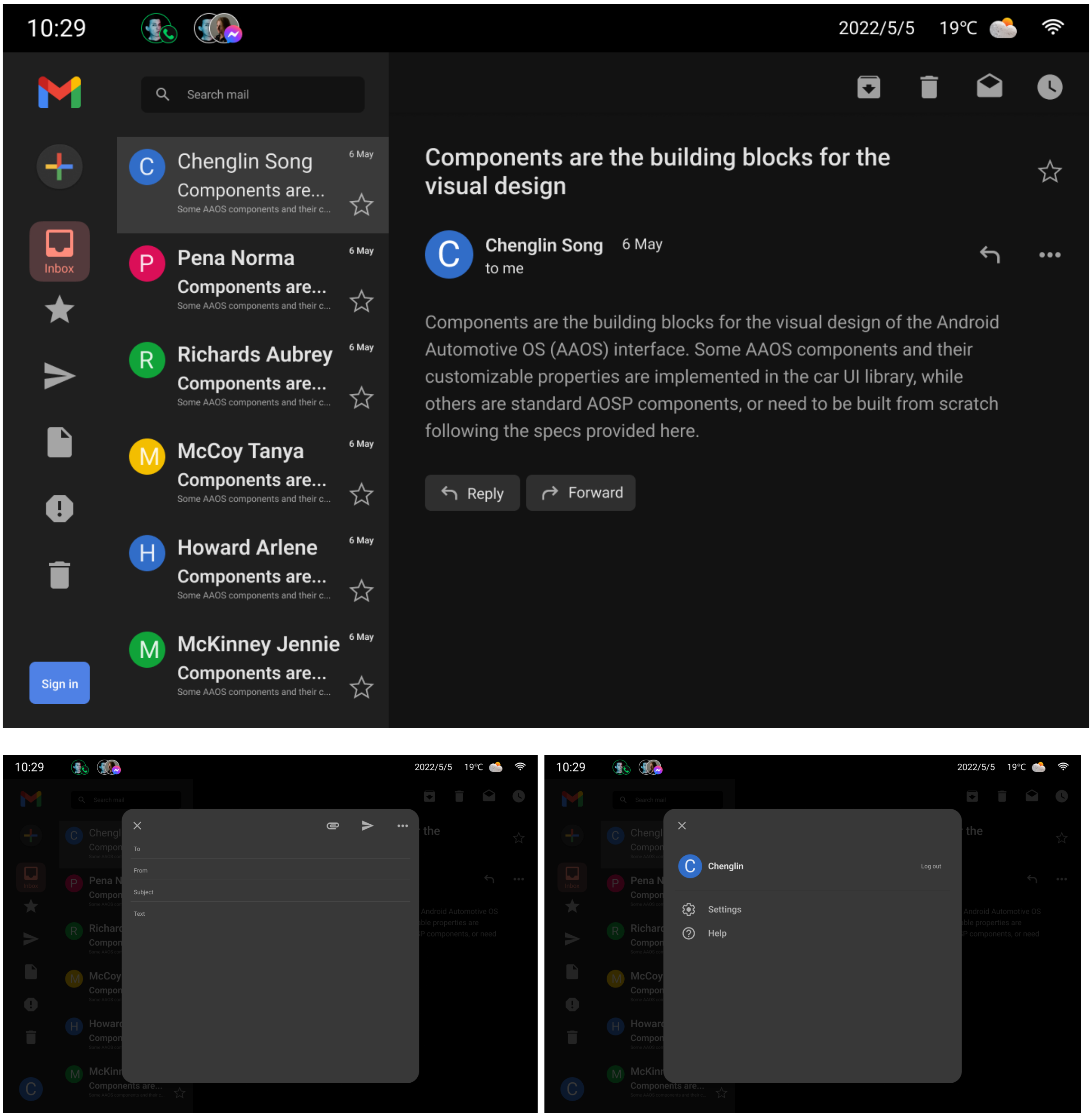


Figure 58：High fidelity prototype of Gmail dark mode

Youtube's high-fidelity user interface is shown in figure 59, we have further optimized the side navigation rail, and further increased the video cover image size in the video list. The navigation buttons in the navigation rail are centered for quick selection via the touchpad. In addition to the layout of each element of the interface is aligned with 8dp grids, we also added a new landing page with a small window to play the video. We also designed a dark theme interface for Youtube, as shown in figure 60.

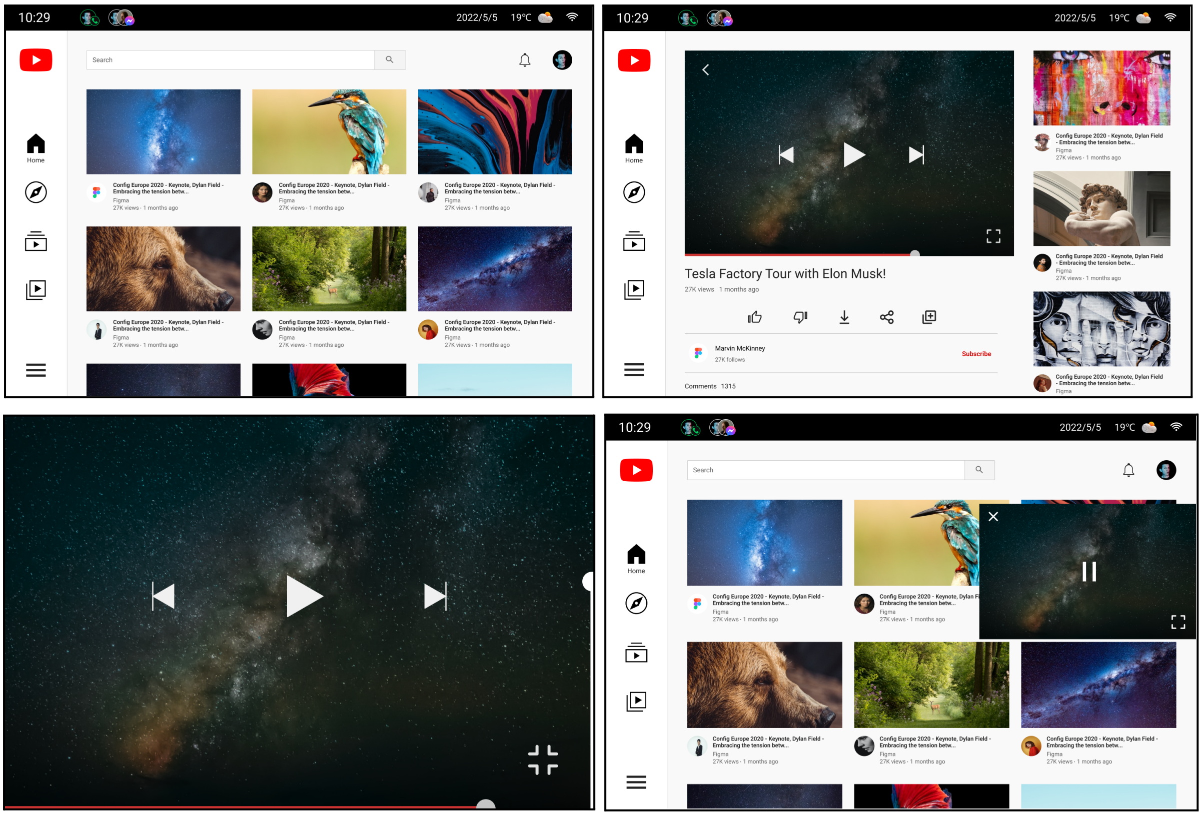


Figure 59：High fidelity prototype of Youtube day mode

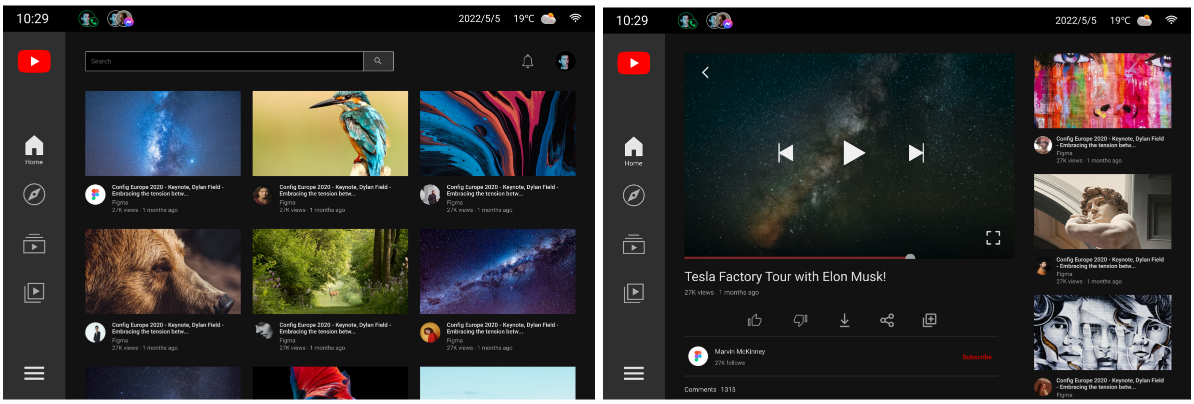


Figure 60：High fidelity prototype of Youtube dark mode

9.5 Connection of interfaces

Shown in figure 61 is the relationship between the YouTube high-fidelity prototype user interfaces (left) and how to use physical buttons with two screens in Gmail (right).

