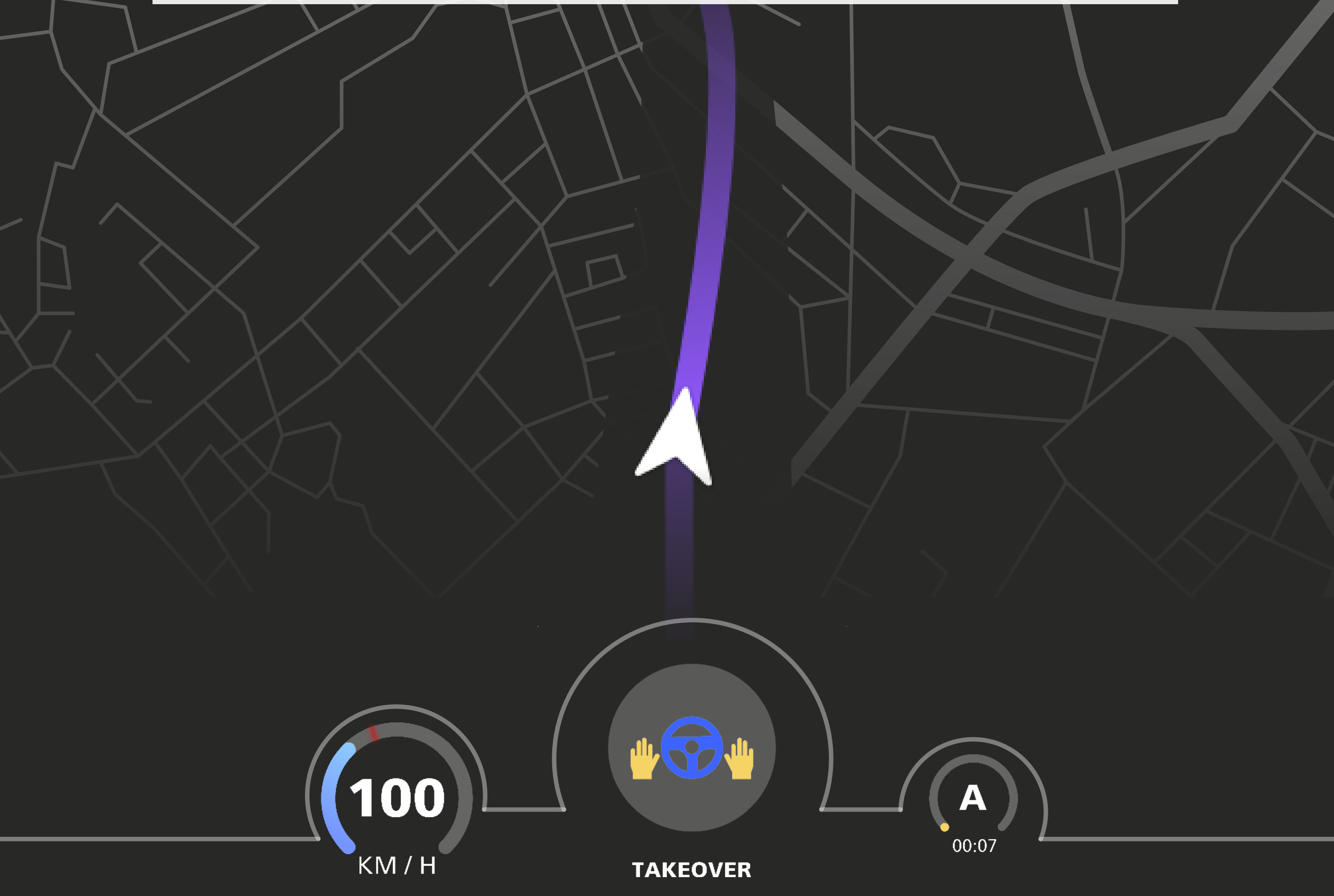
Driver-centered Human-machine interface design

for a better takeover experience in level 4 automated driving



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EXECUTIVE SUMMARY

STARTING POINT

At the beginning of the project, a brief research question was proposed: “when is it needed to communicate what kind of information and how to communicate the information with the drivers during takeover?”

RESEARCH ACTIVITIES

In order to answer the question, literature study was executed to help the researcher gain overall insights on four topics: autonomous driving, HMI design, situational awareness during AD and takeover transition. After gaining these knowledge, the researcher interviewed several automated driving specialists to effectively prioritize the previous insights, understand the current trend of the domain and collect pain points from specialists’ point of view. However, with knowledge from literature and specialists’ opinions, the user’s input is missing. Therefore, a user research was conducted with Tesla autopilot users to collect usability issues they’ve experienced while using the level 2/2.5 automation system. A journey map was concluded to summarize the main takeaways from the research activities.

DESIGN GOAL

Based on insights from above research activities, the design goal was proposed. There are three key points in the design goal: better understanding, effective communication and more support leading to a better takeover performance.

RESEARCH THROUGH DESIGN

Various creative design directions were proposed in the creative session. User-centred design approach that was well-adapted throughout the process supports the whole design process and leads to the development of the final design. The design process is called research through design or iterative design process. During the design iteration, the first user test was executed offline with physical embodiments(car, light strips, screen etc). The takeover journey in the first user test consisted of three main parts: (participants) play angry bird(ST), wakeup call and takeover request. From that test, it is validated that the wakeup call can effectively wake up participants but hardly to keep them remain attentive. In addition, participants were neither aware that they needed to get prepared nor knew the priority of things to prepare. Therefore a step by step guidance was added to the redesign, aiming to support drivers get prepared and get fit for takeover. Later, an online test was executed, focusing on the step by step guidance. In this way, the HMI design was iterated according to the various insights from user tests.

EVALUATION

In the end, a final evaluation was conducted online with several specialists and potential users. The main aim is to see whether the final design meets the design goal and how participants SA changes throughout the takeover journey. Not all design features were able to be validated. For example, the upgraded wakeup call with seat vibration needs to be further tested. It is validated in the final evaluation that the information on HUD enhances the transparency of the automation. Furthermore, the HMI effectively woke up participants, guided them to get prepared.. Moreover, driver's situational awareness is successfully evoked by wakeup call, maintained and enhanced with step by step guidance. At the moment of takeover, with the support of HMI, the driver becomes fit to takeover. This project was aiming to be an experimental and inspirational project for Mediator group. It indeed gave valuable insights on how user/driver-centered design approaches could be deployed in this project and beyond the plan, on how we might be able to adapt the future experiments to online ones.

ABBREVIATIONS

AD
Autonomous driving / Automated driving

AV
Autonomous vehicle / Automated vehicle

TOR
Takeover request

SA
Situational awareness

ST
Secondary task

DT
Driving task

ODD
Operational design domain

HUD
Head up display

AP
Autopilot

DG
Design goal

SUS
System usability scale

INTRODUCTION

This chapter introduces the initial project brief. It is a part of the Mediator project. Figure 1 shows the overview of the project.

Technological advances have led to the development of autonomous driving. The SAE (Society of Automotive Engineers) defined five automation levels in order to differentiate the responsibilities between the driver and an automated driving system, ranging from "No Automation" (L0), to "Conditional Automation" (L3) and "Full Automation" (L5). The transition to full automation, however, brings new risks, such as mode confusion, overreliance, ***reduced situational awareness*** and misuse. Therefore, led by SWOV and together with many other parties, a 4-year project MEDIATOR is launched. The goal is to create a self-learning mediating system which guarantees safe, real-time transition of control between human driver and automated system depending on who is better fit for drive (Mediator, 2019).

When the automation system reaches its

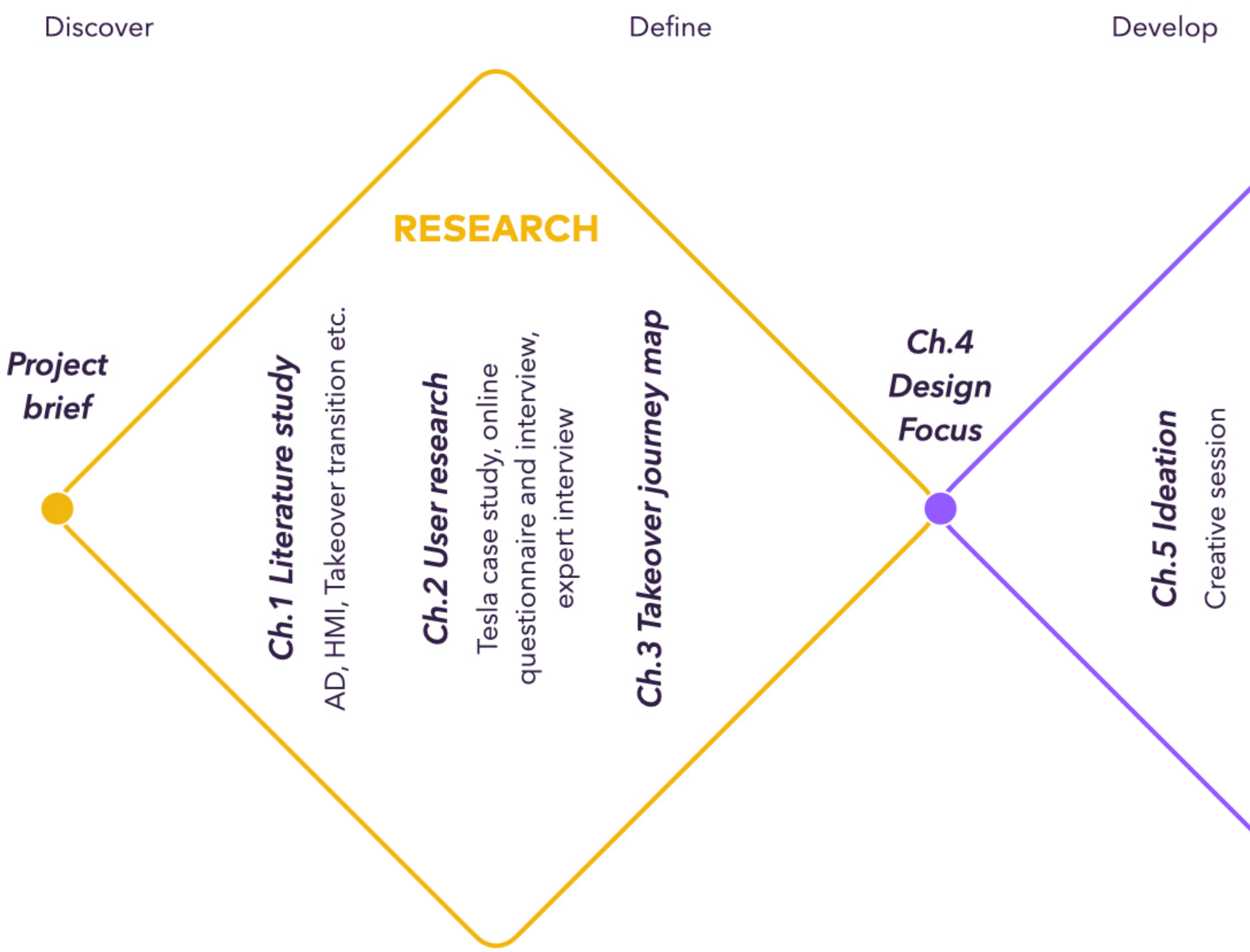
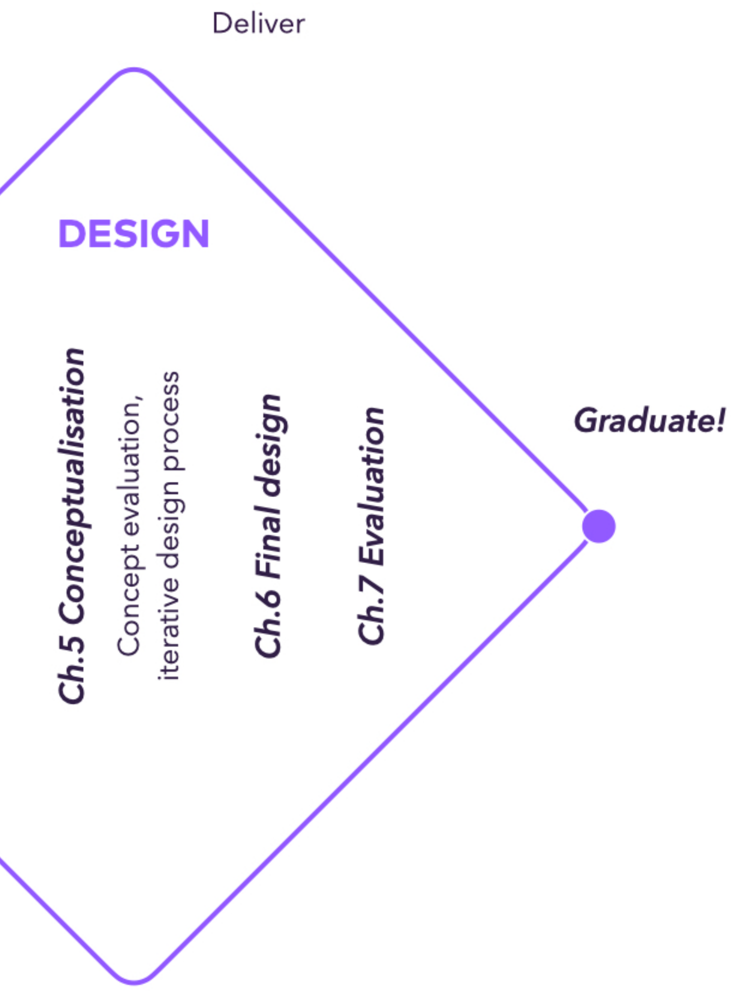


Figure 1. Overview of the project (Design council, 2005)

operational limit in a given traffic situation, the automation issues a so-called take-over request (TOR), asking the driver to take back control of the vehicle (Gasser & Westhoff, 2012; Hoeger et al., 2011). The Human Machine Interface (HMI) plays a critical role on passing signal from the automated vehicle to driver when TOR happens. Therefore, it is of vital importance in avoiding misunderstandings, misuse, over-reliance, reduced situational awareness and mode confusion. However, nowadays, there are various different HMI design for autonomous vehicles in the market. Develop an unified HMI design principle to regulate the autonomous vehicle industry is also one of the tasks of MEDIATOR project.



The graduation project is focusing on the HMI research and design when takeover happens (see Figure 1). The key research questions of the graduation project are ***"when is it needed to communicate what kind of information and how to communicate the information with the driver during takeover?"*** So exploring the scenarios of TOR and then define the similarities and differences are one of the tasks. Simultaneously, from a research of Bazilinskyy and colleagues (2018), the means to communicate take-over requests are divided into three main categories that may be used in different level of urgency for take-over transition: visua l(written messages or signals shown on cluster, head unit or other in-vehicle displays), auditory (sonorous signals or voice messages), and vibrotactile (vibration of the steering wheel or seat). So it will be one of the challenges to explore which modalities to communicate TOR are the most effective means. In addition, driver's situational awareness (SA can be defined simply as "knowing what is going on around us") predicts the takeover performance. Drivers are better able to respond to hazards when they're aware of the driving context. Therefore, enhancing the SA is also another challenge for the design of the takeover journey.

In conclusion, the objective of the project is to ***design the HMI of autonomous vehicles in order to enhance situation awareness for a better take over transition/journey.***

TABLE OF CONTENTS

LITERATURE *STUDY*

This chapter draws a literature study on the background of autonomous driving and the context of HMI. From this starting point, study moves towards more sepcificly on takeover transition, how driver's situational awareness influences takeover performance and the current takeover transition flow as well as existing painpoints

Chapter overview

01

OVERVIEW

The figure below shows the overview of the literature study which lays the theoretical foundation for the project.

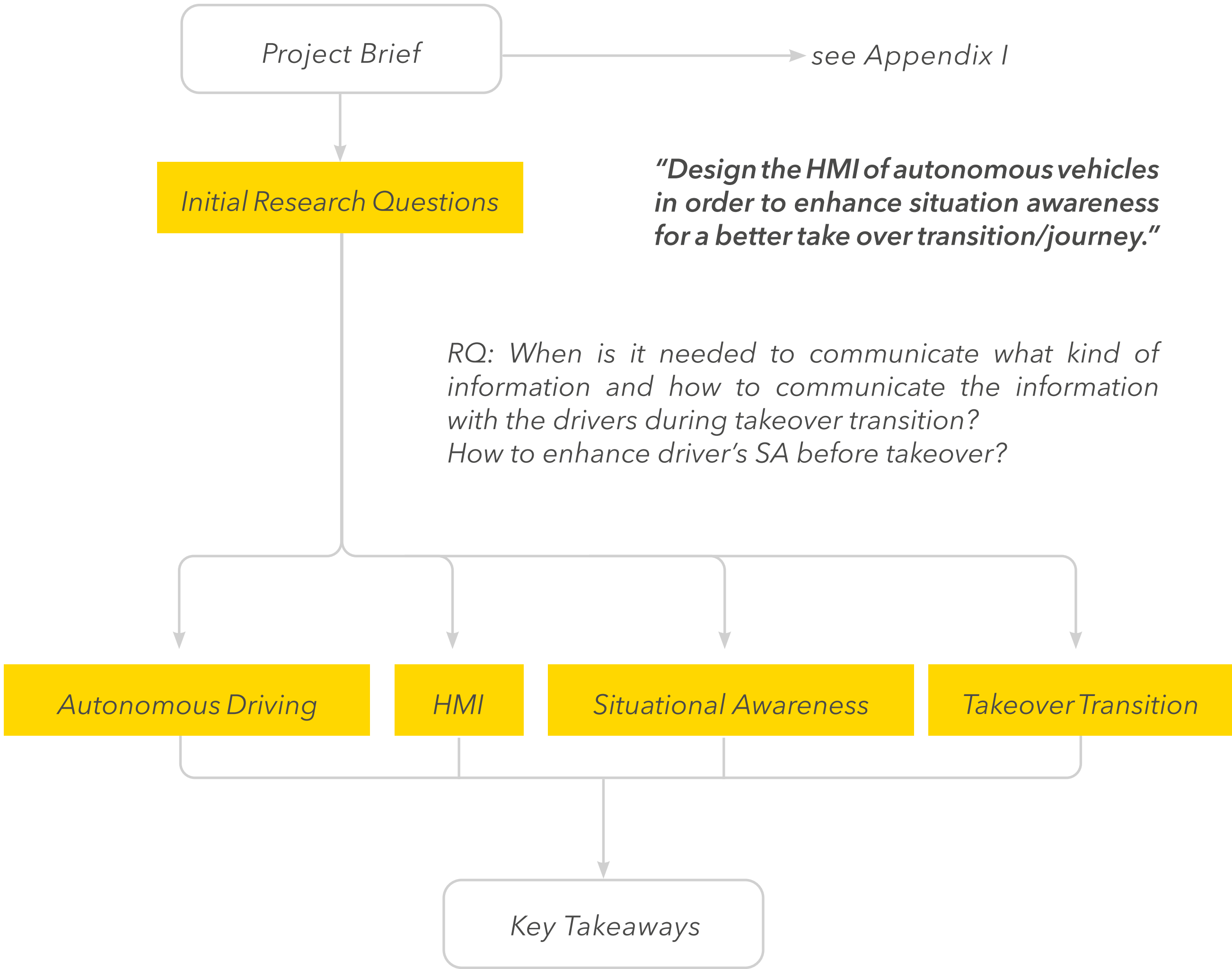


Figure 2. Overview of chapter 1

1.1 AUTONOMOUS DRIVING (AD)

1.1.1 THE FUTURE OF MOBILITY IS AUTONOMOUS

A wholesale shift towards autonomous and electric vehicles would not just reshape the entire transportation industry, but also everyone's daily life. GM's CEO Mary Barra refers to this future as "zero crashes, zero emissions, and zero fatalities."(Jacobs, 2018).