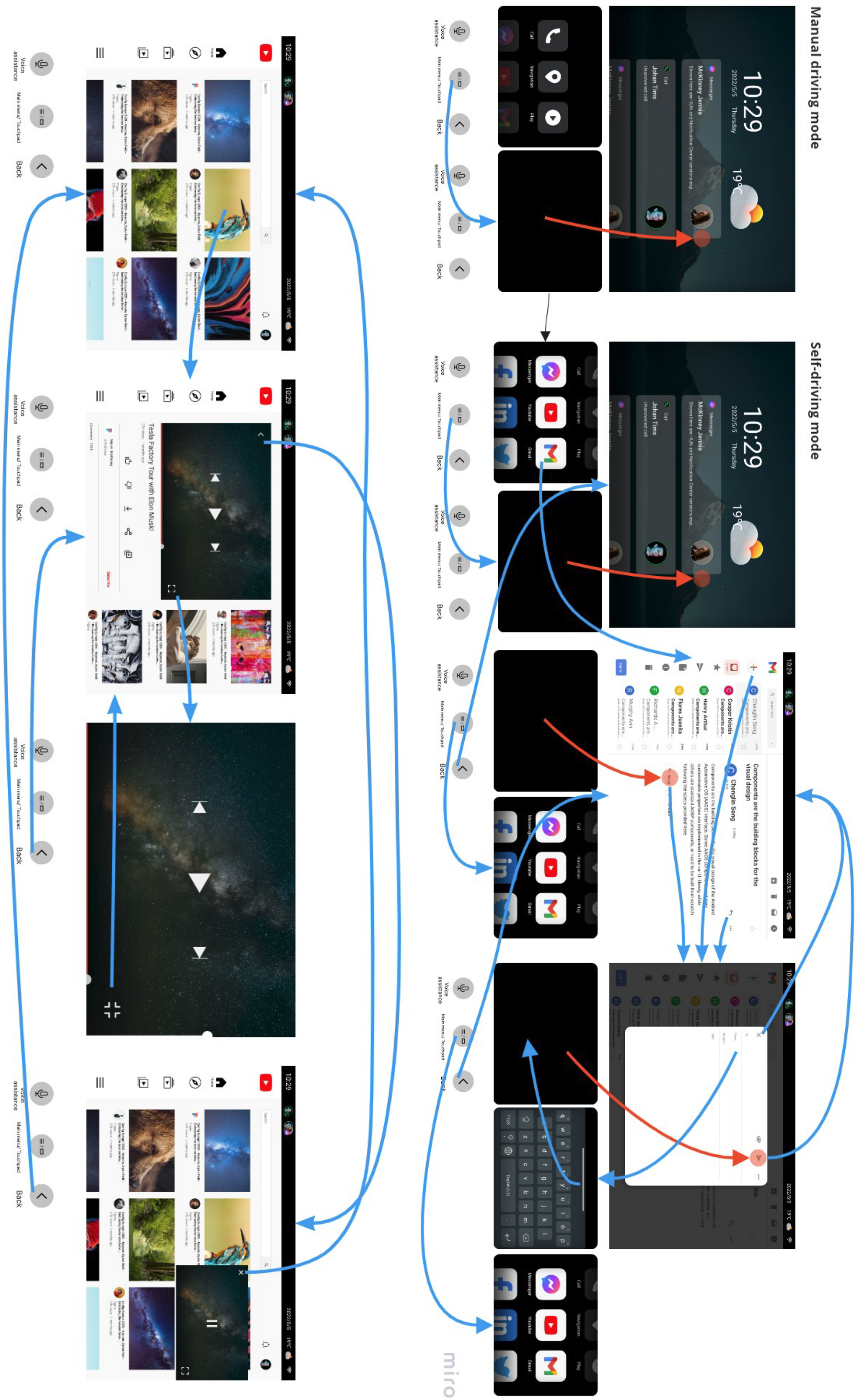


Figure 61 : Use process of Youtube (left); use process of physical buttons and screens (right)

10 User Test

10.1 Method and purpose

As mentioned in Design goals, our design goals are divided into three areas: A. Improve the user's driving safety through the location of the screen, how the content is displayed and controlled B. By providing variety of secondary tasks to meet the secondary task needs of most users. C. Provide an intuitive and highly usability through reasonable screen position, control design, UI design, etc.

First, for goal A, in order to verify the safety problem, a level 3 autonomous driving environment that is closest to the reality is needed. Perspectives related to safety include whether Concepts I and II provide safe and effective basic secondary tasks in manual driving mode, whether the physical buttons of Concepts I and II can be mistouched, and whether the drivers have ability to shift attention from secondary tasks to driving tasks within a short time when doing secondary tasks. To verify these angles, some professional equipment is required, such as an eye tracker. This means we need more time and more specialized equipment and technology to build better physical and electronic prototypes.

Second, for goal B, we need to verify that the types of secondary tasks we provide and functionalities of them meet the needs of most users. This requires us to find as many participants as possible to join in user testing, and as much data as possible needs to be used as support, which is also a task that requires good physical and electronic prototypes and sufficient time.

For goal C, validating the usability of both concepts also requires us to make usable physical and electronic prototypes. For the Concept I, a steering wheel that can be installed with a mobile phone, a larger in-vehicle display, and an interactive system that can be controlled by a stick are required. For Concept II, an interactive system controlled by multiple physical buttons and a touch pad screen was required.

Although we would like to test our concepts and prototypes more rigorously, making usable physical prototypes and connecting the electronic prototypes to physical prototypes was not included in the scope of the project. Making usable physical and electronic prototypes requires expertise in other areas and more time. In response to this problem, the solution that we negotiated with Autoliv is that after the completion of this thesis project, the company will invite experts in related fields to complete the required physical and electronic prototypes and carry out deeper study and test for the concepts, and then keep iterating the concepts during tests.

But it doesn't mean we don't do any user testing on this project. Although the tests for security, diversity and usability are limited by the experimental materials, we can test the effect of the two concepts on the functional reduction of Gmail and Youtube to verify whether the currently provided functions are the user's needs for the two secondary tasks. At the same time, we can also perform a simple test of the usability of the user interfaces, but inevitably the user under test is required to analyze the user interface by imagining and constructing usage scenarios.

10.2 Process

In this user test, two design concepts will be presented in the form of a 30-40min online meeting, and our explanation will help respondents understand the operation of the two interactive systems. Then interviewees were required evaluate the functions and logical relationships of each user interface by imagining and constructing usage scenarios by themselves. We have organized questions for several user interfaces, and the questions are included in Appendix G. We found five drivers, three were 36-50 and two were 20-35. We completed user test in the form of one-by-one interviews. The process of each user test is as follows:

- Brief introduction of project background
- Self introduction
- Introducing Concept I
- Problems of Concept I
- Respondents ask questions
- Introducing Concept II
- Problems of Concept II
- Respondents ask questions
- Thanks

10.3 Results

As far as user testing itself is concerned, two respondents felt that it was difficult for them to construct usage scenarios through imagination, so that more realistic data and experiences could not be obtained. However, this problem cannot be avoided at this stage, but there will be more realistic scenarios and more rigorous experiments after the project ends. Respondents have a clear preference for concept I over concept II because they can associate more possible problems with concept II.

On the home page from high-fidelity prototype of the concept I, several participants suggested adding settings function to make changes to the system. This is the user's functional requirement for a general interactive system, and they thought that the home page of the system needs to provide users with the ability to set the system. After learning about the concept I, two respondents believed that using the stick to operate some specific mobile applications is not very clever, because the stick cannot satisfy some unique gesture operations commonly used on mobile phones, such as swiping up and down to scroll through short videos. At the same time, each interviewee observed that there are objects selected with stroke by default when entering each user interface, and they emphasized that the objects selected by default should be considered carefully because it will significantly affect the efficiency of operations.

Regarding the Gmail interface of concept I, interviewees generally believe that the feedback given by the stick to select a target is very consistent, that is, the elements selected by the stick in the entire system have a blue selection stroke, which is considered to be benificial to the interactivon experience. 4 respondents said that some of the Icon buttons on the reading email page are not easy to understand, especially the "Reply" and "Forward" buttons are very confusing. Respondents believe that the icon selected by the stick needs to display text descriptions to facilitate understanding of the function.The majority of respondents feel that they prefer to use voice input when typing text, but our user interface does not give enough feedback on voice input to make users aware that they are using voice input.

For the Youtube user interfaces, when different content is displayed on the mobile screen and the center screen, the respondents expressed confusion about the target of the stick control, because we did not clarify that the stick is a control method designed for the center screen. In addition, a small number of respondents said that using the stick to perform common operations such as pausing video is not suitable, and some faster gestures or key functions may be required, such as quickly pressing the stick twice to pause the video.

For Concept II, the accuracy of the touchpad was questioned by respondents. 4 of them felt that the touchpad operation would become inaccurate on a moving car. And they also questioned which fingers to use. Although in the introduction we emphasized that the system is used in a similar way to a laptop's touchpad, and that drivers are encouraged to hold the steering wheel with both hands when completing secondary tasks, respondents still expressed the requirement of operation accuray is high and there is too much freedom which will lead to uncertainty.

All respondents could easily tell how to open and toggle secondary tasks after they understood how concept II workes. And it was easy to understand the function and usage of the constituent elements on each page. In concept II's Gmail user interfaces, we asked respondents if they could tell the email sections in the navigation rail by icons. The result is that all 4 people are very familiar with these functions and do not need text as the subtitle. One interviewee did not understand the meaning of one of the icons, but when we further asked her how to quickly understand the meaning of the icon, she could alsoconcluded that moving the mouse over the icon would result in the appearance of text subtitle by judging the interaction method, which is exactly what we designed. Although users may be unfamiliar with the icon, they can still quickly become familiar with the function through our design. At the same time, the respondents also said that the functions we provide in the user interface meet the needs of most users.

Two respondents said that concept II's Youtube interfaces need more fast gestures, after all, using the touchpad to control the mouse arrow to select elements is not a fast way in some cases. Therefore, some gesture operations for touchpad need to be added.