According to data from WHO, nearly 1.25 million people die in road crashes each year, on average 3,287 deaths a day. AVs will be able to avoid all crashes and eliminate traffic fatalities. Since AVs will be battery-powered, it would help to reduce air pollution caused by car emissions. Traffic congestion would no longer be a problem since the car will be connected to the internet. Connected cars can communicate with each other and will be highly flexible. In addition, currently, it is widely criticised that the usage rates of cars are extremely inefficient as cars are parked for the most of time each day. In the future, it is more likely that people will not own a car but AVs will come and take people around when needed.

All in all, AVs will bring us much benefits: less traffic crashes, healthier lives, more free time and make the most of human resources etc.

"The future mobility is zero crashes, zero emissions, and zero fatalities."

GM's CEO Mary Barra

On 2, July, 2019, together with 11 industry leaders across the automotive and automated diving, Daimler published the "Safety First for Automated Driving" white paper (Daimler, 2019) (see Appendix A).

1.1.2 THE SAE AUTOMATION LEVELS

The SAE (Society of Automotive Engineers) has defined five automation levels in order to differentiate the responsibilities between the driver and an automated driving system (Figure 3), ranging from "No Automation"(L0), to "Conditional Automation"(L3) and "Full Automation"(L5). The next technological evolution are Level 3 cars (SAE, 2018). For level 3 cars, drivers are allowed to perform secondary tasks. Meanwhile, drivers are still required to be prepared to takeover the control at any point. In addition, vehicles like the advanced google car(Waymo) etc are actually Level 4 cars. For the level 4 cars, the human "driver" no longer acts as a fall-back. In certain con-

SAE level	Name	Narrative Definition	Execution of Steering and Acceleration/ Deceleration	*Monitoring* of Driving Environment	Fallback Performance of *Dynamic Driving Task*	System Capability *(Driving Modes)*
***Human driver* monitors the driving environment**						
0	No Automation	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	Driver Assistance	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes
2	Partial Automation	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/ deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes
***Automated driving system* ("system") monitors the driving environment**						
3	Conditional Automation	the *driving mode*-specific performance by an *automated driving system* of all aspects of the dynamic driving task with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes
4	High Automation	the *driving mode*-specific performance by an automated driving system of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes
5	Full Automation	the full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**

Figure 3. The SAE automation levels

IN THE MARKET

BMW X5 Extended Traffic Jam Assistant

Level 2

Traffic jam assistant which explicitly allow hands-off and verify via driver monitoring; Remote-controlled parking function

Tesla Autopilot

Level 2

Navigate on autopilot(lane change, adaptive cruise control) and smart summon. It requires hands-on-wheel. and constant human supervision. (Level 2)

Volvo Intellisafe assist

Level 2

Pilot Assist, adaptive cruise control and distance alert.

Audi A8 Traffic Jam Pilot

Level 3

It is claimed as the first production SAE level 3 system. However, the lack of road regulations forced Audi to refrain from enabling it. However, at the end of 2019, Audi announced to skip level 3 and focus on level2 and level 4

UNDER DEVELOPMENT

Mercedes Benz Drive Pilot

Level 3

Mercedes benz claimed that in 2020, S-Class will be equipped with a Level 3 feature.

Google Waymo

Level 4

At level 4 autonomy with no one sitting behind the steering wheel, sharing roadways with other drivers and pedestrians.

Table 1. Current AVs in the market

Figure 4. What do drivers want to do while driving an automated vehicle? (Meixner et al., 2017)

trolled environments, the vehicle performs all driving tasks, e.g, airports or slow inner city zones. This differentiates them from Level 5 cars, which perform all driving tasks all under the control of the vehicle.

1.1.3 THE CURRENT STATE OF AV

We are now seeing SAE level 2 system being introduced by various automakers (Table 1). But when can we start to drive level 3 Avs? Actually Audi announced its level 3 vehicle that the 2018 Audi A8 offers a level 3 Traffic Jam Pilot. Although this feature is already in the market, due to the German road regulations, Audi is forced to not enable it yet.

1.1.4 PREFERRED ACTIVITIES WHILE AD

For higher automation level(level 3-5), drivers are allowed to perform non-driving related tasks when turn the automation on. But what would they do? According to a online survey, the most preferred activity is to ***use mobile devices*** (Figure 4). Besides, drivers would also like to eat lunch, read a book, watch a movie, as well as do some work etc. It's not hard to say that while drivers doing secondary tasks, ***their visual attentions are very likely to be off the road which is one of the major problems that we need to consider while designing for the autonomous driving experience.***

1.1.5 EMERGING PROBLEMS

Level 3, 4 are considered as transition steps towards full automation. However, as mentioned above, it is risky and not yet controllable that human drivers will be required to takeover the control whenever considered as necessary by the automation system. ***There are some different voices emerging that they think it might be better to directly jump to Level 4 from level 2.*** Moreover, there are other human element problems such as mode confusion, overreliance, reduced situational awareness and misuse. To solve these problems, it presents Human Machine Interaction (HMI) designers and researchers with new challenges.

1.2 HMI OF AUTOMATED VEHICLES

2.3.1 concludes the functions of each essential part of the current in-vehicle information system or we could say HMI. The term "HMI" here will be used in a broad sense to encompass the full range of explicit as well as implicit communication between human driver and the car.

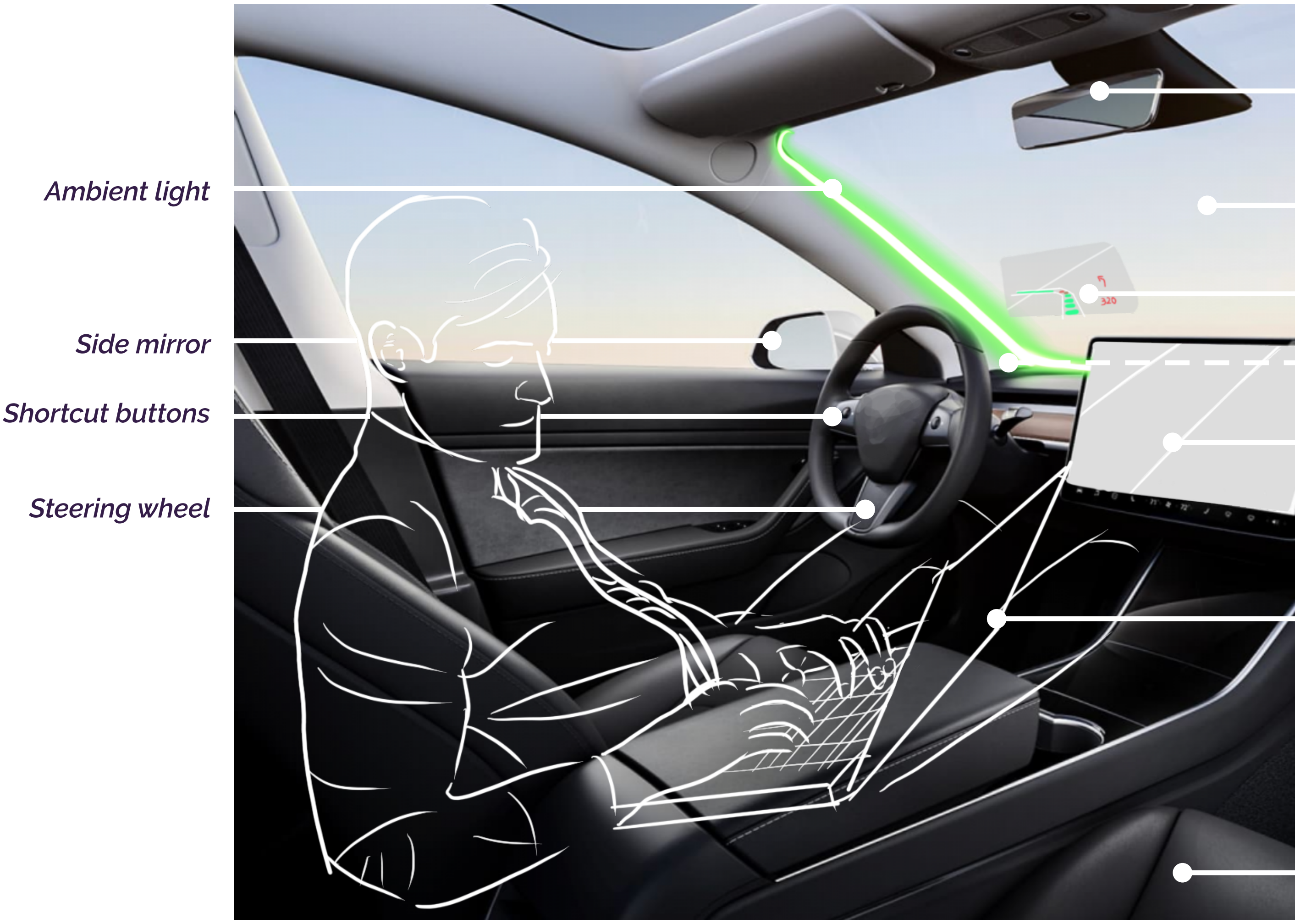


Figure 5. the context of HMI

1.2.1 CONTEXT OF THE HMI

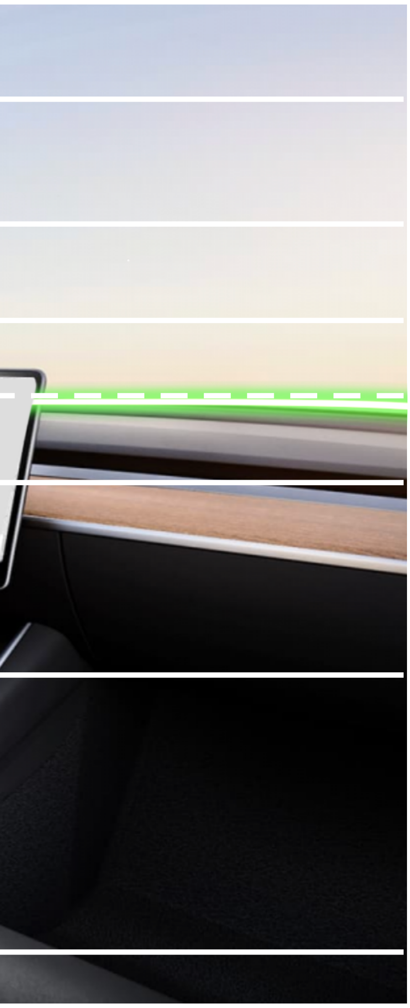
Dashboard (Instrument cluster)
It includes the speedometer, fuel gauge, tachometer, odometer, engine coolant temperature gauge, and turn indicators, gear-shift position indicator, mode indicator, some warning lights like seat belt warning light, parking-brake warning light, and engine-malfunction lights. Some automakers, like Tesla, abandoned a separate dashboard and integrate it into the central display.

Central display (centre console)
Media controls like audio, radio controls, the climate control, air condition system, possibly a display screen, a cigarette lighter and auxiliary power point.

Short-cut buttons
Voice activation, cruise control (increase/decrease cruise speed, resume/cancel cruise),

sound system control (adjusting volume or switching radio stations), lane and gap setting.

Seat
Height and angle adjust, occupant classification system (OCS), airbags, haptic feedback (vibrating seats), or heated and cooled seats.



Headup display
Navigation, road condition demonstration. 2.2.2 lists different modalities of user interfaces and in the end concludes the pros and cons of each modality.

1.2.2 DIFFERENT MODALITIES OF USER INTERFACES

Visual interface
Visual interfaces are mainly used to guide drivers' visual attention for a safe drive. Specifically, they can be used to provide collision warnings, lane change decision aids, visualizing road users and obstacles, displaying speeds, and directing and visualizing gazes (Ayoub, et al. 2019). In terms of visual interfaces, there are multiple types: the classic instrument cluster, dashboard, central display, ambient leds, new displays like AR and headup display etc. But compared to auditory, people makes more errors in the text- and grid-based visual search tasks.

Dashboard and centre console
Visual messages on the dashboard (instrument cluster) are the most used or classic way of visual feedbacks. Nowadays, some manufactures pay more attention to utilizing the central display (centre console) to show most of the visual messages in a unified way like Tesla. The way it tries to put all the information in one single giant screen, however, is controversial. The huge screen makes it easy to see multiple information sources at once. But this also leads to more time spending on the user interface. In a car, time spent with the UI means time spent ignoring the road.

Ambient leds
Light displays based on ambient LEDs are used to inform or warn drivers of road conditions by changing their patterns or colors (Ayoub, et al. 2019). Van Veen et al. showed that peripheral light increased drivers' situational awareness while performing non-driving related tasks (NDRTs).

HUD
HUD presents virtual information in the driver's natural line of sight, which can reduce the number and duration of the driver's glances off the road (Ayoub, et al. 2019). Therefore, HUDs have been increasingly used in order to keep drivers' views on the road while getting the necessary information to assist driving. HUDs are sometimes paired with AR, which helps to give

the driver a clear overview of the driving condition. For example, projecting the texting output using ***HUDs on the windshield was found to improve driving performance (Gabriela, et al. 2016) while HUDs were also found to increase visual complexity and clutter.***

Auditory interface

Auditory interfaces are widely used for communication and especillay warning to manage or attract driver's attention. There are two types of sound cues: critical level: ***warining sounds***; safety level: ***advisory sounds***, which directs drivers attention to potential hazard. Normally, in the vehicle, sound cues are used to convey messages like direction, movement, and urgency.

Haptic

Examples of haptic and gestural interfaces in the vehicle include warnings, assistance, and infotainment systems. Providing vibration either in the steering wheel or in the driver seat is concerned with increasing the driver's awareness and therefore help to prevent accidents. Moreover touch screens, one of haptic interfaces, are very commonly utilized in cars. Some classic dashboards and central displays are now replaced by the touch screens because they can lead to fewer physical controls or buttons and thus create a clean and organised in-vehicle design.In addition, touch screens are often very easy to learn and use even for beginners (Matthew, et al. 2016).

Multimodal Interfaces

Multi-modal interfaces refer to applying multiple modes of interaction between human driver and the car, combining auditory, visual and haptic modalities. Applying multi-modal has proved to be able to reduce driver distraction, mental workload, and reaction time (Ju-Hwan, et al. 2008). Multi-modal are widely used to warn drivers in different emergency-level situations and are more effective than uni-modal. However, depending how the combination of multi-modal, it can be more obtrusive as well.

MODALITY		NOTICING TIME	PROS	CONS
Visual	Visual messages	6.9s	• Able to convey complex messages	• Requires focal visual attention. Considering the time limitation in take-over situation, this can create a bottleneck in the time sharing of visual processing tasks, eg Ignoring the road while reading visual messages (Sadeghian, 2018)
	Ambient lights	6.9s	• Reduce mental workload and assist safe manoeuvres • Do not interfere in users' primary task • Non-obtrusive	• The messages conveyed are limited; • Users have different interpretation of the pattern or color of ambient light
	HUD/AR	6.9s	• Keep eyes on the road • Help understand the driving context	• Might increase the visual complexity and clutter • Mask things in the real world behind the HUD
Auditory	Speech	<3s	• Smart • Vocal assistance in automated vehicle handover assist can be used to guide visual search (Stanton, 2019)	• Due to the limited capacity in memory with the voice, when the speech output requires drivers to react upon the info, it may distract driver's attention and deteriorate driving performance (Kim & Ji, 2019)
	Single tone	<3s	• Requires less cognitive efforts • Prime users with the urgency of TOR • Recognised faster and are rated less annoying	• Can only convey limited information
Haptic		<3s	• For urgent take-over situations, vibration cues are preferred due to being more awakening and urgent (Stanton, 2019)	• For less urgent situations, it is a bit annoying
Multi-modal		<3s	• Result in shorter reaction time and better lateral control of the vehicle than only visual messages(Borojeni et al.,2016) • Mu ltimodal are widely used to warn drivers in emergency situations and are more effective	• More annoying than unimodal

Table 2. The pros and cons of different modalities

Figure 6: Large in vehicle display from Byton

1.2.3 BENCHMARK RESEARCH in the current market

Mechanical Buttons replaced by touch-screens

For years, touch screens, handwriting recognition, and gesture control have been gradually replacing conventional mechanical buttons and switches in the car. 82% of vehicles sold in 2019 came with touch screens, according to market data cited by Consumer Reports.

Large display extended over the entire dashboard, often combined with additional displays in the center stack or head up displays are one of the trends. The M-Byte (Figure 6) is certainly one of the representatives with a large front screen supplemented by separate smaller screens for each passenger.

Uncluttering the cockpit: Companies like Tesla (Figure 9), bosch run the entire HMI through a cockpit computer and will integrate more functionalities in a single central processor. This kind of integration will enable the convergence and synchronization of the infotainment system, the instrument cluster, and other displays.

"We are uncluttering the cockpit. The more complex the technology in modern vehicles, the simpler and more intuitive control systems need to be."

Dr. Steffen Berns, the president of Bosch Car Multimedia

Smart algorithm enables the car be capable of learning and updating real-time. For instance, if the roads are detected as slippery by car, drivers can immediately get a warning signal. In the future, over-the-air updates will ensure that HMI is up to date with the same simple process used for smartphones without changing any physical parts.

Multi modal interaction

Head-up displays

The hierarchy of information given to the driver is: central display is used occasionally, and dashboard is looked at often, leaving the information in the HUD very essential. In combination of AR, the windshield becomes a smart screen (Figure 7, 10).

Car displays with haptic feedback are going to catch on. The haptic display thus conveys the feeling that the user is adjusting the volume using a real slide control. With haptic feedback, driver can adjust buttons without having eyes off the road.

Figure 7. Headup display from HUDway

Figure 8. Mercedes MBUX with the best voice control

Figure 9.Tesla HMI

Voice control: Simply saying "Hey XX" or "XX" will activate a Siri-like assistant that can help drivers with almost everything, from turning on the seat heaters to finding nearby hotels. Some car brands are developing their own in-vehicle voice assistant while others choose to team up with digital companies like Google, Amazon etc.

Vehicle personalisation

Vehicle personalisation means the car or the smart system behind could remember personal settings of different drivers like the seat, mirror positions, climate settings etc.

External HMI

Recent years, the interaction among autonomous vehicles, pedestrians and other conventional cars are getting more and more attention. Designing the external HMI is therefore one of the trends. However, since the master thesis is mainly focus on the interaction between the vehicle and the driver, this part is not going to be further investigated.

1.2.4 CONCLUSION

In conclusion, the HMI is getting more and more intelligent with the development of technology. HUD, touchscreens, Smart algorithms etc are absolutely the furture automotive HMI design trends. While some manufactures in the market are uncluttering the cockpit, others are implementing more and larger interfaces in the vehicle not only for the driver but also for the passengers.
In terms of usability and user experience, there are still long way to make driving a safer and more comfortable activity.