Regarding the usability of the two concepts, three respondents said they felt more comfortable with using the concept I's interactive system in their cars. Because they believed that the operation of performing the secondary tasks during driving requires restrictions, too high degrees of freedom will bring uncertainty. Hence, the operation of the stick matches the overall user interaction system better, and it does not require precise operation. They believed that concept II has a high degree of freedom and a higher probability of false touches, so it requires too much operating accuracy and is not suitable for driving environments.

Other respondents said that they are used to the current operation of mobile phones and laptops, which are the most common interactive devices in their lives, so they prefer concept

II. In addition, one interviewee believed that concept II limited the vision when performing secondary tasks. In most cases, they watched the center screen, which is closer to the road ahead, which is very safe for driving and taking over driving tasks. Importantly, Concept I does not explicitly limit the user's vision when completing secondary tasks.

Although there was no completed prototype, this user test uncovered a number of usability issues with the concepts, as well as bugs in the user interfaces. It has great significance for our subsequent iterations. Being able to discover problems before a more complete prototype being built can save considerable time and money. Therefore, this user test is not only to test the results of the graduation project, but also of great value to the follow-up development of this project.

11 Discussion

At the beginning of user study, we first identified our target user group by reading the literature. Since there is no completed steering wheel screen concept in the market at present, there is no highly targeted product as a reference. We can only start from the conditions of driving a car and the experience of driving a car to define the target group, and first identify drivers above 20 years old. Afterwards, literature reading is the only effective and quick way to determine the age range. We reviewed the literature on the relationship between physical abilities required for driving and age to analyze the likelihood of drivers of different ages participating in secondary tasks from the user's own perspective. This was an effective way to determine unknown target groups, although there is no direct evidence or data on whether this age group performs secondary tasks while autonomous driving to support our idea.

User study 1 was conducted in the form of interviews. Since we cannot get the real use experience, we need to explore the daily behavior of the interviewees as deeply as possible. This requires that we communicate as much as possible with our interviewees and make them talkative. In the pilot user study, we also conducted online video conferencing, but we did not formulate step-by-step questions and emphasize our privacy policy. So in the pilot interview, we found that the respondents were not very willing to express, and it was difficult for us to get answers with personality. Because their minds were hard to mobilize when they were asked about very routine behaviors, they always gave very routine and legal answers. It's like when respondents are asked "what do you eat every day?" they will have a hard time giving specific answers. This will further prevent us from real and effective user requirements. Therefore, in order to make the respondents' thinking more active, we redesigned the interview questions mentioned in the article after the pilot user study. In formal interviews, the progressive questions have a significant effect on the interviewee's willingness to communicate. Most of the interviewees can become talkative by answering the questions step by step, which helped us collect a lot of valuable information. However, interviewees still had some reservations about answering questions about using their phones while driving. If we could go anonymous and not use cameras during the interview, respondents might feel their privacy and be protected to speak more truthfully. Inevitably, this will affect the fluency of communication, further make the interviewee more nervous, and their thinking will not be activated. It was difficult to find a balance between the interviewee's in-depth communication and the awareness that his privacy is protected. The key is whether the interviewer's explanation of privacy protection before the interview has been recognized and trusted by the interviewee.

The variety of user requirements obtained in user study 1 was unpredictable, and we did not use statistical tools or analytical tools to refine the key requirements, because we found that these user requirements were difficult to classify. We can only roughly count the number of times each requirement was mentioned, which cost a lot of time.

In user study 2, we used the bodystorming method to conduct physical experiments and online experiments. For the physical experiment, although we used a car simulator to create a realistic driving environment as much as possible, the user's sense of substitution during the test was not very strong. Factors that affect the sense of substitution may come from simulators and designers. The purpose of using a simulator is to reduce the user's imagination and allow them to experience the driving environment more realistically. Although the driving simulator can simulate autonomous driving, it does not provide the in-vehicle environment we assume with multiple displays. When conducting experiments, users can only rely on their imagination to judge the appropriate location of different components of the application. Therefore, when the physical environment is limited, how to improve the effect of the bodystorming method needs to be considered. In addition, our presence around the simulator as a reminder also affected the tester's sense of immersion in the driving environment. In addition, the methods of online experiments are also worth discussing. We used Miro to build an online driving environment, so that participants who were unable to participate in the physical experiment could also participate in the online experiment. However, there was still a gap between the environment provided by the online experiment and the physical experiment. It provided participants not only visual information, but more importantly tactile and spatial perception. However, the experimental environment built in Miro can only provide some visual information to the participants, lacking spatial and tactile information. Therefore, the driving environment of the online experiment can only provide limited help to us.

The information of Benchmarking came from the official websites of companies. Although it is the most legitimate and reliable way, the information given by the official channels is very limited. Most of the information obtained by such channels came from pictures and videos. We needed to extract information from videos and pictures by ourselves. In this process, there was inevitably a deviation in understanding, which makes what we understand different from what the company wants to present. This will lead to inaccurate benchmarking results and affect the judgment of market regulations and trends. In addition, compared to the steering wheel screen concepts in the market, the number of multi-function steering wheels is more, due to the time factor we cannot find all the functions of each brand of steering wheel to study. Therefore, we can only find the more characteristic steering wheels in the current market for research, inevitably we will get relatively one-sided benchmarking data, and at the same time, there may also be deviations in understanding. If we can get in touch with staffs in charge or the designer of the relevant enterprise, then we can avoid the bias caused by collecting data through self-understanding in the benchmarking process. However, this approach is often time-consuming. Collecting data on the Internet is the most common and efficient method at present. The reliability and accuracy of the data is higher with the increase of the collected data base.

In concept generation, we first considered concepts at the physical level, but according to De Michell & Gupta's (1997) hardware and software co-design theory, there was a problem with the way we develop products. Since there are no members of the group with a background in display device manufacturing, and without an in-depth literature study of the basic construction and principles of screens, the solutions we produce may become impractical. Hence, we didn't think about the realizability of the solution and the realizability of the prototype when we conceived the concepts, it ultimately affected our user test results. This highlighted the importance of interdisciplinary teams. Team members from different backgrounds are involved in the design process, not only can they design more achievable solutions by considering how the concept will be realized in advance, but also can evaluate solutions during the user testing phase by a more complete concept prototype.

Concept 1 integrates the mobile phone as a screen into the vehicle display system, which limits the user's use of the mobile phone which has a good effect on reducing the distraction generated by mobiles. At the same time, the concept provides very good stability, minimising the need for precise control during driving. The stick is ideal for unstable driving conditions. However, there are two control methods, using stick and touching (phone), which complicate the control method. In the user test, it happened that it was not clear whether to operate the mobile phone or the stick. In addition, this solution imposes more constraints on the designer of user interfaces. In order to match the operation of the stick, all application interaction systems must be designed to be able to fit the input of a stick. For applications with complex functions, there is a possibility that some complex and infrequently used functions can only be operated through the mobile phone, but a clear prompt is required to tell the user which functions can be controlled through the mobile phone.

Concept II uses a screen that can change into a touchpad to help the driver control the center screen to complete secondary tasks, while requiring three physical buttons below the screen as an auxiliary. First, it can guide the user's sight and attention well, from the road ahead to the steering wheel, and then to the center screen. And there is no need to frequently shift attention when drivers complete a secondary task, as the touchpad and buttons are designed to be intuitive. Second, concept II draws inspiration from commonly used objects around people, such as mobile phones and laptops. It has benefits to help users get started quickly and use the controller accurately and flexibly without visual confirmation. At the same time, the size and usage of the controller are also close to similar products, which further reduces the user's learning cost, improves the operation efficiency. It also effectively reduces the cognitive burden caused by the use of the interactive system, which helps users flexibly engage in or get rid of secondary tasks. In addition to the above advantages, this concept also satisfies the need to encourage users to complete secondary tasks without leaving the steering wheel with both hands, and has a guiding role for the driver to hold the steering wheel in a safer posture with both hands, which can reduce the probability of danger. This is in line with our design goals.

However, the problem with concept II also comes from the user's familiarity with mobile phone and laptop operation. The gesture operations that can be done by the touchpad screen are limited, and the combination of the mobile phone screen and the touchpad will cause conflicts in some gesture operations. Users may be confused when they find that a certain gesture operation cannot achieve the same effect on this platform. This requires us to further explore and test to study what common gestures users require. In addition, since the current mainstream in-vehicle displays can mostly realize touch operation, which has better accuracy and efficiency. However, when a driver uses the touch screen, at least one hand is off the steering wheel, and it causes visual and behavioral distraction, which is not conducive to safety. However, it is undeniable that the operation method proposed by concept II does not have the advantages of efficiency and accuracy compared with the touch operation, and it cannot avoid the driver using the touch center screen to complete secondary tasks for better efficiency. Although we have made a clear division of labor between touchpad screen and center screen, it has not significantly reduced the willingness of users to adopt other operation methods. Forcing drivers to use inefficient ways to complete secondary tasks may reduce user satisfaction.

Besides, we also consider the case of multitasking in in-vehicle display systems. We believe that multitasking in L3 autonomous vehicles may be a very common situation. For example, a user may want to pay attention to navigation information while watching a video and at the same time replying to a friend's message. Obviously, it is technically feasible to achieve such a usage scenario, but larger screens or multiple monitors are required. However, since we have no opportunity to determine the physical characteristics of the number and size of in-vehicle displays, we cannot give specific multitasking solutions. The specific multitasking concept also needs to be designed according to the size and number of the specific displays of the specific vehicle.