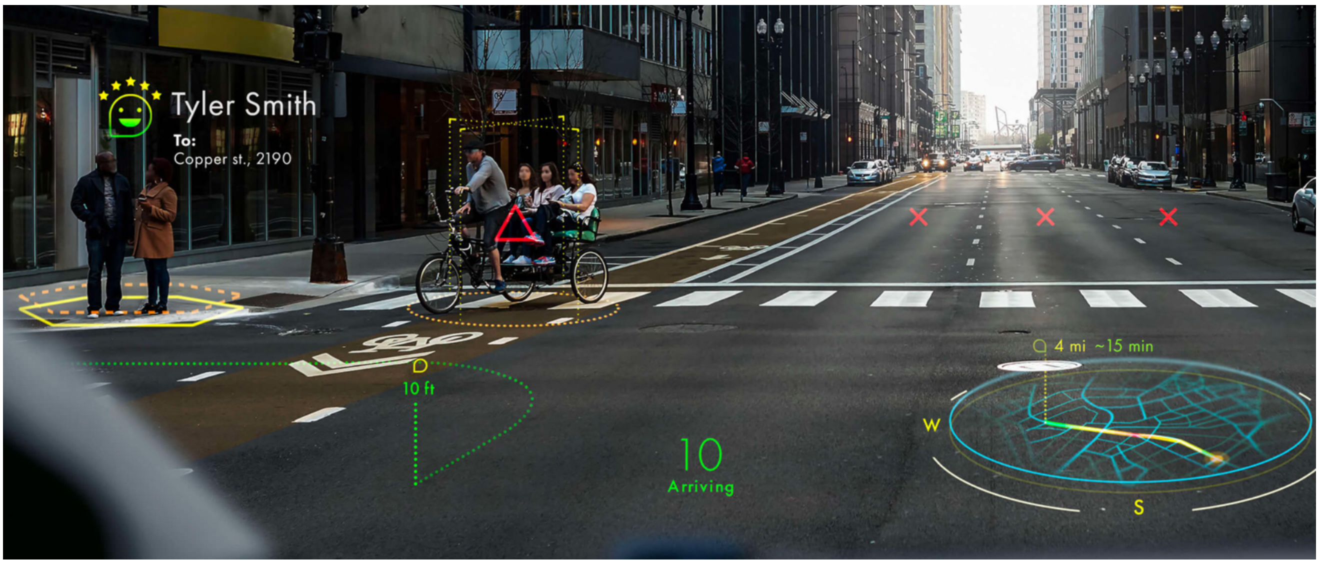


Figure 10. AR experience from Wayray

1.3 SITUATIONAL AWARENESS(SA)

Situational awareness can be defined simply as "knowing what is going on around us" or "being aware of what is happening around you and understanding what that information means to you now and in the future"(Endsley, 2011: 13). Or – more technically – as "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their future status".

Situation Awareness

Perception	**Comprehension**	**Projection**
of elements in current status	of current status	of future status

Figure 11. Endsley's model of SA.

1.3.1 SITUATIONAL AWARENESS IN AD

In the scenario of autonomous driving, the drivers' situational awareness then means: Firstly, drivers should be aware of their current status, current mode and actions of the car; Then, drivers need to be clear about their current tasks and understand the reasons behind the actions of the car; In the end, after understanding systems' actions, they could predict the future intentions of the automation system. SA is a critical factor in a driver's ability to make decisions to avoid hazards, plan routes and maintain safe travel (Sirkin et al., 2017)

Why is it important?

Distraction from the road is associated with reduced situation awareness(Dozza, 2012; Rogers, et al, 2011; Young, et al, 2012). So for level 3 and higher level of automation, within the operational design domain, the driver no longer has to monitor the driving state all the time and they are very likely to perform some non-driving related tasks. This leads to a lower situation awareness and thus very likely worse take-over performance. Moreover, Blomacher et al. indicate that an incorrect or insufficient description of the system also leads to a poor situation awareness.

Recently, researchers have suggested that SA might help to promote trust in automated driving by allowing the driver to better understand the environment and predict what future action (Miller et al., 2014). Building on this prior literature, some researchers assert that automation system which promotes SA could increase trust in automation and ultimately result in better transition performance. In addition, drivers are more prepared and better to react to hazards when they are more aware of the driving context.

1.3.2 PROBLEMS CAUSED BY LOW SA

Problem 1: Not prepared to sudden failures

If a system failure happens and the car is not able to respond, the human driver needs to perform a manoeuvre to avoid an obstacle. However, human driver with low SA is hardly aware of the obstacle and not able to perform actions accordingly, which possibly lead to a car crash.

Problem2: Longer takeover time

When the system requests the driver to takeover the control, low SA leads to a poor decision making and thus poor takeover performance (Endsley, 2011: 11). In the takeover situation, ***drivers firstly need to regain a certain level of SA and then are able to respond to the TOR safely.*** The lower driver's situational awareness during automated driving, the longer time it costs to reach this level, leading to safety risks.

Problem3: Poor user experience

When the driver is in a low SA, the actions made by the car can be surprises for them. The driver may feel surprised about the actions of the car and does not know the reason behind, for example, when the car performs manoeuvres. The reduced predictability causes distrust in the system, and ultimately results in poor user experience (Norman, 2009) and rejection of the technology (Lee and See, 2004). Therefore, many benefits of vehicle automation can be undermined.

1.3.3 HOW TO ENHANCE SITUATION AWARENESS

Many researchers are exploring different ways to enhance the SA during autonomous driving. Some researchers used ambient light as a stimulus to improve SA. Andreas etl. designed and implemented an ambient light display inside the vehicle (Figure 12) to communicate the automated vehicles' short term plans, or "intentions" to drivers and passengers. As you could see from figure 12, the ambient light display is used to inform drivers acceleration, brake and lane change. This helps drivers to keep informed and thus enhance the drivers' trust for the system.

Ronald etl proposed a proactive approach to increase situational awareness through gamified AR. They designed an app that induces SA by displaying world-fixed content and engaging drivers in visually scanning their surrounding driving environment. Gamification (Deterding et al., 2011) works quite well in attracting drivers' voluntary attention (Figure 13).

Some researchers concluded that spatial sound cues work ideally in less complex situations, such as on the highway. The

Figure 12. The implemented light pattern, embedded in out driving simulator. From left to right: accelerating, braking, changing lanes to the left. Research by Andreas etl.

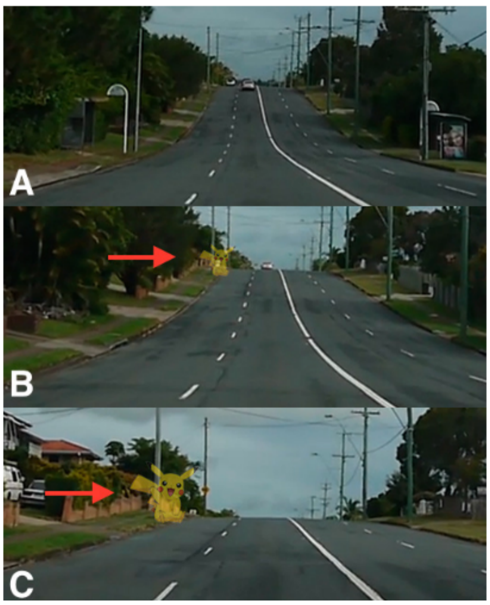


Figure 13. PokemonDrive

sound cues can be quickly perceived and associated with the traffic situation outside of the car. Thus, drivers' SA and performance can be enhanced with the help of sound cues. However, if the situation is complex, spatial sound cues are regarded to be confusing. In these situations, ***supporting sound cue with visual information to avoid confusion*** ought to be beneficial. In addition, it is beneficial to support drivers with both advisory/situational information sound cues and warning sounds. Lee et al investigated how users, working with another task, responded to collision warnings, ***showing that graded alerts led to a greater safety margin and a lower rate***

of inappropriate responses to nuisance warnings(Wang et al. 2017). In addition, they found that graded alerts were more trusted than single stage alerts. Therefore, when drivers switching between driving and non-driving tasks during autonomous driving, ***graded alerts(advisory cues and then warning cues) works better than directly jumping to warning cues***.

1.3.4 TECHNIQUES TO MEASURE SA

In a review of SA measurement techniques, Endsley (1995b) describes a number of different approaches, including physiological measurement techniques, performance measures (external task measures and embedded task measures), subjective rating techniques (self and observer rating), eye-tracking, questionnaires (post-trial and on-line) and the freeze technique (SAGAT). Those methods have different pros and cons. Some of them may require specific embodiment like eye-tracking. For the later tests of the master thesis, in terms of feasibility, Situational Awareness Global Assesment Technique(SAGAT) would be more suitable.

SAGAT

The freeze frame technique (Situation Awareness Global Assessment Technique, or SAGAT) involves halting a simulation in progress, and querying a person about activity in the environment, such as the position, type and future status of elements within the scene (Wang et al., 2017). SAGAT is one of the most well-tested SA measurement techniques. It was initially for the tests for flight interfaces but then later also used for the driving tasks.

It is a freeze on-line probe technique, designed for real-time, human-in-the-loop simulations and provides diagnostic information regarding how well the system in question supports the operator's various SA requirements. The simulation is frozen and subjects are queried as to their perception of the situation at that instant. SAGAT queries cover data criteria corresponding to the three levels of SA: perception, comprehension and projection.

1.3.5 CONCLUSION

SA, as presented in this chapter, is a critical factor in a driver's ability to respond to TOR, make decisions to avoid hazards, enable a safe takeover transition. SA, from my point of view is like an essential part of a car. With better car parts, the car performs better. Higher SA leads to a better takeover experience: fewer surprises about car's actions, more trust on the system as well as better prepared for takeover. Directing drivers' attention to the outside world during automated driving can possibly be one way to induce drivers' SA. Secondly, as mentioned before, a certain level of SA is needed to enable a safe takeover. Therefore, ***making sure drivers have enough time to regain SA to a certain level before takeover is quite essential to ensure a quick and safe transition.*** Last but not least, various exploration has been done by different researchers: Gamified elements are applied to attract drivers' voluntary attention during automated driving, ambient light display is used to keep drivers informed, graded alerts led to a greater safety margin and a lower rate of inappropriate responses to nuisance warnings.

1.4 TAKEOVER TRANSITION

1.4.1 THE TAKEOVER TRANSITION RITUAL

Definition of takeover transition

There are two types of transition in the autonomous driving context which are activation (the driver hands off control to the vehicle) and deactivation(the driver takes over control from the vehicle). Here we talk about the transition of deactivation: When the automation reaches its operational limit in a given traffic situation, the automation issues a so-called take-over request (TOR), asking the driver to take back control of the vehicle (Gasser & Westhoff, 2012; Hoeger et al., 2011). The Human Machine Interface (HMI) plays a critical role in passing signal from the automation system to drivers when TOR happens.

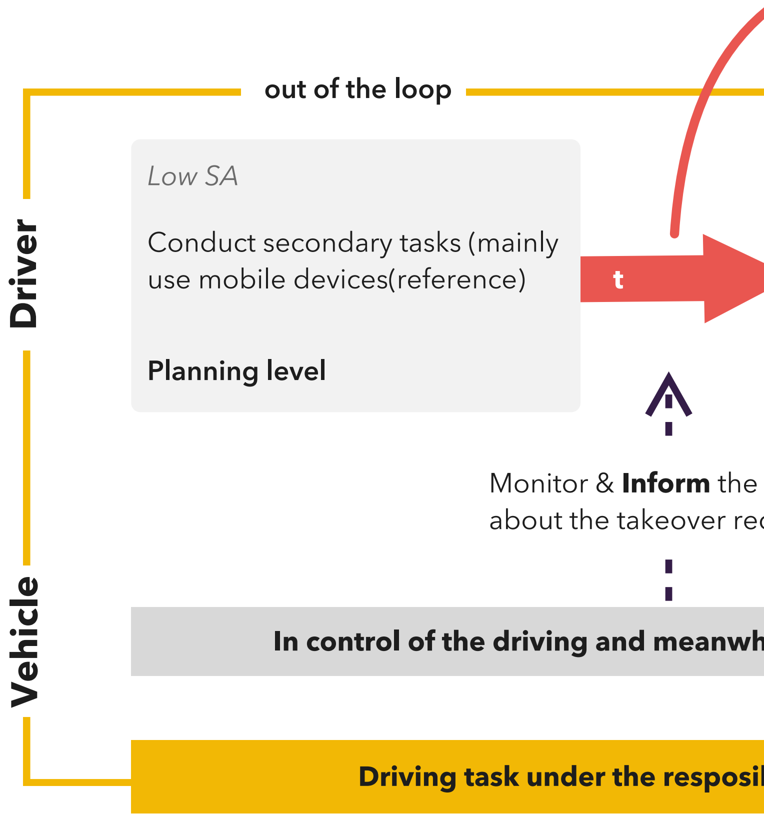


Figure 14. The takeover transition ritual adapted from Elme

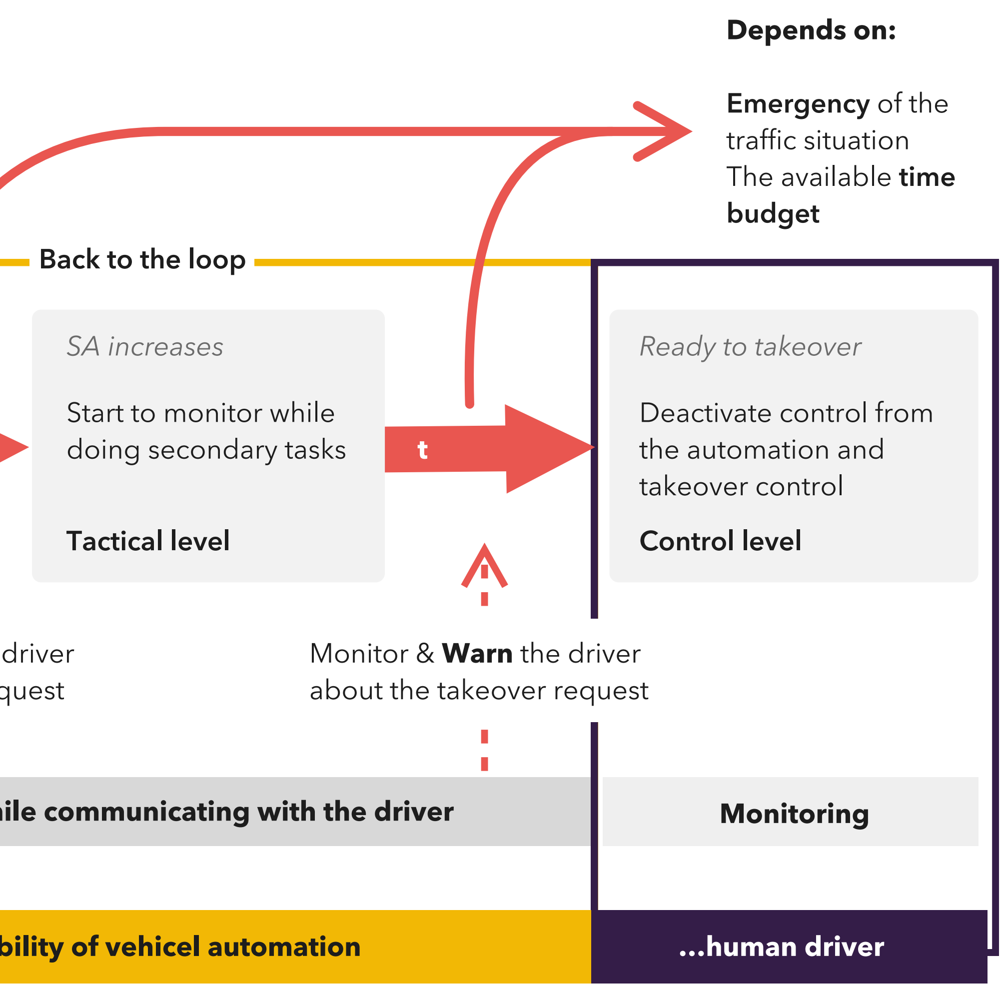
Takeover ritual

Figure 14 demonstrates a typical takeover ritual. First of all, while the driving task under the control of the vehicle, drivers usually perform some secondary tasks(STs) simultaneously. Research shows that people would mostly like to use mobile devices (Figure 4). The state of the driver at that time is called out of the loop. The situational awareness of the driver is quite low. The vehicle monitors the driver. When the automation reaches its operational limit in a given traffic situation (More details about the operational limit is explained in takeover scenarios), HMI informs the driver to prepare to resume control. The TOR helps to drag the driver back to the loop. Then another TOR warns the driver to takeover the control within given period of time (e.g. 7 seconds). After that, the driver deactivates the automation and starts to drive manually. This takeover transition ritual is adapted from Elmer's takeover ritual in combination with some online research. Later it will be validated and optimised with the experts during expert interview.

"Since high urgency scenarios (take over time shorter than 7 seconds) is very dangerous, researchers or manufacturers are trying to avoid the situations less than 7 seconds."

1.4.2 TAKEOVER TIME

One important aspect related to successful take-over is correct timing. Takeover time is defined as the interval from the moment of TOR till the moment the driver takes action to the TOR, for instance, touch the steering wheel or brake etc. Several studies suggest



er's

that at least five seconds is needed for the driver to avoid hazard (e.g. an obstacle in the road) safely (Eriksson & Stanton,2017). It can be noted that five seconds may be insufficient for avoiding hazard. ***Longer times (e.g. more than 7 seconds) improve takeover quality*** and errors as drivers can use the extra time for decision making.

Different driver states leads to different takeover budget

Time budget needed for drivers to back to the driving loop also differs when drivers are in different states before takeover. For example, if during automated driving, driver is still highly concentrated on driving task, the driver can quickly back to the loop and takeover within only several seconds. However, if driver is doing secondary tasks, eg. play mobile phones, the required time budget is longer.

Therefore, the driver states are divided into three states (see figure 15):

1. (Level 2-4) Attention fully on driving task;
2. (Level 3-4) Attention partly on DT, partly on ST;

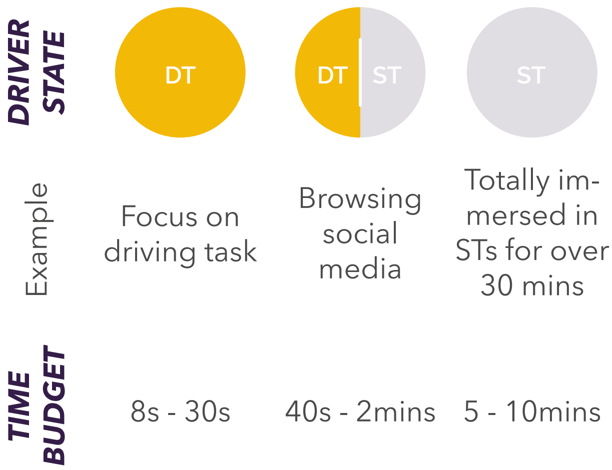


Figure 15. Time budget in different states (Nick, 2017, Endsley et. al, 1999, and Hildtich et al, 2015 *)*

3. (Level 4) Attention fully on secondary task (eg. sleeping or totally immersed in STs for over 30 mins)
According to research from Nick, 2017, Endsley et al, 1999 and Hildtich et al, 2015, time budgets for different states are shown below.

1.4.3 TAKEOVER SCENARIOS

As mentioned above, TOR happens when exiting operational design domain. Some of the scenarios are listed in table 3. In summary, some of the main reasons are system faliure, system limit of lateral control, system limit of longitudinal control and others (Table 3).

Scenario	**Description**
System limit, lateral control	The **absence of road markings** or blurred lane markings or secondary lane marking due to construction
	The lateral vehicle guidance is discontinued during a straight or curved road segment(high road curvature)
System failures	The failure of sensors
System limit, longitudinal traffic	Road works require change to another lane
	Bad visibility due to bad weather conditions like fog, heavy rain etc
	Cut-in vehicle is not detected
	Pedestrians enter road
	Obstacles on the road
Others	The driver is requested to select a particular route or leave the highway

Table 3. Different reasons lead to TOR in level 3 and level 4

1.5 KEY TAKEAWAYS

Key insights from the literature chapter are explained in this section.

CONCLUSION

Autonomous driving is investigated worldwide for many years. Level 2 automation is available in the market for years. Audi announced its first level 3 vehicle that the 2018 Audi A8 offers a level 3 Traffic Jam Pilot. However, due to the road regulation, the level 3 automation feature cannot be enabled on the road. The most recent news say that at the end of 2019, ***Audi, the pioneer of level 3, decided to skip level 3 because the federal regulation is not coming in a forsee future as well as pontential risks behind.***

In terms of the HMI, multi-modal messages should be applied to communicate more efficiently. ***Visual messages require more time to be noticed and understood than audio and haptic messages.*** So for urgent scenarios, audio and haptic messages should be considered more. ***HUD on the windshield was found to improve driving performance (Gabriela, et al. 2016) while HUDs were also found to increase visual complexity and clutter.***

From the benchmark research on HMI, there is indeed some trends in the automotive HMI like more and more intelligent, smart algorithms behind the system etc. However, there is not yet a unified way of enabling a good user experience for automated driving, specifically for takeover transition.