Autoliv's vision of Saving More Lives guides our project work. We have put a lot of effort into improving the safety of users performing secondary tasks on L3 autonomous vehicles. First, the concepts we propose can limit the user's use of the mobile phone while driving to a certain extent, thereby reducing the distraction and danger caused by the mobile phone. Second, from the perspective of the position of the steering wheel screen, it reduces the distance and time that the user's gaze shifts when looking at the steering wheel screen and the outside environment. Third, our concepts encourage users to hold the steering wheel even during autonomous driving, which not only speeds up the process of user taking over the driving task, the grip position is also the least likely to be injured by the airbag when the airbag is deployed. We explored how to ensure the safety of self-driving car drivers from multiple aspects, consistent with the goal of UN sustainable development goal 3, to reduce the mortality rate of future traffic accidents by designing more reasonable car interaction systems and car safety equipment.

A number of ethical considerations have also been taken into account. We took the confidentiality of benchmarking companies and Autoliv's information very seriously, as well as the confidentiality of personal information of user study and user test participants. Irregular access to information was avoided. During user study and user test, recording methods that expose personal information, such as photographs, audio and video recordings, were also avoided. Gender equality and occupational equality of participants in user research and user testing were also considered.

In the literature review section, we found that the biggest limitation of the literature in this field is the lack of up-to-date experiments to provide analysis and design guidance for the interaction systems and steering wheel screens of autonomous vehicles. Our program can create great value in this research vacancy. The proposed two concepts integrate screen on the steering wheel and their interaction system can be used as research materials and provide value for follow-up research in this field. Multitasking in the context of autonomous driving is also a direction worthy of more exploration, but it needs to match the specific physical scene. Regarding the concepts, although we have proposed the concept of physics to a certain extent, there were no specific constraints on the physical implementation. Therefore, the physical implementation of the two concepts can be more refined. From the point of view of automation level, the manual mode and the automatic mode are given equal importance because this project is aimed at partially self-driving cars. For more advanced autonomous driving systems, the variety and manner of secondary tasks that users can perform may be greater due to increased automation. Therefore, the exploration of secondary task systems for higher-level autonomous vehicles also deserves attention.

12 Conclusion

This master thesis explores the possibility of designing a touchscreen on the steering wheel of a Level 3 autonomous vehicle to provide drivers with second tasks more safely. The deliverables were two concepts for steering wheel screens in different directions, including concept sketches and high-fidelity prototypes of the user interfaces for Gmail and Youtube respectively of the two concepts.

In the literature reading, level 3 autonomous driving technology and its related design principles and guidelines are learned and recognized. Drivers use their phones for secondary tasks, which can lead to traffic accidents, and if an interactive system in a self-driving car can cause less distraction than a phone, it will reduce a lot of potential accidents. Secondly, the position of the steering wheel has the best visibility and reachability for the driver, and adding a screen on the steering wheel that can be used to complete secondary tasks can significantly reduce the level of distraction in all aspects. The way drivers hold the steering wheel also affects driving safety, and an interactive system that encourages the driver to hold the steering wheel in the correct posture has a key impact on the driver's physical health and driving safety. However, the limitation of L3 autonomous vehicles comes from the excessive requirements for the driver's cognitive ability, which is an unavoidable problem of the technology. If the design of the secondary task interaction system can make the state of drivers when completing the secondary tasks closer to the state of doing the DDT, which will effectively make up for the defects brought by the technology. Literature findings led to insights regarding the potential benefits and problems of research steering wheel screens and guidelines to watch and follow.

Although there are no self-driving cars with steering wheel screens already in the market, we still used benchmarking to study the concepts that have been released. We studied the related steering wheel screen concepts, the functions of the multi-function steering wheel and the functions provided by the center screen, and found the market situation and design regulations. The steering wheel screen concept is being explored, with only a few screens dedicated to secondary tasks. The left spoke of the current multifunction steering wheel controls basic vehicle functions, while the right spoke houses buttons for secondary tasks. This later also influenced our design concepts, which help the driver not confuse the difference between the functions of their two hands.

After analyzing the findings of literature, two groups of target users were defined because they are more inclined to complete secondary tasks during the autonomous driving. Also in the absence of existing products, we conducted two user studies to help us discover user requirements. Through interviews with well designed questions, we study the mobile phone and driving habits of our target user group. Their requirements for secondary tasks such as text input and video media were discovered. Bodystorming was then used to validate the conclusions from the previous user study and to explore user ideas about the relationship between secondary tasks and multiple monitors. After obtaining the user requirements, two use scenarios were used to help us translate the user requirements into product concepts and functions.

We tried our best to conceive the solutions through the co-design of software and hardware, so that the two can be better adapted. Two alternatives in different directions were ultimately retained and iterated and expressed through prototypes of different fidelity. Finally presented as a high-fidelity prototype. As technical and time factors limited the production and evaluation of prototypes, we conducted internal testing and final user testing after building low-fidelity and high-fidelity prototypes. Although the credibility of the test and the evaluation are limited, we cannot evaluate the safety and usability effect of the concepts, but design flaws in user interfaces can still be found and corrected.

Concept I uses a mobile phone as a screen mounted on the steering wheel to present information and provide control functions. The phone can be connected with the vehicle system to display the user interface through the center screen. In addition the user can use a stick and a voice assistance physical button to control the center screen for secondary tasks. The user interfaces of concept I are designed especially for its control method, and the user-selected target, operation methods and logic are specially designed to help drivers complete secondary tasks efficiently and safely. This concept is prefered by more respondents because they believe that the driver's actions and operations during autonomous driving need to be limited to reduce uncertainty, which can effectively reduce cognitive load. Rest of the respondents are more inclined to concept II due to their frequent usage of mobile phones and laptops. Because users can control the center screen to participate in secondary tasks through a screen on the right spoke of the steering wheel designed in this concept, which can become a touchpad similar to the one on the laptop. The center screen is also the main place for driver annotations. The switching of different states of the steering wheel screen is a feature of concept II, and it is also a special design to help the driver complete secondary tasks safely.

From the design results, user interfaces of the concepts can effectively complete the secondary tasks in the user's cognition, and most interviewees can easily understand and get familiar with the interaction modes of the concepts. The final design concepts came from the analysis and results literature review and user study. We tried our best to design concepts as an interactive system that provides secondary tasks for drivers more safely and presents a better user experience for users through the currently available resources and methods. However, in terms of the safety and practical experience of the concept interaction system, more complete prototypes and real use environments are needed to test.

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Appendix A: Definitions for Terms Related to Driving Automation Systems

AUTOMATED DRIVING SYSTEM (ADS)
The hardware and software that are collectively capable of performing the entire DDT on a sustained basis, regardless of whether it is limited to a specific operational design domain (ODD); this term is used specifically to describe a Level 3, 4, or 5 driving automation system.

DYNAMIC DRIVING TASK (DDT)
All of the real-time operational and tactical functions required to operate a vehicle in on-road traffic, excluding the strategic functions such as trip scheduling and selection of destinations and waypoints, and including, without limitation, the following subtasks:
1. Lateral vehicle motion control via steering (operational).
2. Longitudinal vehicle motion control via acceleration and deceleration (operational).
3. Monitoring the driving environment via object and event detection, recognition, classification, and response preparation (operational and tactical).
4. Object and event response execution (*operational* and tactical).
5. Maneuver planning (tactical).
6. Enhancing conspicuity via lighting, sounding the horn, signaling, gesturing, etc. (tactical)

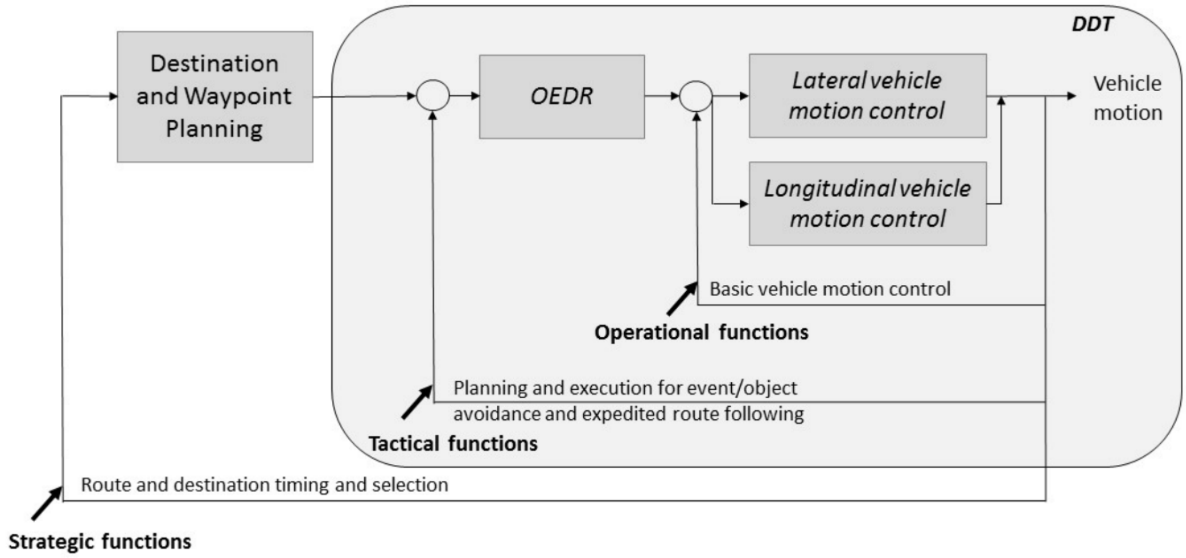

Figure 1. Schematic (not a control diagram) view of driving task showing DDT portion

[DYNAMIC DRIVING TASK (DDT)] FALLBACK
The response by the user to either perform the DDT or achieve a minimal risk condition (1) after occurrence of a DDT performance-relevant system failure(s), or (2) upon operational design domain (ODD) exit, or the response by an ADS to achieve minimal risk condition, given the same circumstances.
NOTE 1: At Level 3, an ADS is capable of continuing to perform the DDT for at least several seconds after providing the fallback-ready user with a request to intervene. The DDT

fallback-ready user is then expected to resume manual vehicle operation, or to achieve a minimal risk condition if s/he determines it to be necessary.