Driver's situational awareness is a key element influences takeover performance.
Low SA many problems (see chapter 1.3). Some possible directions of inducing SA for a better takeover are proposed: directing drivers' voluntary attention to the road while automated driving, ensure drivers regain SA to an adequate level before takeover, using ambient lights to keep drivers informed, and applying graded alerts to achieve a greater safety margin etc. These inspirational directions lay a solid foundation for the later ideation phase.

Last but not least, takeover transition happens in different scenarios and different levels. ***In different driver states, time budget for time over also differs*** (Figure 15). Different response budget should be taken into consideration in the later design phase.

USER *RESEARCH*

After gaining overall knowledge from literature review, in oder to further look into how users/drivers interact and experience the automated driving, an online questionnaire was sent to the Tesla driver's worldwide group. This chapter presents an overview of the results from online questionnaires and interviews that were conducted with Tesla drivers on the Tesla driver Facebook group. In addition, interviews with 5 specialists were also conducted to create better understanding of the automated driving, more specificity, takeover experience from user's perspective(subjective) as well as experts' perspective(objective).

Chapter overview

02

OVERVIEW

The figure below presents an overview of the user research chapter.

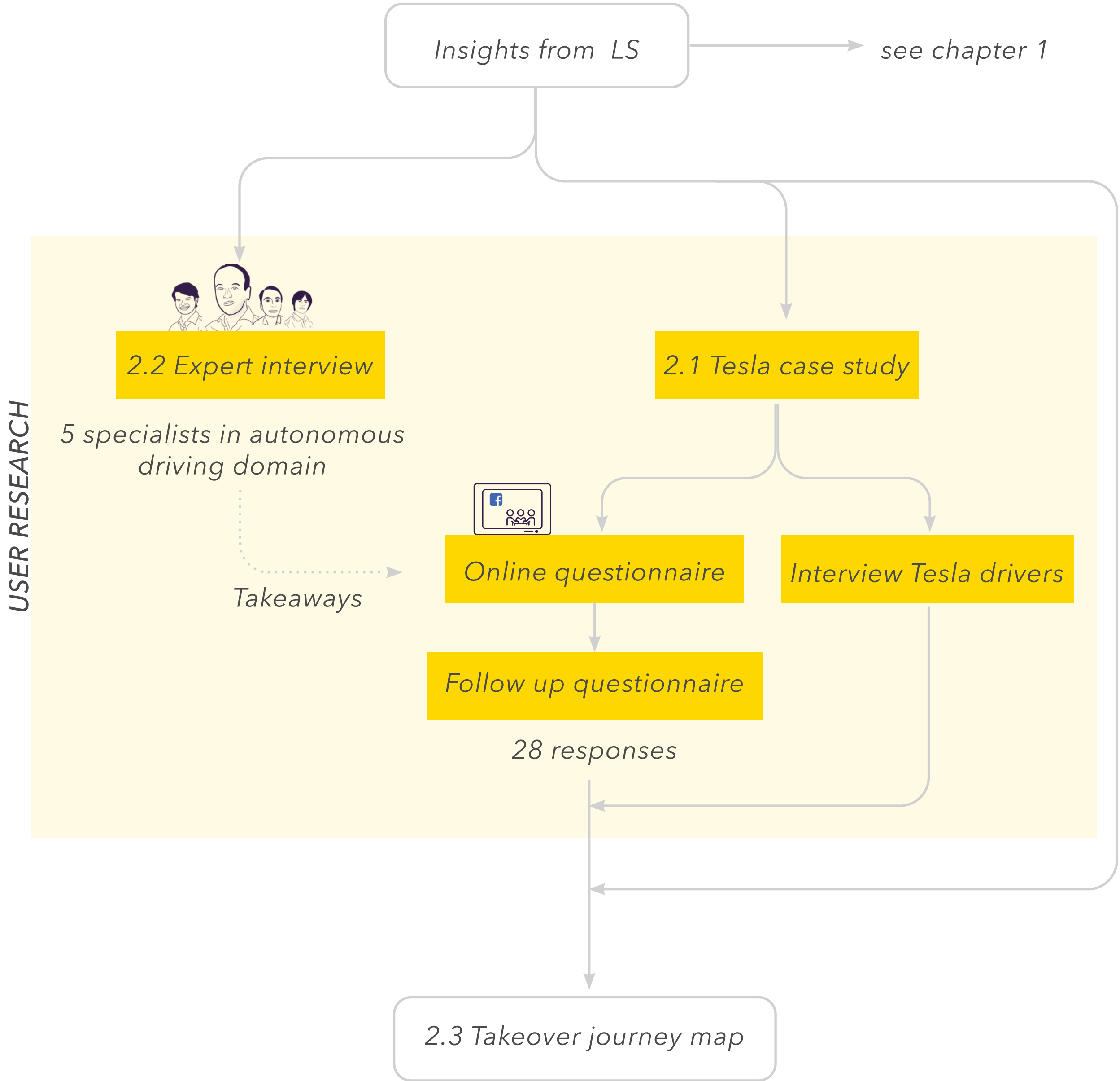


Figure. 16: Overview of chapter 2

2.1 TESLA CASE STUDY

Autonomous driving is on the horizon and, in the current market, SAE Level 2 systems are being introduced by automakers, BMW X5 Extended Traffic Jam Assistant, NISSAN Propilot 2.0, Tesla Autopilot and Volvo etc. Tesla autopilot is one of the most widely accepted and used level 2 system. Though the master thesis is targeting at the higher level of automation, having a look into level 2/2.5 automation could help collect users' needs, insights from users' automation experience and their expectation for the future high level automation.

Figure. 17: Cameras and sensors on Tesla (Tesla, 2019)

2.1.1 AUTOPILOT FEATURES

Updated with Data learning

Many advanced and convenient features are designed to assist drivers with the most burdensome parts of driving, like for traffic congestion. Autopilot ability is keeping updated thanks to the smart data learning process. With large amount of tesla vehicles on the road, it is a fantastic data resource. For example, any time a tesla makes an incorrect action, it will be saved and uploaded to the tesla training data set. In the future, similar mistakes will be avoided. Moreover, Tesla is also applying imitation learning to imitate how drivers deal with varied driving tasks and conditions. With a large amount of empirical information about the real world, it can increase the accuracy of anticipating human behavior. It also makes Tesla more capable over time.

Navigate on autopilot

When autopilot is on, NoA suggests lane changes when find it necessarily in order to optimise the driving route, for instance, when the car gets stuck behind slow cars.

When active, NoA will also automatically steer the car toward highway interchanges and exits based on the destination.However, ***autopilot requires human drivers to supervise the system constantly.***

Smart Summon
Smart summon is a function that the car can navigate, maneuver around parking spaces, self-park the car in the parking lot or come to pick you up.

2.2.2 INSIGHTS FROM ONLINE QUESTIONNAIRE

Introduction
In order to see people's experience with the very first automation system in the market - Tesla Autopilot. From 13 to 20 January, 2019, I published the online questionnaire at Tesla worldwide owner Facebook group including countries like the Netherlands, Germany, USA etc. The groups are for Tesla drivers to share, communicate, complain and bond with each other. The members are all Tesla owners. Till now, there are 26 responses in total (Appendix B). Most of them are around 40 - 49 years old (34.6%%), 50 - 59 (30.8%), some are 30 - 39 (23.1%), and 20 - 29 (11.5%). 92.3% of the respondents have more than 10 years driving experience.

Use autopilot everyday
At the beginning, according to Tesla drivers' response, AP interests people for different reasons: ***ease of use, handsfree driving, safety and future possibility etc.*** According to the result, tesla drivers use autopilot very often, 69% of them use it everyday, mostly on the highway. This shows that tesla drivers, though not necessarily young, hold ***very open attitude towards automation and strong adaptability*** towards it. Mostly, they use adaptive cruise control and lane changing functions.

Unexpected failure
However, when tesla drivers are using autopilot, most of them encountered unexpected failure to some degree. For instance, some complain that ***the autopilot brakes without warning either too early or too strong.*** 2 respondents says barricades of construction sites are sometimes ignored by the system. One serious occasion is that the driver ***thought the AP is on but it was not***. It caused car crash when going off the road. It also happened that the system refused to switch lanes because of EU limitations. However, interestingly, one respondent says that there was never unexpected shocking things happen with the system. But instead, the system prevent possible mistakes that might be caused by his human "errors": ***" The autopilot leaves the highway correctly when I forget and it changes lanes perfectly while I am still figuring out which lane to go."*** Most of these unexpected failures were able to be handled immediately at that moment. So they did not stop drivers from using the AP and in general, drivers still hold positive impression towards the AP features.

**AP=Autopilot*

"Everybody does non-driving related tasks, even when not using autopilot."

Human nature to do ST even for level 2
80.8% participants have performed non-driving related tasks while turning on autopilot. The non-driving related tasks vary from checking phones/emails/whatsapp/socialmedia (9), eating snacks (3), stretching the back (2), to changing central display (radio/music/climate) settings (6) etc. One respondent says: ***"Everybody does non-driving related tasks, even when not using autopilot"***, which is indeed a fact. Many research also proves that human beings are not good at monitoring and easily got distracted from monitoring (Lu et al., 2019). Most participants claim that they will only do ST for less than a minute every time when AP is on.

The Notifications: Annoying but useful

Tesla will give alerts (visual and audio alert) when it detects drivers' hands off the steering wheel longer than 10s or so. 44% find the notifications are annoying but very necessary. 28% find them quite annoying while the other 16% find the notifications pretty good. Nearly all respondents agree that the notifications are strong enough to bring them back to the loop. One respondent says ***"I'm glad they do it (he means alert) to discourage idiots who put far too much trust in the technology to do the driving for them."***

This positive feedback does mean that the current tesla alert system works quite good in bringing people back to the loop for level 2 automation(very shortly out of the loop), however, it does not guarantee a good user experience as many people find the system reminders annoying. ***Bringing drivers back to the loop in a higher level of automation is gonna be more challenging since at that time drivers are more likely to be out of the loop for longer period time and thus harder to effectively bring them back to the loop.***

Changes of SA: manual vs automated driving

Last but not the least, in order to understand how drivers' situational awareness changes between manual driving and autopilot. I ask the participants to rate their performance in terms of ***"to what extent do they concentrate on the driving task and the road"***. 5 means fully concentrated and 0 means not paying attention at all. The result shows that more than 84% of participants rate their performance 4 - 5 (highly concentrated). Results are shown in Figure 18. On average, they give a score of "3.88" to their performance. So we can conclude that while manual driving, drivers have good performance regarding concentrating on the driving tasks.

On the contrary, while using autopilot, 62.5% of participants rate their performance under 3 (two "1", four "2" and nine "3"). This gives a solid evidence for an explicit decrease of driver's situational awareness while turning on autopilot, compared with manual driving. In fact, while using autopilot, drivers are required to constantly supervise the system. For higher level of automation, drivers' situational awareness can get even lower which is proved by large amount of literature.

2.1.3 CONCLUSION

The key takeaways from online research are concluded below (Figure 19).

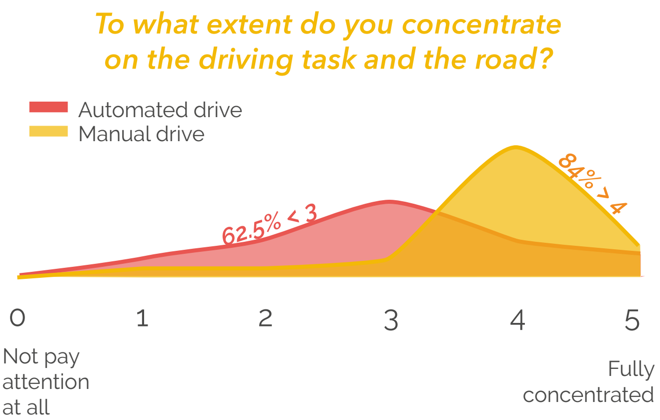


Figure 18. participants feedback on their SA

MOTIVATION	*Ease of use*		*Safety*		*Future possibility*
PROBLEM	**Easy disengagement**	**Contradiction** between vehicle's decision and drivers' intention	**Driver gets surprised** by vehicle's sudden actions	**Passengers gets anxious** if something unusual happens	**System limits**
	Lower SA	The system refuses to switch lane because of EU limitations	Brake suddenly without warning Quit AP suddenly	When something unusual happens, passengers tend to be very anxious and even shout at the driver	Wrong lane detection Ignore barriers in constructions sites Late lane change leads to drive past the off-ramp
EFFECT	**Maintain SA**	**Less obtrusive way**	**Explanation, warning needed**	**Guidance needed**	**Smarter system**

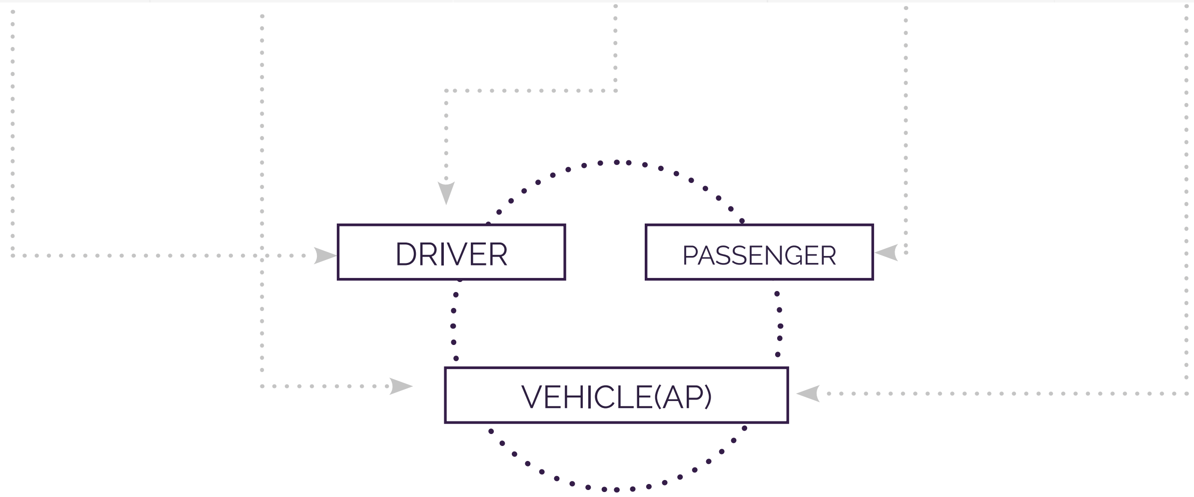


Figure 19. Key takeaways from the online questionnaire

MEET THE TESLA DRIVERS

According to the responses of the online questionnaire and the Tesla groups' members' profile, three representative personas are made as followings.

Tanguy 42
Senior IT engineer

#Environmental protector

#TECH GUY

Motivation for using AP
Cleanness, ease of driving and future possibility

Behaviour when uses the AP*:
When the car is cruising along in a calm environment and autosteer is on, I feel it's OK to avert my eyes for a couple of seconds to have some rest, like stretch my back, eat some snacks, and check whatsapp etc. I would never do it in any other conditions.

Quotes
"I really feel like autopilot is more beta testing of the technology at the moment. It is constantly changing and improving. At this point, you almost have to be MORE aware driving on autopilot as it can be unpredictable."

Wim 55
CEO at XXX Traffic Management

#Frequent flyer around the world

Motivation for using AP
Hands free, ease of driving and safety

Behaviour when uses the AP*:
He uses NoA on the highways, country road and major city roads. It helps him to be a safer driver in traffic.

Quotes
"AP is very good if you use it like you should. I am happy with it and it makes me a safer driver in traffic especially on longer trips."

Steven 35
Part time youtuber

#Roadtrip traveller
#Aikido lover
#Tesla fan

Motivation
Cool, handsfree driving, share with others

Behaviour when uses the AP*:
He uses AP nearly everywhere because he wants to help train the network. He did a lot Tesla testing videos while he was doing road trips around Europe and also in daily life and shares with others on Youtube.

Quotes
"I am very glad Tesla do this(frequent reminder) to discourage idiots who put far too much trust in the technology to do the driving for them. AP is a helping tool, its not self driving. It should be faster self learning"

Figure 20. Tesla driver persona

2.2 EXPERT INTERVIEW

MEET THE INTERVIEWEES

Joost de Winter
Associate professor from 3ME, involved in the Human Factors of Automated Driving project.

Dr.Ir. Bastiaan Petermeijer
involved in multiple automated driving projects such as HF-Auto project

Pavlo Bazilinskyy,
Postdoctoral researcher at TU Delft focusing on the communication between automated cars and vulnerable road users.

Ir. Jork Stapel,
from automotive human factors

2.2.1 BACKGROUND

Automated driving is a popular topic that has been investigated for many years. Many insights were drawn out of the previous literature study, online research and user research. But the insights are scattered. Interviewing experts who has years of experience in this domain is a good way to validate my assumptions, quickly organise and prioritize those scattered insights.

Here in the technical university , there are many researchers, professors who spent years in studying automated vehicle. Therefore, I decided to make the most of the resource and contacted some of the experts here in Delft.

The goal of the interview is to:
1. Validate and modify the take over transition experience/journey that I concluded

Cluster	Description
Painpoints	***Level 3 takeover is risky and contr***
	The automation world is still a lot
	Conflict may happen
	Risky to give control back when d
	Stability off control
Opportunities	Less research on level 4
	Going towards planned takeover
	Level 4 knows when takeover com advantage in helping driver get p
	Sufficient time for takeover is criti
	Make sure driver's state fit for take

Table 4. Summary of the interview insights

from literature and online research with the experts;
2. Identify the keypoints and existing/potential problems in the journey;
3. Discuss about the scenarios of TOR.

2.2.2 RESEARCH METHOD

In total, 4 semi-structured expert interview were conducted at 3ME faculty, TU Delft. Experts were interviewed individually and each interview took approximately 40 minutes to an hour. Interview questions are attached in Appendix C. The interview questions are aimed to tackle the interviewees experience, opinions and knowledge on the autonomous driving and more specific takeover transition.
An empty takeover experience journey were presented to interviewees in order to have a centralised topic and also used as probes. Since interviewees were asked to describe takeover experience, a set of small cards are provided as a tool to help them express better as well as inspiration. The interviews were recorded for analysis later on.

2.2.3 ANALYSIS

The interviews were transcribed and analysed referring to the context mapping method (Sanders & Stappers, 2012).
After transcribing the interviews, important quotes were selected. Secondly, the quotes were printed and cut into different pieces. In this way, the quotes from different interviewees can be mixed and clustered together. In the next step, quotes were clustered into different core categorises.

2.2.4 RESULTS

Results are concluded in table 4.