OBJECT AND EVENT DETECTION AND RESPONSE (OEDR)
The subtasks of the DDT that include monitoring the driving environment (detecting, recognizing, and classifying objects and events and preparing to respond as needed) and executing an appropriate response to such objects and events (i.e., as needed to complete the DDT and/or DDT fallback).

OPERATIONAL DESIGN DOMAIN (ODD)
Operating conditions under which a given *driving automation system* or *feature* thereof is specifically designed to function, including, but not limited to, environmental, geographical, and time-of-day restrictions, and/or the requisite presence or absence of certain traffic or roadway characteristics.
EXAMPLE: A level 3 *ADS* highway *feature* with an *ODD* requirement of clearly visible lane lines encounters a short stretch of roadway with obscured lane lines. The *ADS feature* is able to compensate for brief periods of faded or missing lane markings through other means (e.g., sensor fusion, digital map, lead *vehicle* following) and continues to *operate* the *vehicle* for a brief period before the lane lines again become clearly visible. A short while later, the lane lines again become obscured and remain so for longer duration, causing the *ADS feature* to issue a *request to intervene* to the *fallback-ready user*.

REQUEST TO INTERVENE
An alert provided by a Level 3 ADS to a fallback-ready user indicating that s/he should promptly perform the DDT fallback, which may entail resuming manual operation of the vehicle (i.e., becoming a driver again), or achieving a minimal risk condition if the vehicle is not operable.

[HUMAN] DRIVER
A user who performs in real time part or all of the DDT and/or DDT fallback for a particular vehicle.

[DDT] FALLBACK-READY USER
The user of a vehicle equipped with an engaged Level 3 ADS feature who is properly qualified and able to operate the vehicle and is receptive to ADS-issued requests to intervene and to evident DDT performance-relevant system failures in the vehicle compelling him or her to perform the DDT fallback.
NOTE 1: DDT performance by a Level 3 ADS assumes that a fallback-ready user is available to perform the DDT as required. There is no such assumption at Levels 4 and 5.
NOTE 2: A DDT fallback-ready user who transitions to performing part or all of the DDT becomes a driver (in-vehicle or remote).

Level 3 - Conditional Driving Automation
The sustained and ODD-specific performance by an ADS of the entire DDT under routine/normal operation with the expectation that the DDT fallback-ready user is receptive to ADS-issued requests to intervene, as well as to DDT performance-relevant system failures in other vehicle systems, and will respond appropriately.

EXAMPLE: An ADS feature capable of performing the entire DDT in low-speed, stop-and-go freeway traffic.

Appendix B: Questions in User study 1

1. **Did you go to work this morning? How did you get there? Do you use your cell phone on the road? What are you doing with your phone?**

   If your methods of travel restrict your use of your phone, what do you want to use your phone for?

2. **So you did the same thing after work/school?**

3. **Short-distance travel for non-work purposes,**

   Have you recently traveled for non-work short-distance travel? For example, within 1-2 hours, go to the supermarket, go shopping, go to a friend's house.

   What is the mode of travel?

   Do you use your cell phone on the road? What are you doing with your phone?

   If your mode of travel restricts your use of your phone, what do you want to use your phone for?

4. **Long-distance travel for non-work purposes**.

   Have you recently traveled on a long-distance non-work basis? For example, more than 2 hours, or to travel.

   What is the mode of travel?

   Do you use your cell phone on the road? What are you doing with your phone?

   What do you want to do with your phone if your mode of travel restricts your use of your phone?

5. **Drive relevant**:

- The purpose of driving, what are you driving for, and under what circumstances would you choose to drive out
- Driving age, the way you hold the steering wheel. One or two-handed, location and other information

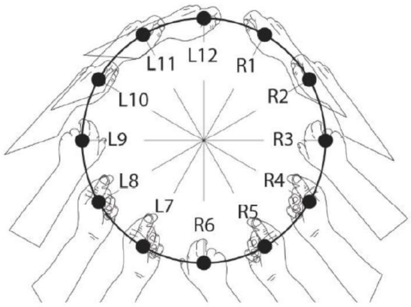

Figure: Scheme of the positions of individual

grips according to the analog clock face. (Hruška, 2018)

- What is the car's home screen usually used for while driving? What function to use? Frequency of each function? (For example, 30 minutes on the way to work, listening to the radio all the time, every day)
- Is there a need to use a mobile phone while driving, and what are the needs?
- Have you ever used a cell phone while driving? If used, under what circumstances (emergency? red light? highway? traffic jam?), and what did it do?

6. **What do you think while driving? Think about what categories of things? Like work? What are you going to eat at home? some type of (after work, on the way to work….travel)**
7. **If you are driving a self-driving car at the moment, it allows you to not drive the car for a period of time, you can just sit in the driver's seat. So what do you think this time can be used for? What do you want? What kind of functionality would you like to have?**

Appendix C: Participants' answers of the interview in User study 1

Young driver 1

1. I went to school this morning;

   By bus or tram;

   Yes, use app to track the bus route, usually listen to music, pop, read news Ukraine;

2. I did the same thing this morning. I wear headphones for music;

3. Yes, to hometown, a little far

   I drove;

   I connected my phone to the car, listened to music, cut songs; if I sat down, the co-pilot would read facebook. That depends, only yourself or be with someone else. You can't use mobile phones while driving in Sweden;

4. To Stockholm; Took plane, I watched TV on plane and Youtube for some videos;

5. Go farther, go home, go to the grocery store. buy hardware, small businesses, need to ship things that hard to carry on bus;

   9 years driving experience, L10 for short distance, L7 for long distance, one-handed;

   It is not a screen in the real sense, it is mostly used to listen to music, radio, link mobile phones, The car navigation function is basically useless, all use mobile phones which refreshes quickly;

   Mainly cut songs, rarely make calls and text messages, and use mobile phones poorly;

   It depends on the situation, mainly depends on your own needs, you may call when you are late. I rarely look at my phone when stuck in traffic, I mainly listen to music and watch the scenery;

6. Talk with others in the car, enjoy music when no one is there;

7. Listen to music, watch facebook, watch youtube, and watch the scenery.

Young driver 2

1. Driving to school to work, navigating, playing music (plugging in the phone, playing music in the car), using the phone stand. I hope I can reply to the message, because I can see the message jumping out, but for safety, I will not read it, but I will be worried about an emergency. The news is generally not urgent. The most important things in the United States are emails, so I hope to reply to important emails. Her car

doesn't have a car play, so she needs to plug in, and her phone needs a phone holder. If there is a car with car play (car home screen), the mobile phone can be placed casually. If you commute within an hour, you will pay more attention to the police on the side of the road, because you will be fined for speeding. won't think more;

2. If it's 10 minutes, and you know the way, then play the song, and look at your phone when you wait for the red light. If you use navigation, you can't stop and look at your phone.

   More leisurely after get off work, will want to do unfinished things;

3. If you know the way, you can also listen to music. If you don't know the road, you should also look at the navigation. As long as you don't know the way, you need to look at the navigation, and the mobile phone can't be used. I usually chat with the people in the car, chatting for a while about what to eat and what to buy.

   Going to a friend's house: I want to go to play for a while, what to eat, is there anyone I don't know, and I haven't seen each other for a long time to chat. I often want to check my phone, they ask where it is, is there a pigeon or something;

4. For more than 3 hours, I will stop on the road, refuel, sell water, and go to the toilet.

   When you stop, swipe your phone. Look at social media. It's tiring after a long drive, and I need to exercise my brain.

   Software used: most important things, mail, gmail app

   WeChat (family and friends)

   Ins, Xiaohongshu, Weibo;

5. As long as I go out, I have to drive, I don't want to walk. 1 minute drive is possible;

   3 years driving experience, 8 o'clock on the left hand, right above the right hand;

   No car play and no bluetooth. Need to listen to songs and navigate, because she thinks the screen is bigger and more important;

   Watch navigation, listen to music, email, reply message;

   Sometimes I will watch it at the red light, especially if I know someone is waiting for her to reply, I will watch it, otherwise I will wait until I get home;

6. Except for the road. Go to work: things to do today, important things recently, such as when will you send me an offer. Go shopping: what to buy and what to eat;

7. Zoom meetings, sometimes driving to commute and miss important meetings;

   Chatting, playing mobile games, someone may wish to speculate on stocks, monitor the stock market (specializing in stocks anytime, anywhere);

Log on to the website to see discounts at supermarkets and menus at nearby restaurants. You have to stop every time to do these things.

Young driver 3

1. Work from home；
2. Work from home；
3. Navigation, (no navigation, familiar road sections) chat, play songs, read novels (I didn’t read it before going out, then read it), games；
4. 1 hour is a long distance, and in places that are relatively unfamiliar, more energy will be allocated to see the road conditions. focus on your phone, navigate, make sure you're on the right track. And listen to radio；
5. As long as I go out, I have to drive;

   3years, both hands, left 7, right 2. But sometimes hands off;

   Half of the phone is in the pocket, under the buttocks or between the legs, take out the phone when there is free time;

   Messaging, entertainment - depending on the length of time (videos, novels, chat software);
6. It depends on the destination you go to when you drive;

   Purposeful short trips, go to the supermarket, what to buy, what I haven't thought of

   on the list, and is there anything else I need;

   For long distances, most of my energy is in the car, find some topics to communicate with, and keep my mind clear;
7. Play a game, but not a game that cannot be paused, not a game that is fully engaged, otherwise it is equivalent to falling asleep

   Watch video.