	Quotes
roversial uncertain	*“The the big question is “Is it reasonable to ask the driver to takeover the control in like 7s on the road.” I think nobody knows where the future brings us.”*
	“When the system decide that the driver’s state is not appropriate to takeover. It might cause conflict with driver intention.”
river is not fit	*“ For level 4, it would be stupid to let a driver who is not in a good state, just woken up, and say “oh, here is the control back and have fun.””*
	“Drivers tend to steer a lot when they are longer out of the loop. They need to get used to the steering dynamics.”
	“Much research has been done around level 2 & 3.”
	The whole community found forced takeover is not the most safe way. So it is going towards less forced/planned takeover.
es, thus has repared	*“For level 4, since the car know a takeover is coming, it can help driver get prepared. But for level 3, the car not necessarily knows it.”*
cal	*“Sufficient time for takeover is critical to ensure safety, but for level 3 forced takeover, it is not guaranteed. Therefore, it is very risky.”*
eover is critical	*“Make sure the driver gets back to the good state or SA before takeover and help him/her back to the driving dynamics especially there is a long drive.”*

2.3 TAKEOVER JOURNEY MAP

The takeover journey map is constructed with a horizontal timeline of different steps of the takeover transition journey. This timeline of four general steps that was concluded through literature review, online research, expert interview and tesla case study. The journey map gives an overview of vehicle and driver actions at the same time. Importantly, since vehicle actions in level 3 and level 4 are different, they are separately shown. The situational awareness line is drawn to show its dynamic changes throughout the journey. Then the keypoints/problems are highlighted in different steps respectively. Some quotes from expert interviews and user research are marked in the last row.

JOURNEY MAP

	04	05
STEPS	**04** *Automated driving*	**05** *Requesting take over*
SA	**SA during automated driving is not always low. Here it shows the situation when driver is doing ST without any intervene from the system.* *SA gets lower due to driver engaging in STs*	*SA increases because of Notifications*
VEHICLE ACTIONS	Automated driving	HMI signals Notification **Level 3**: Monitor & **Inform** / M & **Level 4**: Monitor & **Inform** / Evaluate
DRIVER ACTIONS	Secondary tasks	"Wake up" from ST Back to driving position Evaluate s
KEY POINTS	L3&4: **Lack of driver education** L3&4: **Driver's fitness decreases**, eg. get bored, distracted and etc. L3&4: **Passengers get anxious** if something unusual happens. It can stress the driver. L3&4: **Continous messages** helps driver maintain SA, but it also distracts ppl's attention	L3: Only visual feedback won't work. L3: **Sufficient time** for takeover is critical to ensure safety, but for level 3 forced takeover, it is not guaranteed. Therefore, it is very risky. L3&4: **Lack of clear federa for AD** L4: When the system deci driver's state is not approp takeover. It might cause co **driver intention.**
QUOTES	*I'm glad they do it (notification) to discourage idiots who put far too much trust in the technology to do the driving for them.*	*They (passengers) tend to shout at me when the car is again refusing to change lanes.* *Current EU laws are too restrictive!* *"The the big question is to ask the driver to take in like 7s on the road." _ knows where the future*

06 **Resuming control**

07 **Driving manually**

Usually forced takeover

onitor
Warn

Deactivation

Exit automation

Controlled by driver

driver state

Hand over or not

Monitor
& Inform

Pullover

Controlled by driver

Less forced takeover

*NOTE:
For L3, TOR can happen at any time*

For L4, TOR happens when exiting ODD

surroundings

Make decisions

Resume control

Take action

Take action

l regulations

de that the
riate to
nflict with

L3&4: Whether the driver is in a good state to take over is unknown.

L3&4: Driver takes over the control not in a good state of mind or in a low SA would be more catastrophic.

L3&4: Stability off control: Drivers tend to steer a lot when they are longer out of the loop. They need to get used to the steering dynamics

L4: Safe pullover is not that safe and drivers would not prefer it.

*"Is it reasonable
eover the control
l think nobody
e brings us."*

" For level 4, it would be stupid to let a driver who is not in a good state, just woken up, and say "oh, here is the control back and have fun.""

I think cars with "driver assist" functions should allow the driver to switch ALL of these things off if they are not desired and just have a plain or dumb cruise control.

DESIGN FOCUS

With the key learnings from literature study, online user study and expert interview, this chapter shows the design directions of the project. The design goal and design guidelines will be explained.

Chapter overview:

03

USER GROUP

Figure 21 shows the technology adoption process. Since high level AV is not yet in the market, so we are supposed to focus on the early users, including innovators, early adoptors and early majorities (see Figure 21). Together with the insights from user group of Tesla, we can catagorize early users into two user groups in the early stages: Geek and amateur.

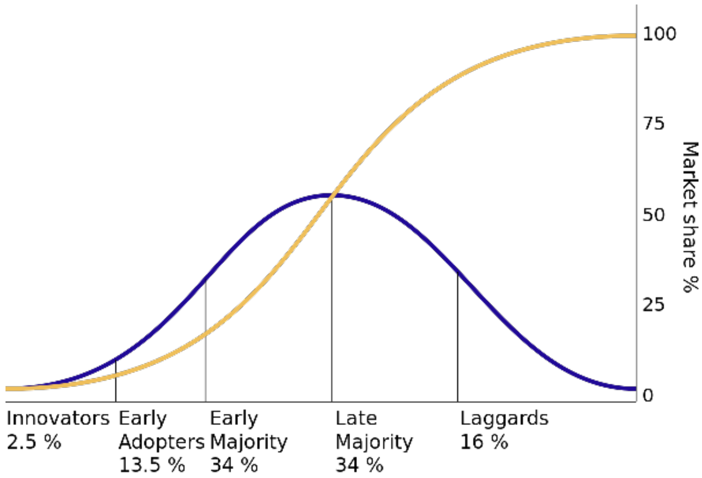
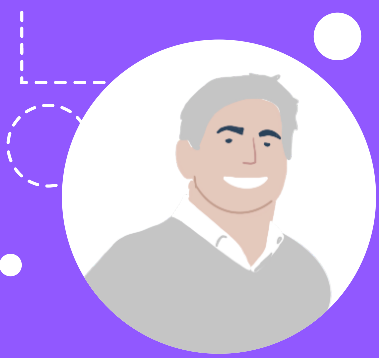


Figure 21. Technology adoption curve(Rogers, 2003)

AMATEUR(early adopters / majority)
Don't have much knowledge about automation. Choose automated vehicle for a safer, easier driving experience (Figure22).

GEEK (Innovators and early adopters)
Familiar with automated vehicles and be aware of the limitations of the automation system (Figure22).



Wim 55
CEO at XXX Traffic Management

AMATEUR

#Frequent flyer around the world

Motivation for using AP
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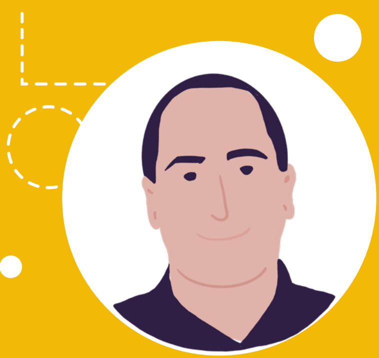


Tanguy 42
Senior IT engineer

GEEK

#Environmental protector

#TECH GUY

Motivation for using AP
Cleanness, ease of driving and future possibility

Behaviour when uses the AP*:
When the car is cruising along in a calm environment and autosteer is on, I feel it's OK to avert my eyes for a couple of seconds to have some rest, like stretch my back, eat some snacks, and check whatsapp etc. I would never do it in any other conditions.

Quotes
"I really feel like autopilot is more beta testing of the technology at the moment. It is constantly changing and improving. At this point, you almost have to be MORE aware driving on autopilot as it can be unpredictable."

Figure 22. Persona

3.1 PROBLEM STATEMENT

PHASE	*AUTOMATED DRIVING*	*REQUESTING TAKEOVER*	*RESUMING CONTROL*	
PROBLEMS	Lack of driver & passenger education. *Ch. 1.1 & 2.1* ***Driver's fitness&SA decreases: gets bored and distracted by ST.*** *Ch. 1.3 & 2.1* ***Sudden actions like sudden brake/ lane change surprise driver and passengers.*** *Ch. 2.1* Extra task for driver: explain AD to passenger(s) *Ch. 2.1*	Federal regulations are lacking and restricting. *Ch. 1.1* Single-modal notifications won't work due to inclusiveness and also ***not efficient enough to bring driver back to the loop.*** *Ch. 1.2& 2.2* Conflict might happen when driver's idea differs from automation's. *Ch.2.2* ***Sufficient time for takeover*** is critical to ensure safety. Level 3 forced takeover is rather risky. *Ch. 1.4&2.2*	***Whether the driver is in a good state to take over is critical.*** *Ch. 2.2* Driver takes over the control not in a good state of mind or in a low SA would be more catastrophic. *Ch. 2.2*	***Stab*** tend are l They steer Safe and it. *Ch*
KEY INSIGHTS	*INTERVENTIONS NEEDED ACTIONS NOT PREDICTABLE*	*ADVANCE AND EFFECTIVE "WAKEUP" NEEDED*	*EVALUATION OF DRIVER STATE NEEDED*	*A*
	↓ *SUPPORTIVE UNDERSTANDABLE* ↓	↓ *EFFECTIVE* ↓	↓ *SUPPORTIVE* ↓	

DESIGN GOAL

*"Design an **understandable, supportive, and effective** tem to improve driver's takeover performance during co highway(level 4)."*

*Ch. x= chapter x

DRIVING MANUALLY

ility off control: Drivers to steer a lot when they onger out of the loop. need to get used to the ring dynamics. *Ch. 2.2*

pullover is not that safe drivers would not prefer *n. 2.2*

FTER-CARE MISSING

↓

SUPPORTIVE

↓

e HMI sys- ontinious

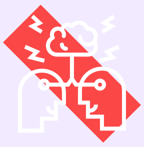
3.2 DESIGN GOAL

THE SYSTEM SHOULD:

DURING AD / BEFORE TAKEOVER REQUEST
automation's actions/intentions should be understandable

DURING AD / TOR
HMI should effectively communicate with/ evoke the driv- er's situational awareness

DURING TAKEOVER
ensure drivers' state is appropriate



Better mutual understanding between the driver and the automation

DURING AUTOMATED DRIVING

Evoke drivers' situational awareness while maintain its comfort

BEFORE TAKEOVER REQUEST

Support the driver to get prepared and ensure drivers' state is fit for takeover

DURING TAKEOVER

Why understandable?

- A large group of users are the amateur of automation. The lack of driver education leads to over- or underestimation of the automation capability. Therefore, knowledge about automation system is needed;
- Drivers sometimes get surprised by vehicle's sudden actions due to no explicit reasons for the actions. Therefore, the actions should be understandable;
- It's even harder for passengers to understand vehicles' actions. So, not only for drivers but also for passengers, the actions should be understandable;
- Not only the actions but also the visual, auditory, haptic messages should also be intuitive and understandable.
- If the vehicle decides not to hand over the control, messages provided should be understandable for the drivers to avoid possible contradiction.

Why supportive?

- During automated driving, drivers are very likely to get out of the loop and the drivers' fitness thus decreases. Especially when driver stay out of the loop for a long time(more than 10 mins), supports are needed from the system to maintain driver's fitness(here mainly refers to situational awareness) during automated driving and help regain SA before takeover;
- If drivers' states are not appropriate to takeover the control from the system, supports from the system are needed to ensure a safe takeover;
- After takeover, drivers might need some time to get used to the driving dynamics. Therefore, supports are needed to assist drivers.

*"Design an **understandable, supportive, and effective** HMI system for driver and passenger(s) to improve the takeover experience during continuous highway."*

When?

Throughout the takeover transition from automated driving to successfully resuming control.

Why effective?

The wakeup call should be effective and efficient to be able to bring driver back to the loop from what he/she is doing.

Scenario:
Level 4 Long out of the loop scenario

DESIGN GUIDELINES

Design guidelines are proposed to lay the basis for the next design phase

OVERALL

1. Clear information

- The limitation and capability of the automation should be clear

2. Universal Visual, auditory cues

- All the visual, auditory messages should be universally used in the automotive HMI design, intuitive and will not cause ambiguity

3. The driver's eye should be off the road as less as possible

DURING AUTOMATED DRIVING

Help maintain driver's SA but do not disturb driver too much

Provide clear information to enhance understandability

- What the automation is doing should be clear
- Reasons for the automation's actions should be explicit
- Intentions of the automation should be predictable

Indicate TOR in advance and support driver get prepared

- Notify TOR in advance, leave sufficient time for drivers' to get prepared
- Give support/guidance to help driver know what he/she needs to prepare to become fit for takeover
-

Evoke driver's SA effectively before takeover

DURING TAKEOVER

Effective takeover request

- Takeover request should be clear, effective and takeover actions should be easy and intuitive

AFTER RESUMING CONTROL

Explicit feedback

- Give explicit feedback when exiting the AD

04 CONCEPTUALISATION

In the following sectors, several concepts are proposed. These concepts are the result of the integration of insights from the various research activities performed throughout the project (see chapter1.2.3). The overview of this chapter is explained in Figure 23.

Chapter overview:

OVERVIEW

The figure below shows the overview of design process: ideation, design iteration with quick user tests and design contents.

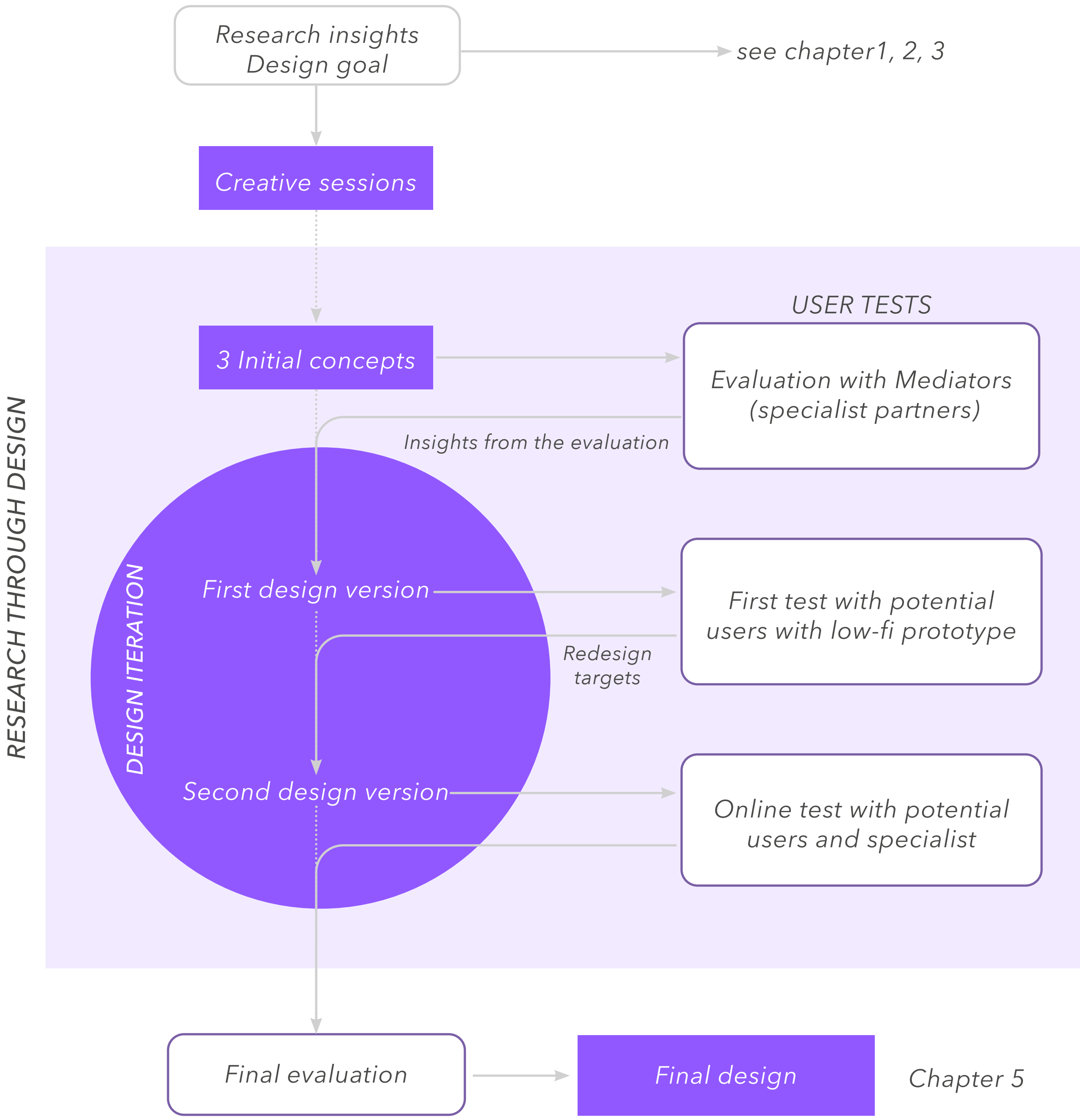
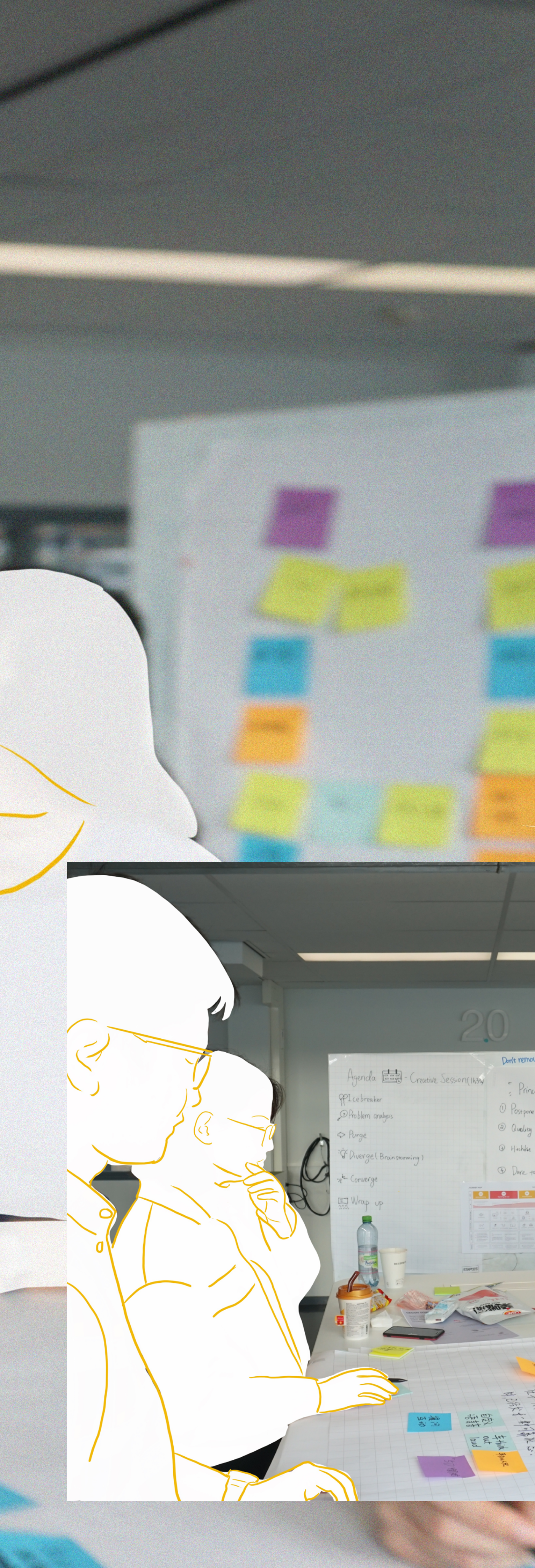


Figure 23. Overview of chapter 4

Figure 24. Creative session with IDE students



Conceptualisation

4.1 CREATIVE SESSION

In order to generate more ideas and in the end come up with a solution that meets the DG, a 1.5-hour creative session is conducted at IDE faculty with 4 DFI students. A wide and bright studio was prepared with all the necessary materials. I was the facilitator of the session and the plan for the session (see below) was made according to the Creative Facilitation Book (Tassoul, 2012).

After analyzing the problem, participants proposed a problem statement to solve for the session:

"How to let the driver already be in a reliable state before takeover, in the scenario of vehicle handing over control to the driver (A -> M)?"