Young driver 4

1. Yes, by bus, used mobile phone, played mobile game, listened to novel, checked bus route, chatted;
2. Same as this morning;
3. Riding a bike, using a cell phone, chatting, checking the time;
4. By train; I like to read novels, watch videos, play games, listen to audiobooks;

5. 1year, both hands on the rim; L9 R3;

   Listen to music;

   Send and receive messages, make calls, watch navigation, watch the time;

6. Think about how to get to my destination and route;
7. Play games; reading novels; listen to the book; watch video or series;

   Browse the website; Do everything I can do on my computer and phone;

   Probably reply Email if I need to;

   Chat with friends.

Young driver 5

1. Yes, I went to school for lunch;

   By bus, 5 mins on the road;

   I read news;wear headphone for music;

2. Same as I went to school;
3. Go sport last week; I drove there; I only used GPS when I drove; I tried avoid using phone; I wanted to text someone,but I should not to do so; I only read notice;
4. Go home; 2 hours on the road; I drove; I connected my phone to the car to use the speaker for podcast;
5. Very casual; I think car is convenient;

   7 years; one hand on the rim; L11 or L12, hardly L7;

   There is only a stereo;

   I need to connect phone to car for GPS;

6. I think about podcast or what I am listening to and where is the next turn; it is easy to forget the road when I listen to podcast;
7. Read news; listen to the radio; watch my phone; do some reading.

Adult driver 1

1. Yes; by bus, checked the phone, checked the bus information, and the departure situation. Listened to the radio with headphones. Often watch the news (UC, Baidu) and deal with work (WeChat);

2. By bus, there were many people on the bus, so I didn't look at my mobile phone, so I listened more. But I prefer to watch dramas, read information, refresh the screen, and deal with work;

3. Took a taxi to a party at a friend's house without using a cell phone. Paid by mobile phone. Because it was purposeful and not boring, I didn't look at my phone. Looking at the phone is usually because of boredom;

4. On the way to a business trip to a meeting, 6-7 hours by train. Mobile phone - see less, listen more. The main thing to watch is to swipe the screen. Listen to music, radio, and the Himalayas;

5. Go to work; travel;

   7 years; both hands on the rim; L9 R3;

   Every time I listen to the radio, and watch the reversing video. The screen also has the function of playing cd and navigating;

   Want to use the mobile phone to navigate and answer the phone on the road;

   Cell phones are generally not used. When the phone is on the stand, it will make calls and navigate. I won't use otherwise;

6. Driving will want to work things, relationships;

7. Navigation, video calls, phone calls, news, watching dramas, reading books, work: receiving files, editing files, video conferencing, taking pictures (inside and outside the car) image retention.

Adult driver 2

1. I do not drive to work;

5. Drive to shop, do business, drive to meeting;

   It takes about half an hour to drive to meet investors and want to talk about points in a meeting, but it takes a short time to think about it;

   Meeting minutes will be sent after the meeting;

   1 year; L10 R2;

   17-inch screen, display speed and speed limit, real-time monitoring of road conditions, navigation mainly; If necessary, sometimes let the mobile phone read text messages, but cannot reply with voice; Listen to books most of the time, and use your phone to handle in-app actions, such as skipping a section; the phone will be placed next to the gear;

7. I swipe my phone to send emails back and forth, but the screen is too small to be at

at least the size of an ipad. It takes half an hour to process emails every day. It’s best if I can finish it in the car; Watch streaming, station B, YouTube videos.

Adult driver 3

1. Yes, I walked to work, used phone once, check the time;
2. Walked back;
3. Walking for shopping, but do online shopping most of the time, searching on Google, Bilis, Amazon;
4. To travel, I hired car;
5. I usually only drive on holidays;

   6 years; L10 R2;

   Navigation, which will be set before driving, rarely look at the screen while driving, mainly listen;

   Basically do not use mobile phones, mainly pay attention to road conditions, think about the way, want to navigate, read road signs and traffic signals, etc.;
6. Mainly thinking about the road, and navigation, and thinking about driving tasks;

   Don't want to work, don't want to work while on the move;
7. I will relax, listen to music, broadcast, watch movies, and read books.

Adult driver 4

1. Yesterday I took my car, drove to work, a lot of cues, 1hour 20mins;

   Yes, use it as a GPS, a new place. Since I Do not trust the GPS of iphone”maps”, i use google maps instead. They are connected through bluetooth. I only have the screen on the phone, but i have the sound through the car;
2. I did text, I do look stuff up while i’m driving. I know it's super bad…

   from time to time i do that;

   I do messages; I try to text while as few cars around me as possible. I always like just type phrases, just one word at a time,so I can always look up and try to have as good situational awareness as possible;

   Go surfing, search for something really fast, some kind of information that I need to get really quickly;

3. I went shopping really much for a month. I drove. I don't remember using my cell phone.

   I prefer to think about preorders, eg: ikea. we order what we want, so i just go and pick it out/up;

   I do smaller shopping, eg: coop, have a list in my head. remember the shopping list;

4. I drove during summer vacation. with a couple of other friends, and they took their cars. when we drive, we need to communicate if you need to have a stop, then you make phone calls through each other. perhaps you also look out for certain areas in your phone where you want to visit;

5. Taking myself from point a to point b, as simply as possible; I live outside of Gothenburg, on the countryside, the car is used to take the family to certain places;

   Driving is often used for family trips, and sometimes to work, when time is tight. If I have enough time, I will take public transport, trains and buses;

   9 years; I use one hand; L12;

   There is no screen;

6. No answer;

7. Look up stuff with my phone more frequently, longer time than now; use safari internet; email; linkedin; messenger.

Adult driver 5

1. Yes, by bus train and walk;

   I used Duolingo, and listen audio book on bus; Prepare presentation and read ebooks on train;

2. Same as this morning;

3. Go by bus and tram; I watched Youtube, talked with friends

   when I feel tired , I look out the window;

4. Took plane to spain; I read, listened to audio books but mainly sleep;

5. Spain's public transport is not good, I need to borrow a car to travel;

   10 years; L10 R2 when tense, L8 when relaxed;

I don't look at my phone, I might listen to a piece of music, If I have a short time to look at my phone, I will take notes, watch Ins, read news；

6. Think about the driving task;
7. Almost like being on a bus. Listen to books, read books, watch videos, listen to broadcasts.

Adult driver 6

1. Yes I walked;

   I used my mobile phone to listen to spotify, watched news related to my country, but the old battery of my mobile phone has a power problem, so I need to less use it;

2. Same as go to work;
3. I recently did not have short travel;
4. I went back to Spain for Christmas by plane; the same use of mobile phones;
5. Going to the store, rushing to meet people, visiting, going out of town;

   Go to IKEA and drive when you have to carry heavy things;

   Got driver's license in 2003 so 19 years, both hands on the rim, L9 R3, sometimes I put my left elbow on window sills;

   There's a black and white screen surrounded by buttons;

   I will try not to look at the mobile phone, you need to connect the mobile phone to the car with a cable, the mobile phone is used to listen to songs (because there is no music in the car) and cut songs (you can press the physical button that comes with the car to cut songs, and the mobile phone is placed in the car; If you have your own music in the car, you will not use your mobile phone. If you have to make a call in an emergency, you will pull over to the side and then pick up the phone. The built-in voice function in the car is very bad and not easy to use; I like to focus on safe driving, dislike distractions; and I think physical buttons are best, touch screen buttons are dangerous;

6. I will think a lot, the actual situation depends;
7. Sleep, either drive or sleep; I do not trust the autopilot system;

   If at ease, watch Netflix, on the center screen, watch your phone, and chat with friends.

Appendix D: User requirements statistics

This appendix is the daily use requiremnets of mobile phones mentioned by respondents in User study 1, and also the requirements of using mobile phones during driving, the secondary tasks expected by users, and the driving habits of the respondents. The number before each requirement in the requirement list represents the number of times the requirement is mentioned in all interviews, and the content in parentheses indicates which applications are specifically included in the specific requirement.

<u>Young drivers</u>

Habits of using mobile on the way to work

1 Apps for tracking bus route
2 Music with headphones（pop）
1 Listen to the novel
2 Watch the news
3 Navigation
1 Play song
1 Send message
1 chat with
1 Check emails, reply emails
1 Reduce phone screen brightness
1 Games

Habits of using mobile, not for work

3 Play music
1 Facebook
2 Youtube
3 Navigation
3 Chat with the person in the car
1 Ins
2 Read novel
2 Play game
1 Radio
1 Listen to the book
1 Check time
3 Message
1 Podcast

Purpose of drving

Transport things, going to distant places, shopping, things that don't make it to public transportation. Just go out and drive

Driving patterns

3 years L8 R12
3 years L10 R2；or hands off
7 years L10 - short distance, L7 - long distance
9 years L11、L12、L7
1 years L9 R3

Requirements of using mobile while driving

Listening to music
Radio
Navigation
Calling or texting
GPS
Broadcast

Secondary tasks of Autonomous car

1 Ins，facebook
3 youtube
1 Series
2 Write email (Gmail)
2 Text（Chat（Message），messager，whatsup，groupme，Chat（googleThe chat software that comes with the mailbox has recently added an app. It turned out to be only in the software.））
1 zoom meeting
3 Games
1 Stock
2 Browser
1 Reading
1 Audio book
1 News
2 Podcast
1 Music
1 Landscape

<u>Adults</u>

Habits of using mobile on the way to work

1 Check time
5 GPS Google map
1 Connect

1 Duolingo
3 Audio book
1 Prepare presentation
1 Ebooks
4 Music
3 Reading news
2 Podcast
3 Message

Habits of using mobile, not for work

Navigation
Podcast
Music
Read news
Phone call
Youtube
Landscape
Read book
Llisten to audio book
Sleep

Purpose of drving

Work, drive to vacation, family trip, urgent time to work, drive out, go to the grocery store, meet people in a hurry, go out of town, carry stuff ikea carry stuff

Driving patterns

1 year L10 R2
6 years L10 R2
19 years L12
10 years   Tense L10 R2   Relax L8
19 years L9 R3
7 years L9 R3
16 years   L10 R2

Requirements of using mobile while driving

Listen to the book (skip a section, skip a chapter)
SMS (read, voice reply)
Navigation
Listen to music
Take notes
Ins

News
Cut song
Answer the phone

Secondary tasks of Autonomous car

1 Sleep
2 Netflix (a platform for watching TV series)
2 Chat with message (messenger)
1 Listening book
3 Reading
2 Watch video (youtube)
3 Podcast
2 Navigation
1 Safari
2 Mail (return to mail, but the screen is too small to use)
1 Linkedin
1 Relax
2 Music
1 Movie
1 Video call
1 Video conferencing
2 News
1 Phone call
1 Receive/edit file
1 Take photo
1 Look at the scenery
1 Instagram

Appendix E: Precess of User study 2

This section documents the flow of the User Research 2 online experiment, including scenarios built with Miro and our questions.

1. Start Here

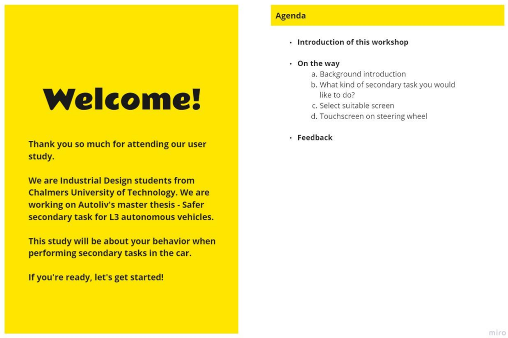

Figure 1: Introduction of the study

Facilitator: Thank you so much for attending our user study. We are Industrial Design students from Chalmers University of Technology. We are working on Autoliv's master thesis - Safer secondary task for L3 autonomous vehicles. This study will be about your behavior when performing secondary tasks in the car. If you're ready, let's get started!

2. On the way

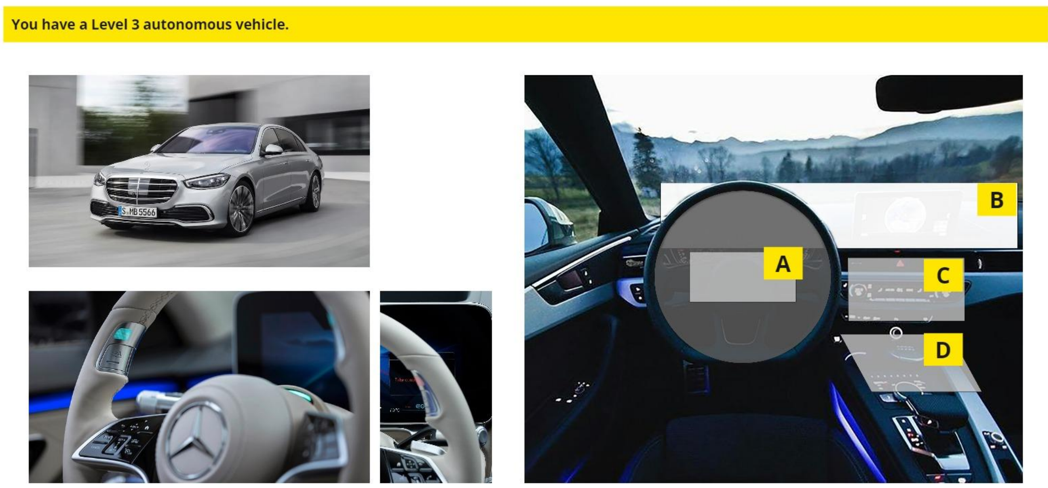

Figure 2: Introduction of the L3 autonomous vehicle

Facilitator: You have a Level 3 autonomous vihicle. Under certain conditions, the vehicle can take over dynamic driving tasks. Which means you can leisurely take your hands off the steering wheel then no longer pays attention to the road, but instead concentrates on other tasks. In this car, the DRIVE PILOT will take over the driving tasks. The DRIVE PILOT can be activated via two buttons in the steering wheel rim. If the DRIVE PILOT is available, they will turn white. If the DRIVE PILOT is activated, they will turn turquoise. If the buttons turn red, the vehicle requests you to retake control within ten seconds.

Facilitator: For secondary tasks, this car have some possible places to display information. First, there is a small screen on the steering wheel. The size of screen is roughly what the picture shows, but it could be any shape, and it could be anywhere on the steering wheel, not just what the picture shows. Besides, there are some other possible positions to place human machine interface.

Figure 3: Driving scenarios

Facilitator: Now please imaging you are driving this car to work. These pictures are designed to help you imagine the scenario. When you are on your way to work, you don't need to control the car. You can focus on whatever you want to do. This car has every function you could think of as an electronic device. So, under this scenario, could you tell me what secondary task you would like to do?

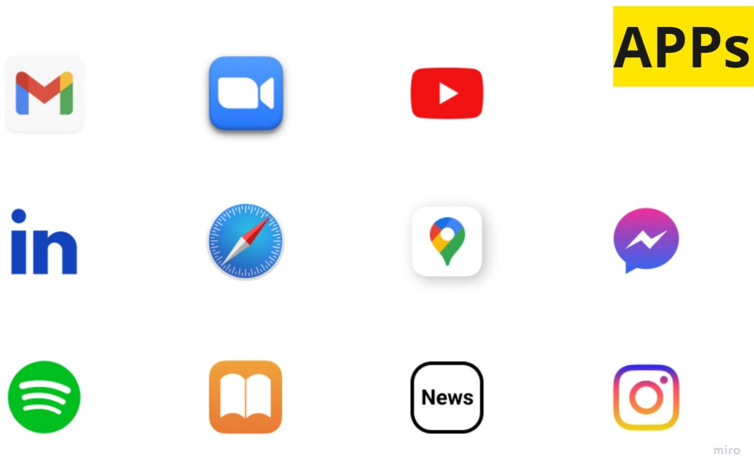

Figure 4: Possible secondary tasks

Facilitator: Here I prepared some interfaces of these APPs. Please drag their components one by one to the appropriate positions that you feel comfortable using or comfortable viewing. Let me give you an example. If I would like to read and write email during this time, I would like to read emails through screen B, because it is big enough and it is a great and suitable position to display thing. And I hope I have a keyboard on screen A, because using this position is more like i'm using my laptop. but I hope the email I write will be shown on screen B.