Agenda of the session

- ***Icebreaker***
  Roleplay(5 mins)
- ***Project introduction***
  Journey map(5 mins)
- ***Problem analysis***
  5W method(10 mins)
- ***Purge***
  Write down first ideas and leave them aside(15 mins)
- ***Diverge***
  Brainstorming, reverse thinking and translate back(25 mins)
- ***Converge***
  Idea clustering (10 mins)
- ***Idea selection***
  Select the favorit ideas and explain why (5 mins)

PERSONATE THE VEHICLE

Ideas:

- Car should "think out loud";
- Car's heart beat increases when requesting takeover;

Insights:

- Car should not only inform driver commands but also tell the "why" to the driver to increase mutual understanding;
- Create clear "mode rhythm" so that driver can "feel the change instinctively";

STEP BY STEP GUIDE

Ideas:

- Pinch the steering wheel in advance;
- Programmatic and guided preparation: "xx check", "check" "check";

Insights:

- Instead of fully relying on driver to prepare for takeover, car could help the driver to prepare step by step. The prepare progress should be visible and clear;

SMART SYSTEM

Ideas:

- Learn driver's driving behavior and adapt to it;

- Mobile devices should be connected to ensure driver sees the notification;
- Show the route(when manua driving and when automated driving) clearly;

Insights:

- The ability of machine learning that can enable personalization should be ultilized;
- Connect all the devices in the car so that notifications are less likely to be ignored;

IN-CAR ENVIRONMENT

Ideas:

- Locate the target on HUD and guide drivers' attention;
- Obvious mode change through light, scent, air-conditioner etc;

Insights:

- Different in-car environment should fit to different mode and easily be perceived;

PASSENGER

Ideas:

- Passengers should also be prepared/limited for the transition;

Insights:

- Not only drivers, but also passengers should be prepared for the mode transition;

CONCLUSION
The ideas came out of the creative sessions were concluded using the C-box method.

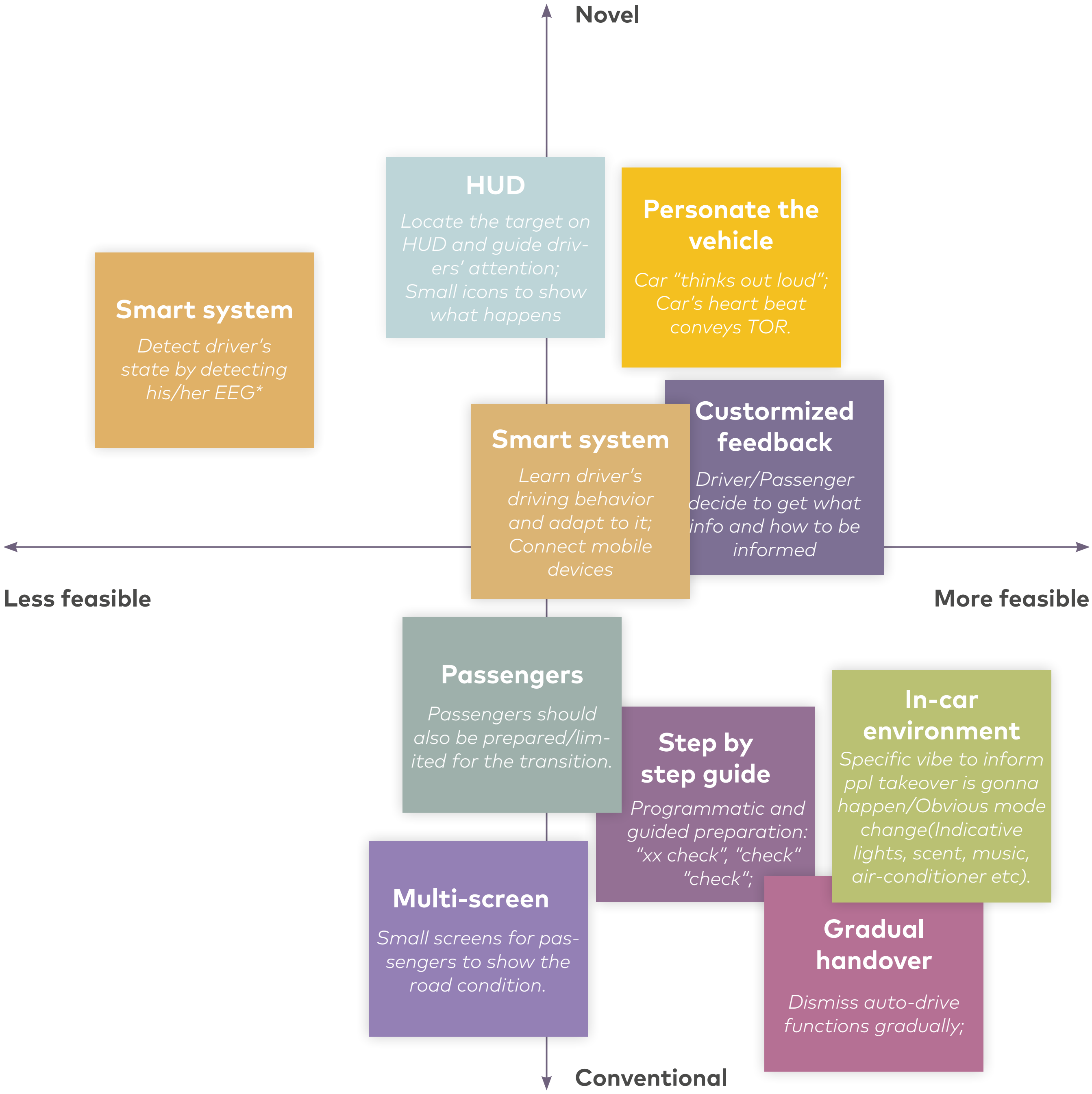


Figure 25. C-box cluster of ideas

**EEG: Electroencephalogram*

4.2 INITIAL CONCEPTS

With various creative ideas came out of the session and insights from previous chapters, three concepts are proposed as initial concept directions. In next section, in order to converge concept directions, an evaluation with Mediator group is conducted.

CONCEPT 1

In the near future, with technology like 5G, mobile connectivity is a trend. So while AD, all devices can be connected with the car HMI. The idea of concept 1 is firstly during autonomously driving, giving ppl constant updates about the car actions and driving states *to where the driver's attention is*. Details about concept 2 are explained in figure 27.

CONCEPT 2

Concept 2 is viewing the vehicle HMI as a living organism. Mode distinctions are conveyed via distinct mode vibe. For instance, during the automated driving, the whole vibe is very calm. Then the "living organism" starts to breath more and more exciting(breathing light pattern) like it starts to awake. When takeover, the "living organism" turns completely into an urgent/ intense vibe. Details about concept 2 are explained in figure 28.

CONCEPT 3

The idea of concept 3 is to attract driver's attention to the road during automated driving using live world points of interests(POIs). Moreover, the HMI learns about driver's behaviour and adapt to it. For instance, the HMI adjust the steering wheel angle if the driver tends to steer too much/less after resuming control. However, since the idea of POIs are quite often proposed and technically not yet feasible, concept 3 is not further developed.

Figure 26. Inspirations for the concepts from creative session

Concept 1 Connected everything

1. While automated driving

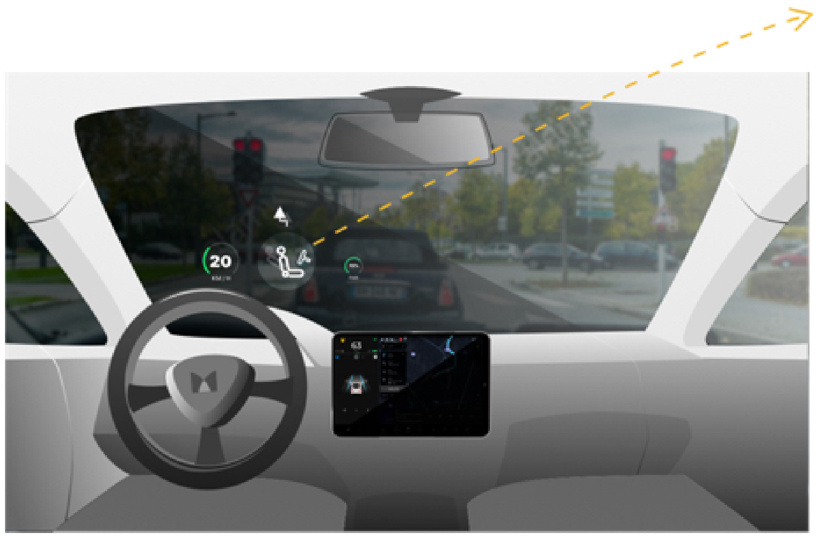
Driver and passenger chooses what kind info and notification while playing with the phone. Then just enojoy playing with the phone!

2. While automated driving

Driver get the notifications that she wants to know.

3. While automated driving

And a takeover request pops up when the automation wants the driver to take over the control.



4. Before takeover

Give step by step guidance to help driver get prepared.

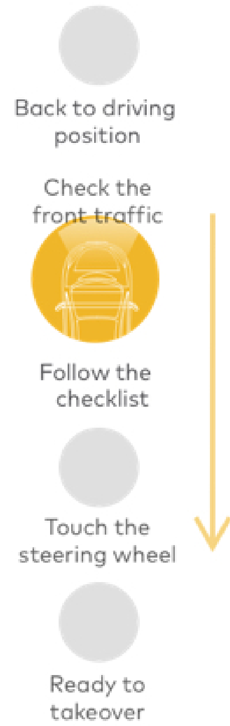


Figure 27. Concept 1

Concept 2 "Follow the breath"

1. While automated driving
Light stripe as indicator

2. While automated driving
Light "breaths" from calm to a bit exciting: slow to a bit quick

Philips wakeup light

3. While automated driving
Rapid blinking: urgent vibe. The length intuitively shows the time left for takeover.

4. Before takeover
Takeover! Similar to when braking, there is a "undertransition" mode.

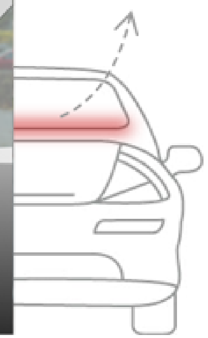


Figure 28. Concept 2

4.3 CONCEPT EVALUATION

The concept proposals as explained above were presented to the mediator group with 13 experts in design, human factors, autonomous driving etc. On the one hand, they hold different domains of knowledge dealing with autonomous driving. On the other hand, they are also users (potential AV drivers). The aim of this evaluation is to validate concepts with experts with following questions:

- How efficient the "wake up call" is to wake up the driver from secondary tasks?
- Which core values as well as problems do they see from each concept?

4.3.1 APPROACH

To better communicate concepts, storyboards are made together with evaluation questions. Since the light pattern in concept 2 is hard to describe both verbally and visually, a simple animation is made to better present the concept. Experts presented were invited to fill in the evaluation forms. Later some of them shared their opinions further with me. There are three evaluation questions for each concept:

- *How efficient do you think the "wakeup call" is to wake up the driver? (Quantitative question)*
- *Concept 1: Do you find the step by step guidance necessary for helping drivers get prepared for the takeover? (Qualitative question)*
- *Concept 2: Do you think the light stripe patterns are understandable? (Qualitative question)*
- *What do you think about concept 1/2 in general? Any advice? (Qualitative question)*

Feedbacks for the quantitative question is presented in figure 29. Feedbacks from the same participant for two concepts can be compared very clearly. For qualitative data, thematic analysis is conducted to identify the main themes in feedbacks.

4.3.2 RESULTS

To my surprise, the mediator team showed great interest in my concepts and gave lots of inputs on each concept. After analysing, more detailed research questions are proposed to further develop the concepts.

Concept 1

☺ **Providing information to where the attention is is appreciated and regarded as effective (S3, S5, S10)**

"It can be effective to communicate via the same channel of the driver focus/attention."

☺ **Checklist is regarded as helpful (S5)**

"Very helpful, like the checklist in aviation;"
"No but maybe relevant info should be pointed out."

☹ **It is limited to only when the driver's attention is on the phone (S3, S8, S10)**

"Mobile phone should not be the only channel"

☹ **Not convinced about using the phone (S2, S4)**

"Smartphones will be gone in some years. Focus on car possibilities."
"I think you should let the user connect the phone to the car and use GUIs integrated

in the car"

ⓘ **In combination with concept 2 "wakeup call" can be definitely effective (S7)**
"Only a wake up call won't be enough. I wonder whether you can combine the 2 concepts?"

Concept 2
☺ **The "wake up call" is regarded as more efficient than Concept 1**

ⓘ **Colors and variations needs to be further investigated (S4, S10)**
"How about color change in day/night or different conditions?"

ⓘ **If the light stripe patterns are understandable for drivers needs to be tested with users (S1, S2, S5)**
"For me, it is very intuitive, but not sure about users. It requires more research."
"If they learned about it, then it is understandable."
"Instead of countdown with the decreasing of light stripe, how about the opposite way?"

ⓘ **Multi-modal interventions should be applied (S2, S3)**

"It will be different in day than at night. Need audio vibrating etc. "
"If drivers are asleep, it would not be able to wake up the driver. "
"Drivers might get used to the light."

ⓘ **Communications with other vehicles should be left out (S7, S8,S10)**
""Under transition mode" is not necessary. Do not expect other traffic to solve the safety issue."

4.3.3 CONCLUSION

Each concept has its pros and cons. Though from quantitative feedback (Figure 29), and qualitative feedbacks, concept 2 is more appreciated. Details are concluded in key takeaways.

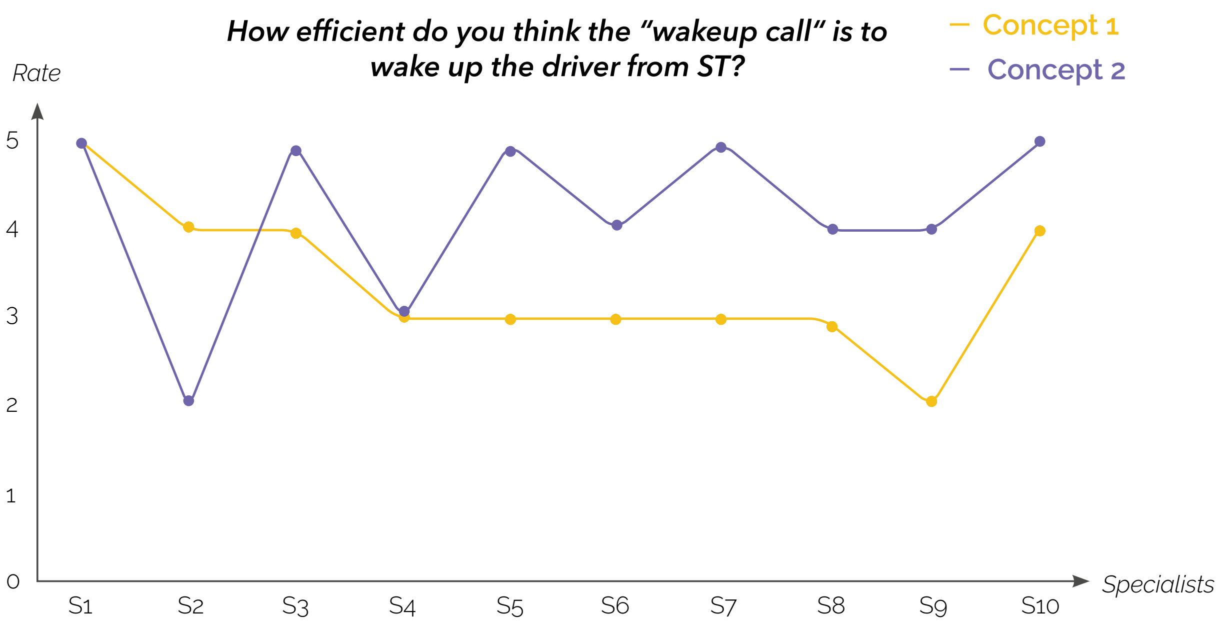


Figure 29. Quantitative feedback

Figure 30. Collected evaluation forms

KEY TAKEAWAYS:

- Provide **notifications to where the driver's attention is** can be effective;
- Provide **checklist to guide** driver to get prepared is regarded as helpful;
- Users **do not like to be bothered** too much while AD;
- Wake up call with ambient light strips is regarded as more efficient but the efficiency and understandability **need to be tested with users.**

HEAD-UP DISPLAY

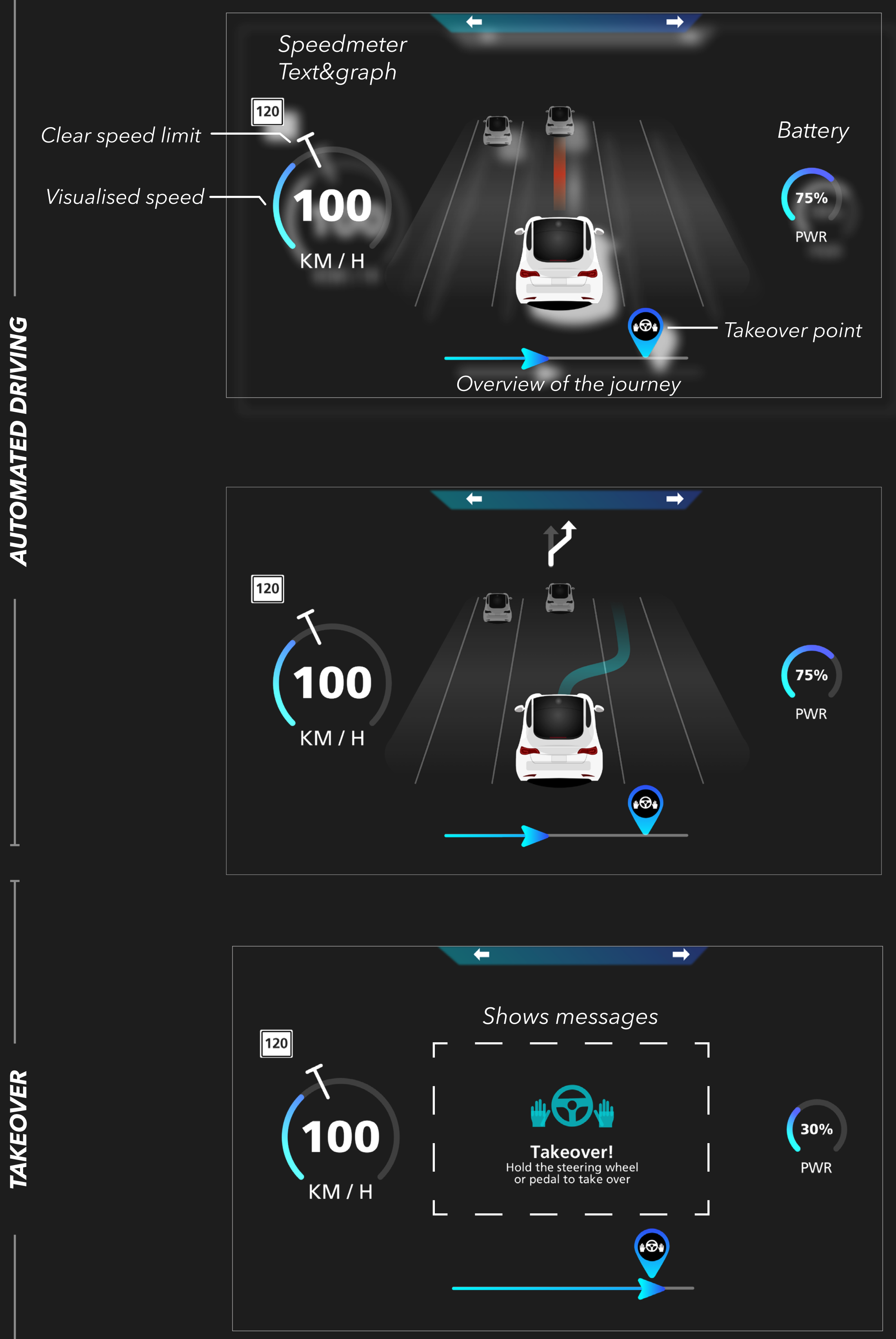


Figure 31. 1st version HUD design

Figure 32. Impressions of HUD on the simulation in the test

4.4 USER TEST

To evaluate the understandability of visual info on the head up display, light signal of wakeup call and takeover and also how effective the wakeup call is, a user test was conducted. A quick prototype was set up to simulate the autonomous driving experience and enable participants to interact with. The prototype consists of two light strips, an Arduino shield, two buttons, a big screen, and a car. The light strips are attached to two sides of the windshield(A-pillars) and meanwhile connected to the Arduino shield to control the different light signal. The screen is used to show the road simulation and the head-up interface.