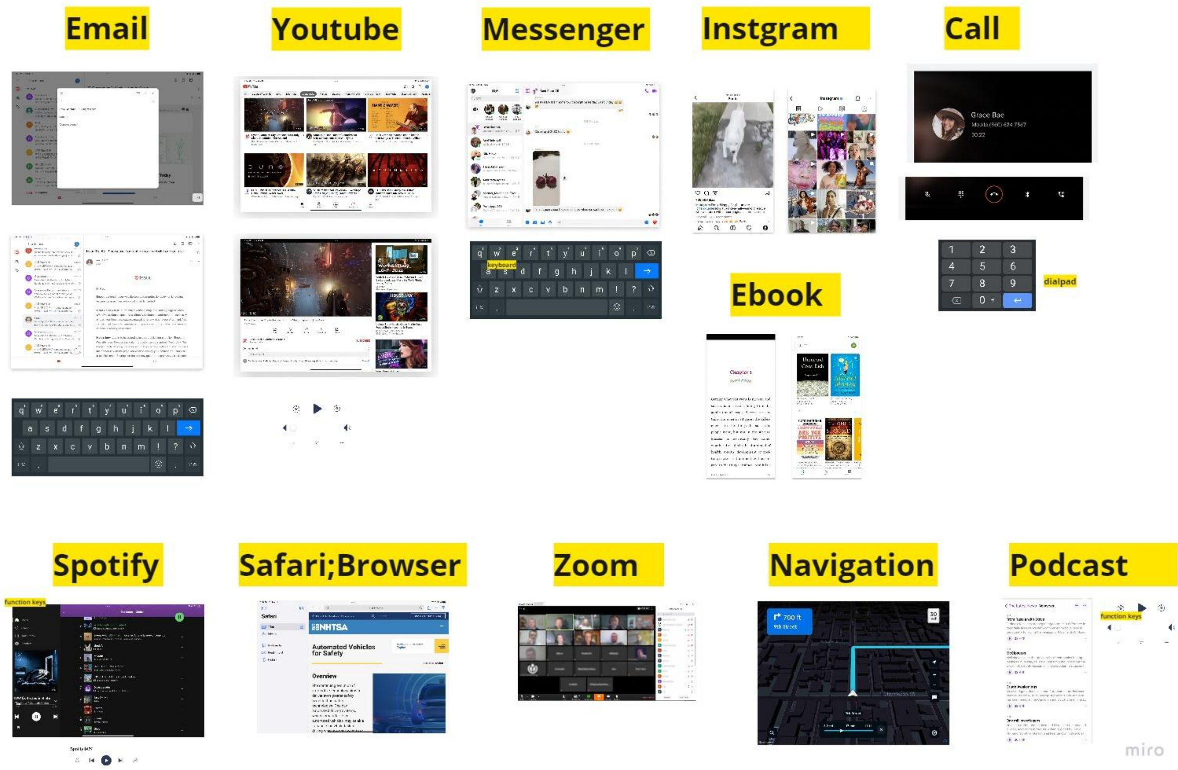

Figure 5: Important interfaces of possible secondary tasks

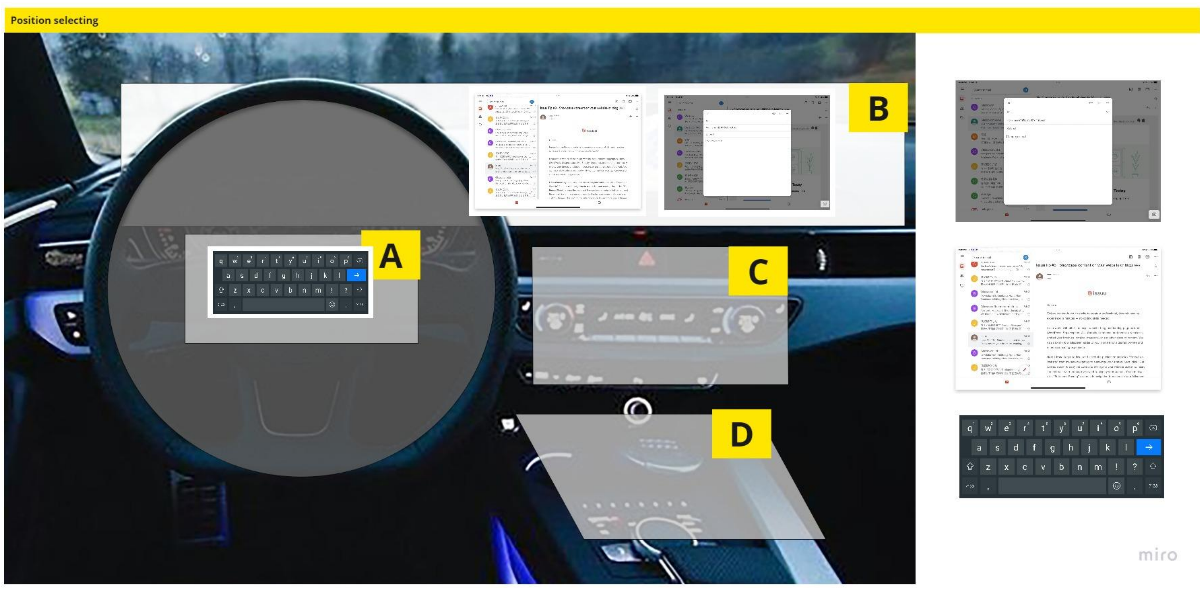

Figure 6: An example of how to use the given canvas

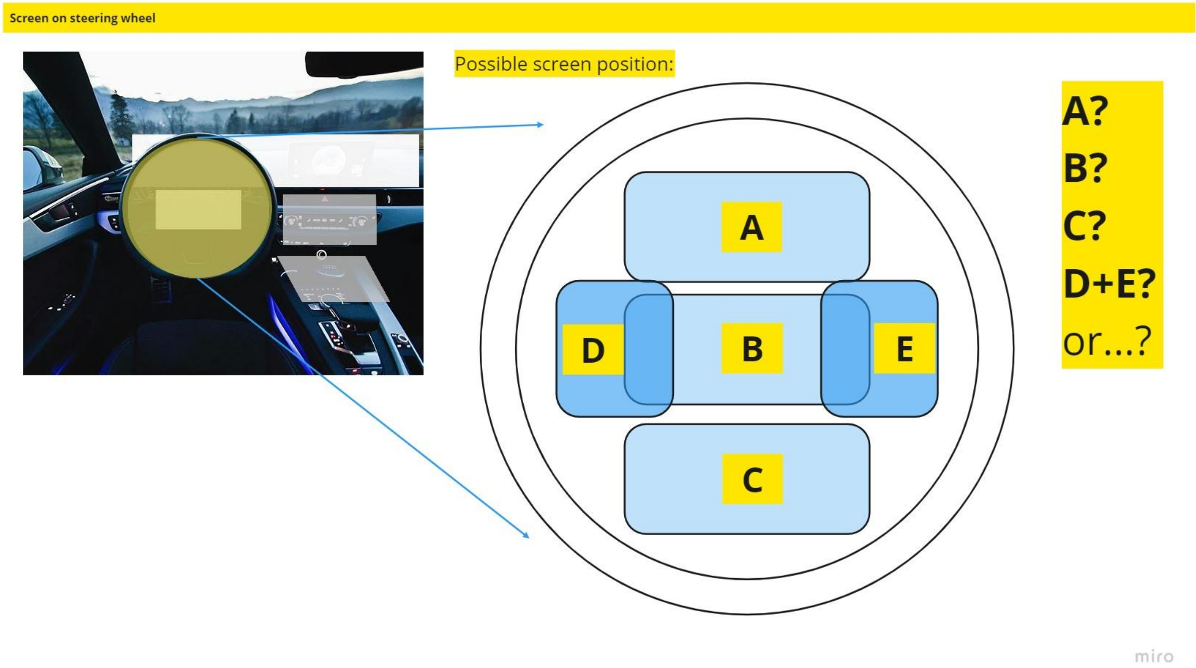

Figure 7: Multiple possible locations of the screen on the steering wheel

Facilitator: After that, I would like to invite you to select your favourite position of the screen on the steering wheel. The figure only shows the position of the screen. It dose not means that the screen will be this size or this shape.

3. Feedback

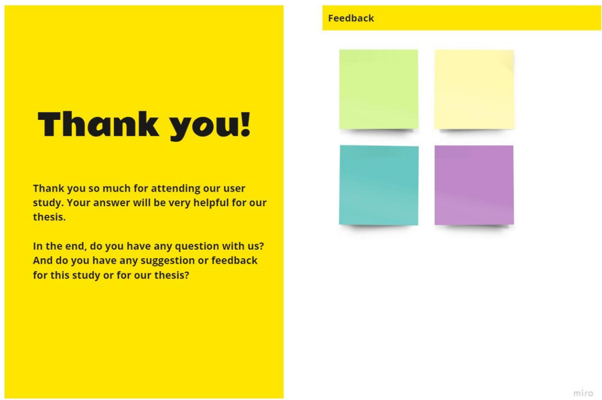

Figure 8: Places for participants to give feedback and suggestions

Facilitator: Thank you so much for attending our user study. Your answer will be very helpful for our thesis. In the end, do you have any question with us? And do you have any suggestion or feedback for this study or for our thesis?Thank you for your participation, let's finish the study. Thank you so much!

Apendix F: Results of User study 2

Participant 1

Spotify
Music list: C
Music cover: A
Function keys: A

Messenger
Friend list: B,C
Chat: B
Keyboard: A

Youtube
Play: B
List: C

Position of steering wheel screen: top area of steering wheel center

Participant 2

Spotify
Music list: C, D
Music cover: C I dont need to see it
Function keys: D

Safari
Website: A

Email
Email list: B, D
Write: B
Keyboard: A

Position of steering wheel screen: steering wheel center

Participant 3

Spotify
Music list: C, A
Music cover: C
Function keys: A

Messenger
Friend list: A,C
Chat: B
Keyboard: A

Youtube
Play: B
List: C

Position of steering wheel screen: steering wheel center

Participant 4

Spotify
Music list: A
Music cover: C
Function keys: A

Email
Email list: B, D
Write: B
Keyboard: A

Youtube
Play: B
List: A

Position of steering wheel screen: top area of steering wheel center

Participant 5

Messenger
Friend list: B
Chat:B
Keyboard: A

Email
Email list: B
Write: B
Keyboard: A

Youtube
Play: B
List: B

Position of steering wheel screen: top area of steering wheel center

Participant 6

Ebook
Content: A,B
List：B

Zoom
Screen: B
Participant: B
Function keys: A

Podcast
Play: A
List: B

Position of steering wheel screen: top area of steering wheel center

Apendix G: User test questions

For concept II:
(Introduce how to use concept II)

- For how to use concept II, do you have any questions？

(Introduce user interfaces of Gmail)

- Have you ever used Gmail before？
- In concept II, do you know how and when you can open Gmail?
- Do you know how to compose and reply email?
- Please tell the meaning of the icons in navigation rail? If you do not konw some of them, according to your understanding of the concept II, how do you think you should take a quick look to understand what this icon represents？
- Are these functions available in Gmail enough for your daily use? Are there other functions that need to be added?

(Introduce user interfaces of Youtube)

- Have you ever used Youtube before？
- How can you open Youtube？
- How can you go back to Youtube landing page from full-screen play page？
- Do you know how to close the small window?
- Do you have questions about the logic of Youtube user interfaces？

(introduce center screeen landing page)

- Do you know how to quickly answer a call？
- Do you how to check all the notifications？
- Do you have questions towards concept II？

For concept I:
(Introduce how to use concept I)

- For how to use concept I, do you have any questions？

(Introduce user interfaces of Gmail)

- Do you know where you are now? What is the meaning of the bule frame?
- In concept I, do you know how and when you can open Gmail?
- Do you know how to compose and reply email?
- Please tell the meaning of the icons in user interfaces? If you do not konw some of them, according to your understanding of the concept II, how do you think you should take a quick look to understand what this icon represents？

(Introduce user interfaces of Youtube)

- How can you open Youtube？
- Do you know how to play this vedio?
- How can you go back to Youtube landing page from full-screen play page？
- Do you have questions about the logic of Youtube user interfaces？
- Do you know how to open noticication center from this page?

(Introduce notification center)

- Do you know how to quickly answer a call？
- Do you know where you can find the notification center?
- Do you have questions towards concept I？

Conclusion：

- Which concept do you prefer to use in terms of usability? Why?
- What are your thoughts and suggestions for this user test?

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