Figure 33. User test set up

4.4.1 GOAL OF THE USER TEST

The user test was conducted to evaluate the usability and experience of the chosen design concept(the Heads Up display interface, the light strip signals). The goal was to evaluate whether the design goals were met and if not, how to further develop/iterate on the design.

4.4.2 RESEARCH METHOD

As mentioned above, a quick prototype was made for the user test. The test was conducted in the car model displaying at applied labs. Two light strips was attached to the windshield and connected with the arduino. A big display was put in front of the car. It simulates the real road scene and head up messages. With this quick and dirty set up, participants can experience the takeover procedure in level 4 as close to the real situation and immersive as possible: conduct secondary tasks while autonomous driving, be woken up from STs, take over the control and then drive manually.

Before the test, a short introduction was given to participants. The intro contains two parts. First of all, the project is about level 4 autonomous driving and focuses on the takeover in the journey. Then they were informed what the takeover is and later in the test, they will be a takeover request. Secondly, they were asked to play the game"Angry Bird" while automated driving. (Since the test is mainly to test planned takeover, participants were asked to sit in the car and play "Angry Bird" during AD in order to distract their attention from driving tasks to secondary tasks in a short time.)

After the brief introduction, the test started. While the participants were playing the game (Figure 34), he/she was aware that the car is driving automatedly on the highway. And he/she decides how much attention they would like to pay to the road and to the game. After 2.30 minutes, the wake up mode was turned on by pressing the button on Arduino secretly (Wizard of Oz). And the takeover request comes after. As there is no steering wheel or pedal, participants were told to take over by acting to grab the invisible steering wheel.

Here is the detailed information about the set-up:

- *Time and Location*

The test took place on the 3rd of March at the Applied Labs in IO.

- *Participants*

Since my target users range from experi-enced drivers to inexperienced drivers, I invited two experienced drivers (5+ years), one medium (2+), two inexperienced (less than 1 year) and one participant with no driving experience. Each test was about 15 - 25 mins.

- *Procedure*

After experiencing the automated driving and takeover experience. Participants were asked to fill in a quantitative evaluation form (Appendix G). Meanwhile, participants were interviewed about the reasons behind the answers. The interviews were recorded and transcribed. Interesting quotes were selected and grouped into clusters.

Figure 34. Participant play with the Ipad

4.4.3 RESULTS

Quantitative results

Participants were required to fill in a quantitative evaluation form after the test. Results are presented in appedix G.

Post-interview

During autonomous driving:

Since participants were concentrating on playing "Angry Bird" and there was no physical movement of the car, they did not notice the lane change. Therefore, during the interview, they did not know the reason for the lane change. So the scene of lane change was showed again. According to user's feedback, in terms of the user interface of the HUD, there are following problems:

It was still unclear why the car decide to change lane

First of all, from quantitative feedback, on average participants rate the understandability 2 (0-5) as not very understandable.

Participants misunderstood that the front two vehicles as a future indication of its car's movement since the graphs of cars look the same. Either the graph should match the cars on the road or in the graph, "my car" should be distinguished clearly from other cars. Secondly, when drivers feel the movement of the car and then they might want to check what's going on. At that moment, normally messages are gone. Therefore, this delay should be taken into consideration.

"...When my father is driving and I feel the movement of the car, that's the moment when you look up and a second or so that's because of that. (Lars)"

"I though the front cars (visual) were my car. I thought maybe I could go straight or I could go there." (Benni)

"The transparency of the car graphs makes it look less real." (chengye)

The indicator sign was not clear for testers.

"The indicator, in the regular car, there are not there when it's not turned on."(Lars)

Participants like the indication of the takeover point but also want to see the ETA.

"I really like the visual of when you need to take over but I would also like to have a ETA of how long I still have. If I have 5 mins, I would not turn on a video." (Soyeon, Lars)

Wakeup call:

The wakeup call is overall efficient in bringing people back to the loop intuitively(rated as 3.2, quite attractive);

Participants were attracted by the light intuitively without knowing the meaning of the "wakeup call" before. They find the "wake up call" easy to understand(3.5/5). After being woken up from ST(paying the game), they were more attentive to the driving situation. In other words, their situational awareness is regained. The breathing rhythm and tint color make it feels neither very urgent nor annoying for participants. Instead, it feels comfortable and one tester said: *"It seems like it's saying"hi, good morning, wakeup.""*

"It definitely woke me up. I did not feel it was very urgent but I understood I have to do something." (Lars) 4/6

The color looks calm and comfortable. It seems like it's saying"hi, good morning, wakeup."(chenye & Lars)

In between the wakeup and takeover request, intervention needed to keep drivers remain attentive;

Though the "wake up call" effectively wakes up participants from ST, however, in between the wake up call and TOR, the regained situational awareness can be hard to maintain. Some of the participants keep playing games till the takeover request. They did not know the priority of things to focus on and how to get prepared. (Before the test, they are not informed that they need to get prepared.) Besides guidance to help preparation, participants said they also want to give input to the car to confirm that you in fact have control of the situation. Otherwise they are like spectators who were watching a scene of a movie. One the other hand, in terms of liability, who's responsible won't be an issue then.

"I find it a bit hard to stay attentive after the wakeup call cuz I was not doing anything. I still felt like I was a spectator who was watching a scene of a movie. "(Jooyoung)

Takeover request:

Most participants took over without checking the driving situation first (not

well-prepared for the takeover);
When the car requested testers to take over, from my observation, as mentioned above, they actually did not get prepared. They did not check the surroundings, the mirrors. Moreover, they did not put down the ipad properly in advance but put the ipad on their legs after hearing the TOR (Figure 35).

"Although I feel if i was really driving, I would not know what is the most important thing to focus on at first. I immediately started drive without checking mirrors."

Mode change from wakeup to takeover, in terms of light signals, is not clear for participants.

The blink is clearly conveying the urgency while the countdown is not very noticeable(countdown was rated as 2, not clear);
Together with the visual and audio info, the blinking signal of the TOR is understandable for participants. However, how much time is left for them to takeover(the countdown of the light stripe) is not clear for them. Some said because the countdown is in his peripheral vision so that the countdown is too minimal to be seen. Besides, some said their attention at that moment was more absorbed into the front(visual info on the head up display and the road situation) than the light signals. Also, for the participant who was aware of the countdown, the end point was not clear for her when she sat inside the car. From the evaluation form, participants felt the takeover very urgent(3.7/5). But still, they don't feel it is annoying.

"I did notice the blinking but not the countdown. Since it is in my peripheral vision, the countdown was a bit too minimal to make me aware that there's a ddl. I think color change would be better."
"During takeover I was more absorbed to the screen than the light signals so i was not aware of the countdown."(Jooyoung)
"I don't know where the end point is when I sat inside the car."
"I did not notice the countdown so I took over immediately . From my point of view, color coding will be more effective in conveying the urgency. It stayed blue."

Affirmative of control after takeover is missing;
Participants were hesitant about whether they successfully took over or not. So direct and clear affirmative of control should be given after driver takes over.
"I don't know if I actually take over or not. When I turn off cruise control, there will be a sign" (Soyeon)

4.4.4 CONCLUSION

From the user test, some of the initial design targets (Chapter 3) are met: The wakeup call is validated as efficient in catching driver's attention and waking them up from secondary tasks. Meanwhile the wakeup call is perceived as not too urgent (exciting); The takeover request is conveyed efficiently and perceived as urgent;

However, some design targets are not met and some problems came out of the test:
- During autonomous driving: It was still unclear why the car decide to change lane (the "why" of automation actions are still unclear and unpredictable);
- Wakeup call: In between the wake-up and takeover request, intervention needed to keep drivers remain attentive;
- Takeover request: Most participants took over without checking the driving situation first (not well-prepared for the takeover);
- Takeover request: The takeover light signal (blinking while countdown) is not clear for drivers and the tint color is not urgent enough;

Therefore, the design should be further optimised and redesign targets are proposed.

Figure 35. What's in common in the above photos : Participants put down Ipad on the legs right before taking over

KEY TAKEAWAYS

- The wakeup call is overall effective in bringing people back to the loop intuitively

Redesign targets:

- The “why”s of car’s intention and next move should be more clear for drivers
- The HMI should support driver to remain attentive after wakeup call
- The HMI should support driver to get prepared before takeover , which is also in line with the feed-back from concept evaluation (see chapter 4.3 key takeaways)
- The takeover request(light pattern) should be more clear

4.5 2ND DESIGN VERSION

According to insights from the previous user test (chapter 4.4), the design was further developed (Figure 36).

OVERVIEW OF THE REDESIGN

The redesigned takeover experience is concluded in Figure 36.

There are two main phases: Automated driving (AD) and manual driving. Under these two phases, 5 sub-steps/modes are employed: (Driver) conduct secondary tasks, wake up call, get prepared, takeover request, and resume control.

The redesigned journey is divided into four parallel time-lines, one shows the change of driver's situational awareness under different interventions, and the other three illustrate the design interventions throughout the journey which are UI design on the HUD, different light strip patterns and notifications via other modalities.

1. HUD

According to the redesign targets, some changes were made on the HUD design. First of all, the "why" of the automation action is more clearly demostrated by highlighting the target(for example highlight the front car when the front car is too slow to drive behind) and associating the text reasons with the target (eg. "TOO SLOW"). After showing the "why", indicate the next action of the automation (eg. when change lane, indicate the move by showing the blue path)

2. PROVIDE NOTIFICATION TO WHERE ATTENTION IS

In the automated vehicles, there are camera monitoring driver's state. The camera identifies where the driver's attention is (eg. playing with phone). The automation sends "wakeup call" on the phone via notifications

2. WAKE UP CALL

If the driver is not woken up by the wake up call, first of all, the color will change from tint to orange to increase the preception of urgency. Meanwhile, the HMI gives notification via single tone audio reminder and vibration on the seat

Figure 36. 2nd design version

3. STEP BY STEP PREPARATION

As mentioned in design targets (chapter 4.4), design interventions are needed to keep driver remain attentive and guide them get prepared. Therefore a step by step guidance

3. PROVIDE INFORMATION ACCORDINGLY

Eg: Virbartion on the seat

4. TAKEOVER REQUEST

If the driver is not woken up by the wake up call, first of all, the color will change from tint to orange to increase the preception of urgency. Meanwhile, the HMI gives notification via single tone audio reminder and vibration on the seat

4.6 ONLINE USER TEST

According to insights from the previous user test (Chapter 4.4), the design was further developed. Initially, the 2nd user test was planned to conduct with physical prototypes. However, due to the coronavirus, we need to isolate ourselves at home and are forced to embrace the "digital transformation" all of the sudden. Luckily, as designers, we are well prepared to face this challenge. So I decided to shift the 2nd user test online.

4.6.1 GOAL OF THE USER TEST

The redesign targets are listed in chapter 4.4

4.6.2 RESEARCH METHOD

Instead of making physical prototypes, an animation is made to simulate the whole takeover experience. Some cons of the online test are inevitable. In the animation, the simulation effect of the light strip may not be very close to reality. But since from the previous test with real light strips, the effectiveness of the light strips are validated. So for the online test, though there might be deviation in terms of interaction with light strips, it is a good way to evaluate the targets.

The test process is similar to the previous test (Chapter 4.4). After they experiencing the takeover online, they were asked several questions:

[Understandability] Do you find it clear why the car changes lanes?
[Understandability&support] Did you find the guidance guide you to get prepared clearly?
[Understandability] Did you notice the countdown of the light-strips and do you understand what it means?

4.6.3 RESULTS

The lane change is clear
In last test, participants find it not clear why the car change lane. After redesign, targeting the reason and associating reason in text with it, testers find it more clear.

[Step by step guide] Too much information
One participant find it hard to understand why you need to have so many guides to takeover. One participant find there are too much information. For the first one, after explaining to him that in level 4, you can sleep or watch video for 30 minutes and then takeover. Before takeover, it is of vital importance to wake up, get prepared and get fit to takeover. Then he said: "Now I understand. You need to let ppl know this point. Otherwise, we will just think from our driving experience."

"You get too much information."
"When see the guidance, my attention is on the screen."

KEY TAKEAWAYS

Redesign targets:

- The step-by-step guide can be ***more intuitive and simple***. For instance: open the mirror as an indication of mode change and driver needs to check it etc.
- The light pattern can be ***more attracting.*** For example: spreading to the whole windshield

EVALUATION&OPTIMISATION

In the following sectors, a final evaluation is conducted to validate whether the final design meets the design goal as well as the usability of the design. After final evaluation, together with insights from previous iteration, a final design is illustrated. The final design is explained with first of all, a redesigned logic flow map and secondly the redesigned takeover journey map.

Chapter overview:

05

5.1 FINAL EVALUATION

The last phase of design process is to evaluate the final design with specialists from Mediator group and potential users. The aim is twofold: validate whether the final design meets the design goal (understandability, effectiveness and support and supportiveness) and evaluate the usability of the system. This section introduces the evaluation process, the obtained results. Meanwhile a recommendation is given based on the evaluation outcomes. Last but not least, since the final evaluation is conducted online, limitations are also given.

5.1.1 GOAL OF THE USER TEST

The aim is twofold: validate whether the final design meets the design goal(understandability, effectiveness and support and supportiveness) and evaluate the usability of the system. Research questions for the evaluation is :

1. *Is the design goal achieved (understandability, effectiveness and supportiveness) ?*
2. *How's the system's usability (System usability scale)?*
3. *What are the pros and cons of the final design?*

5.1.2 RESEARCH METHOD

3 specialists from Mediator team and 5 potential users were invited to take part in the online evaluation session (Invitation letter

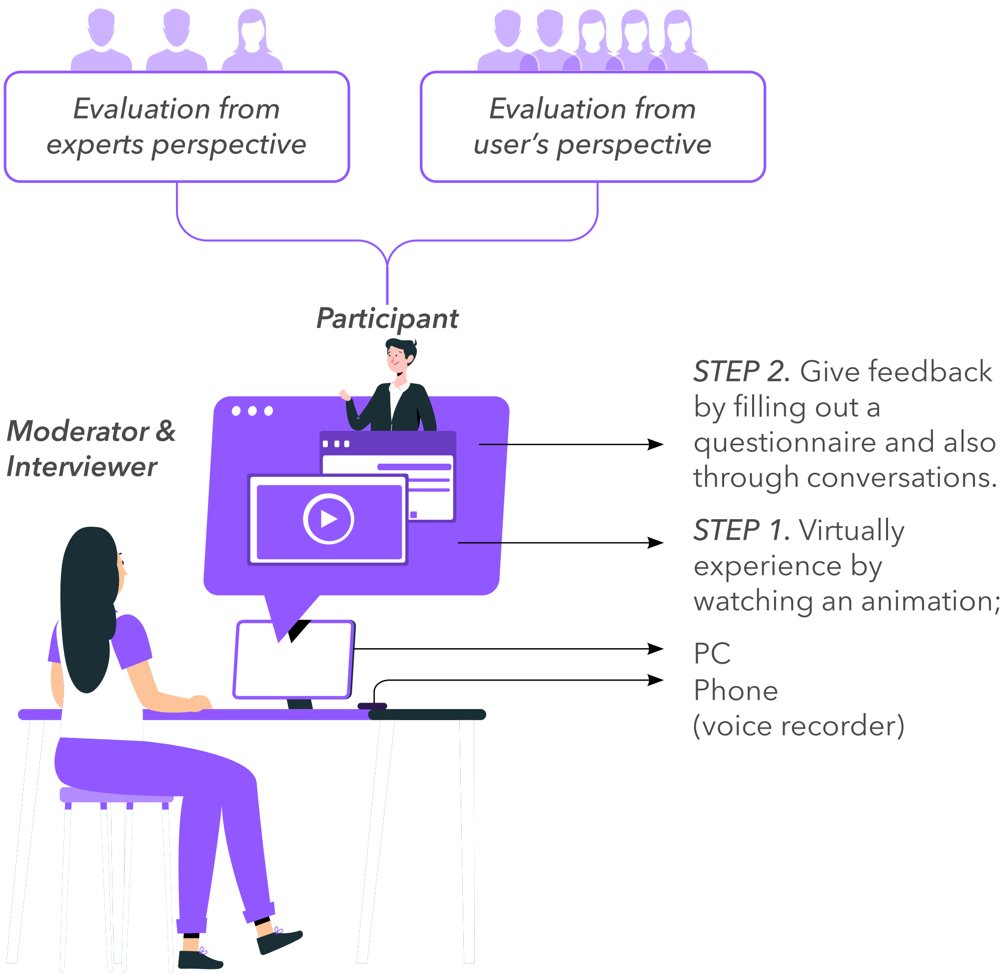


Figure 37. Setup of the final evaluation

see Appendix H). Each session took around 30 - 40 minutes. Figure 37 shows the setup and content of the evaluation session.

5.1.3 RESULTS

Qualitative feedback

Conduct secondary tasks (During automated driving)

[Understandability]

Showing some transparency about what the automation is doing is an added value.

Presenting the reasons for automation's actions and its next moves is regarded as enhancing the automation's transparency and ultimately enhancing the user experience while automated driving.

"Seeing the simple explanations makes me feel less anxious." Potential user

Showing the time left before takeover is useful for drivers so that they can better arrange the time and decide what STs to do.

"I think like the bar is a very good idea. If the driver wants to know, shall I write this email or not? So you can check the head up display to see Well, I have 10 minutes left. Yeah, why not?" Specialist

Information on the HUD should be the most essential ones. However, some information on the HUD display is still regarded as less priority. For example, time, temperature and even power capacity are suggested to be left out since the driver will only check those info occasionally.

Situational awareness:

Only have a very brief idea of surroundings e.g. if it is crowded on the road and mostly focusing on STs. When feeling the car moves (lane change or brake), drivers will pay a bit more attention.

Wake up call

[Effectiveness]

Wake up light works not as effective in waking up ppl as the in first user test (see Chapter 4.4) with physical light bar. The wakeup call through light signals is very intuitive in conveying the information that "something is about to happen". So participants consciously pay more attention to the driving context from the secondary tasks. Specialists said the closed loop to check if the driver responds is indeed essential.

[Effectiveness]

Providing information to where the attention is regarded as effective and clear.

"This indeed works. It's a nice way of integrating into the context of being distracted." Specialist A

"Put them in a place where the attention is a very good idea." Specialist B

Situational awareness:

After woken up, participants become a bit alert, pay more attention to the road and expect something to happen soon.

Step by step guide

[Supportiveness]

Participants feel supported and guided on what to prepare. But some of them miss feedback from the HMI to confirm that the HMI knows they follow the steps.

"I think with step by step protocol or guidance and it's clear what you have to do." specialists

The swiping (dynamic) transition of steps ensures the change of information can be better perceived. With the swiping, it's quite a subtle way to attract attention to the interface and read the next messages.

"I really like the fact that the circles and the text that they are swiping, because if it says pay attention to the road that you will look around ideally. And if the icon changes without swiping, use the same circle size, then you may miss the fact that the mes-

sage was replaced." Specialists A

Not knowing when the takeover is gonna happen causes anxiety (First time use). For the first time use, participants expect takeover to happen anytime soon. So they feel quite nervous. But they also think it easy to learn about the system/steps since it is very ***intuitive***.

"I already had the feeling takeover is gonna happen anytime I need to put my hands close to the wheel. But if i use it twice, I will learn about the system very quickly because it's quite intuitive." Specialist A

Participants think after getting used to the system, the step by step guidance ***won't be either annoying or intrusive*** as it is rather subtle. Instead, the step by step guidance is regarded as a helpful, clear and a ***pleasant journey***.

"It's not like loud whistling bells all the time. So I don't think you will be too annoyed by this protocol. It's rather subtle." Specialists B

Meanwhile ***the consistency of the steps is regarded as very important***. As drivers will get used to it and know the exact steps of the procedure, if once the steps change, there's a risk that the driver might overlook the change and ultimately lead to less trust in the system.

Situational awareness:
Participants follow the step by step guidance, feel guided, and less anxious. Meanwhile, as guided, check the surrounded driving condition.

Takeover request
[Effectiveness]
Takeover request turns out to be quite clear and efficient in conveying the message to participants.

"Oh, it's very clear!" Specialists
" I think it's really good that it really works to help you work towards the points where you will have to regain control. So for me that's clear."

"Also with the timer and the sounds, I mean, that's very clear." Specialist

Though the ***activation process*** is rather short, some participant find it necessary to have it to make the system more transparent and prevent false activation.

"I need clear affirmation of the activation when I put my hands on the steering wheel."potential user

Situational awareness:
Participants become very concentrated on the driving task as well as the surrounding road as he/she is driving on his/her own.

System usability scale
The SUS score given by participants are 72.5. According to Bangor, 2008, SUS score from 68 – 80.3 is regarded as *Good* in terms of the usability performance in the aspects of effectiveness, efficiency, and overall ease of use. Table 4 shows the detailed outcome of SUS.

5.1.4 CONCLUSION

Based on the evaluation, the design meets the design goal quite well in terms of the understandability, effectiveness and supportiveness. The information provided on the HUD adds to the transparency of the automation system. It enhances the mutual understanding between drivers and the automation system. Furthermore, the design (wake up call, step by step guidance and takeover request) effectively communicates information (mode changes etc) with the driver and helps driver regain SA effectively. In addition, participants feel supported by the system and guided to back to the loop intuitively. Last but not least, according to the SUS result, the usability performance is also validated as *good*.

Figure 38. Impression of the online evaluation

SYSTEM USABILITY SCALE

- Rate given by each participant
- Average rate

Strongly **disagree** — Strongly **agree**

1. Would like to use frequently
2. The system unnecessarily complex
3. The system was easy to use
4. Need the support of a technical person
5. Various functions were well integrated
6. There was too much inconsistency
7. Most people would learn to use it very quickly
8. The system very cumbersome to use
9. Felt very confident using the system
10. Needed to learn a lot of things before get going with this system

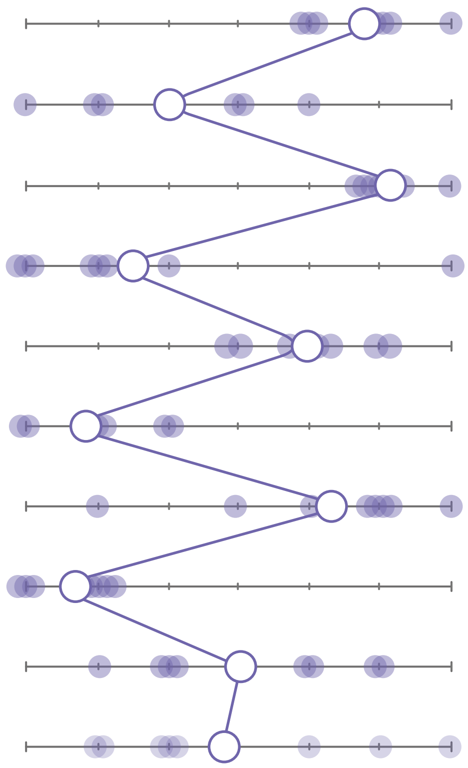


Table 4. System usability scale result

5.2 FINAL DESIGN

After the design iteration, a final design is proposed according to the insights from various users/experts feedback.

5.2.1 OVERVIEW OF THE REDESIGN

This chapter illustrates final design from two perspective:
1. The redesigned takeover experience flow is explained in Figure 38 with a focus on the logic flow behind;
2. The redesigned takeover experience with a focus on the design is concluded in Figure 43.

There are two main phases: Automated driving (AD) and manual driving. Under these two phases, 5 sub-steps/modes are employed: AD: (Driver) conduct secondary tasks, wake up call, get prepared, takeover request, and MD: resume control.

5.2.2 REDESIGN LOGIC FLOW

In Figure 38, the redesigned flow is divided into three parallel time-lines, showing the driver's actions(input), detection loop and HMI (output) respectively.

Conduct secondary tasks during automated driving
The detection of automation system is two-fold:
1. detect driver's state whether driver is in state C (fully out of the loop (e.g.sleep)) or state B (partly out of the loop);
2. detect where the driver's attention is to better notify driver for later wake up call.

Wakeup call
Then when and how to wake up driver from STs are decided according to the detection results. In other words, if driver is in state B, wake up the driver two minutes before the takeover. If driver is in state C, wake him/her up 5 minutes before the takeover since longer response time is required in state C. Meanwhile, if driver's attention is detected on the phone, then wakeup notification will be sent to the phone together with wake up light.

While the HMI is trying to wake up dirver, the automation system detects if driver is woken up and responds to the wakeup call. If not, the wakeup call will upgrade to a more exaggerated one: light turns to orange, seat starts to vibrate along with a warning tone.
After driver responding to the wakeup call, then the HMI switches to next phase.

Step by step guide
The detection loop confirms driver's response to each step by tracking driver's eyesight. The guidance switches to the next step if the driver is detected to check each step.

Takeover request
After getting prepared and driver becomes fit to takeover, the HMI request the driver to takeover control. The takeover is achieved when driver puts both hands on the steering wheel for more than 3 seconds. If confirmed, the car mode switches back to manual driving.

REDESIGNED JOURNEY FLOW

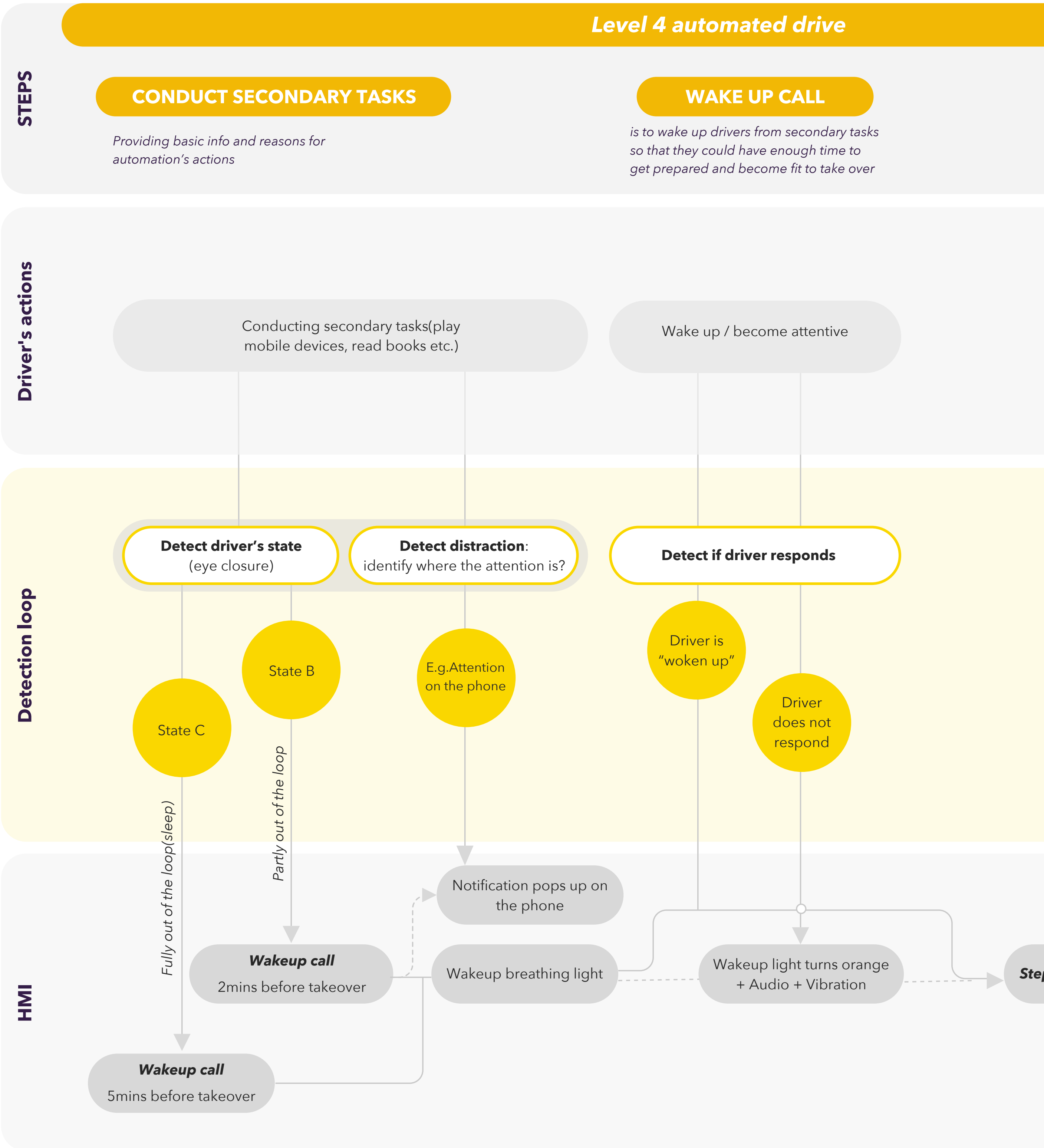
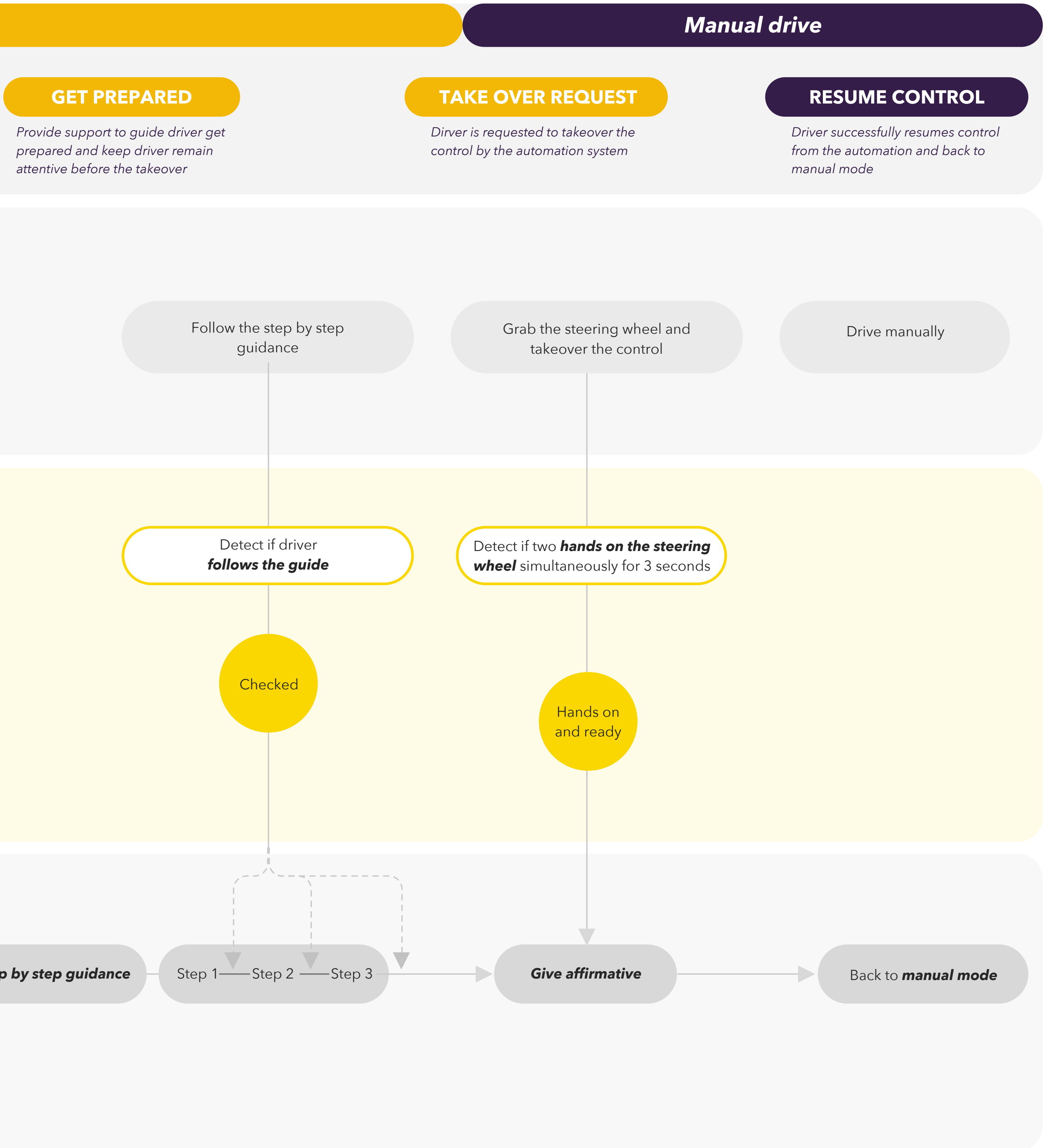


Figure 38. Redesigned logic flow


Manual drive
GET PREPARED
Provide support to guide driver get prepared and keep driver remain attentive before the takeover
TAKE OVER REQUEST
Dirver is requested to takeover the control by the automation system
RESUME CONTROL
Driver successfully resumes control from the automation and back to manual mode
Follow the step by step guidance
Grab the steering wheel and takeover the control
Drive manually
Detect if driver follows the guide
Detect if two hands on the steering wheel simultaneously for 3 seconds
Checked
Hands on and ready
p by step guidance
Step 1
Step 2
Step 3
Give affirmative
Back to manual mode

5.2.3 REDESIGN JOURNEY MAP

The redesigned journey map illustrates the design in detail. It is divided into four parallel time-lines, one shows the change of driver's situational awareness under different interventions, and the other three illustrate the design interventions throughout the journey which are UI design on the HUD, different light strip patterns and notifications via other modalities.

Tne overview of design is demonstrated in Figure 40.

Conduct secondary tasks during automated driving

HUD: Information displayed on the HUD is minimalised in to only three parts in the final design: the speedmeter, the road simulation (changes in different phases), and

Figure 40. E.g notification on the phone

the Mode indicator (Figure 39).

Wakeup call

The wakeup call is given by:
1. Initially the wakeup call is breathing in color tint (Figure 43) to inform driver that "something is going to happen and be attentive!" Meanwhile, notification is given to where the driver's attention is (Figure 40).
2. If driver is not woken up, then the wake up will given in the form of "orange breath-

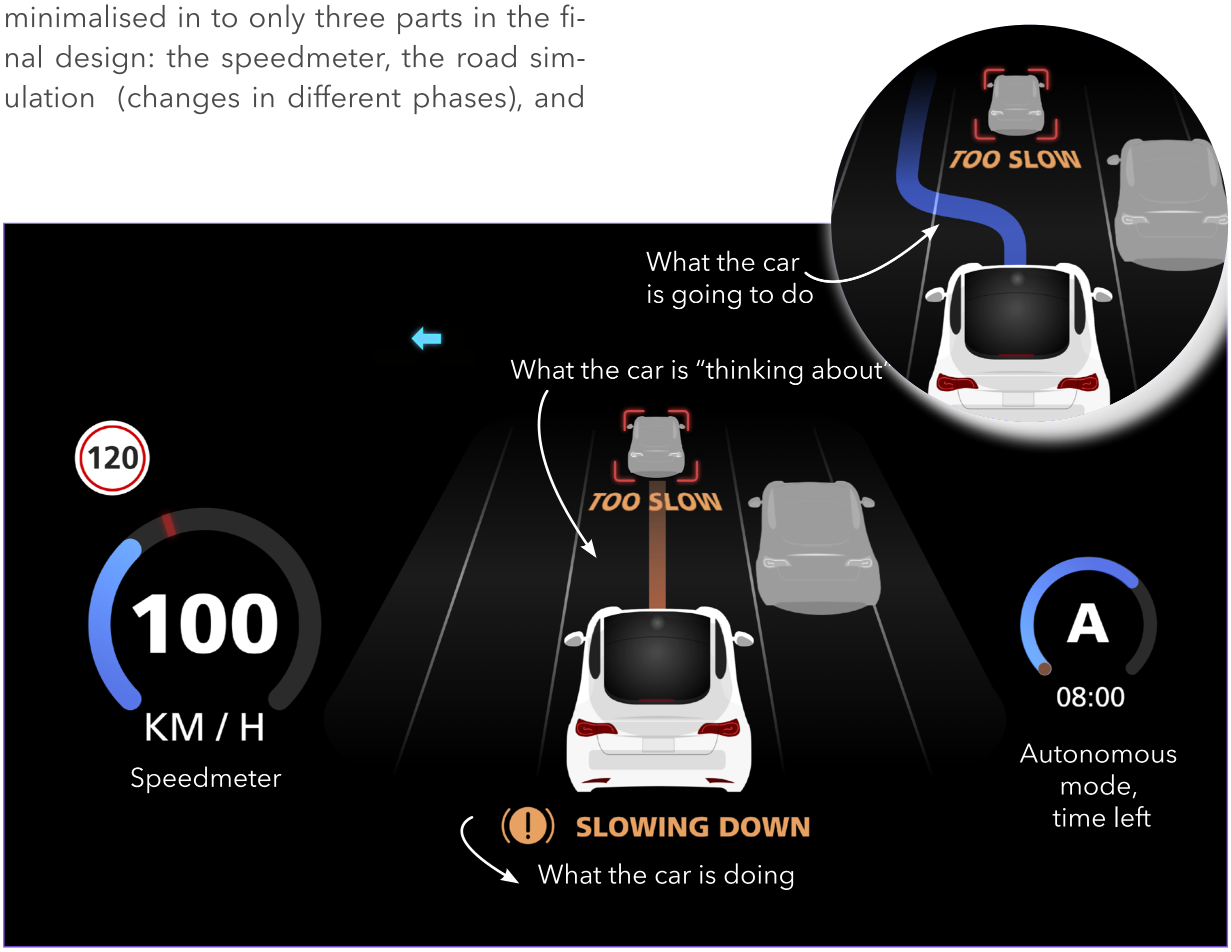


Figure 39. Information on HUD

ing light, vibration on the seat with audio sound"

Step by step guide
A three step guidance (Figure 41) is given to drivers to support them get prepared and ultimately become fit for takeover.

The swiping transition ensures driver notice the change of steps.

Takeover request
After driver gets prepared, the takeover request follows up seamlessly. The takeover request is given with multi-modal notification at the same time: visual(blinking and gradient light signal, universal takeover message on the HUD), auditory(takeover warning sound).

Situational awareness
The overall change of driver's situational awareness is shown with the red line in Figure 43. While driver paying a lot attention to secondary tasks during automated driving, his/her situational awareness is quite low. If he/she is required to takeover directly, as shown with dark purple line in figure 43, it is very difficult for driver to regain SA in a short period of time. Thus, it is rather risky.

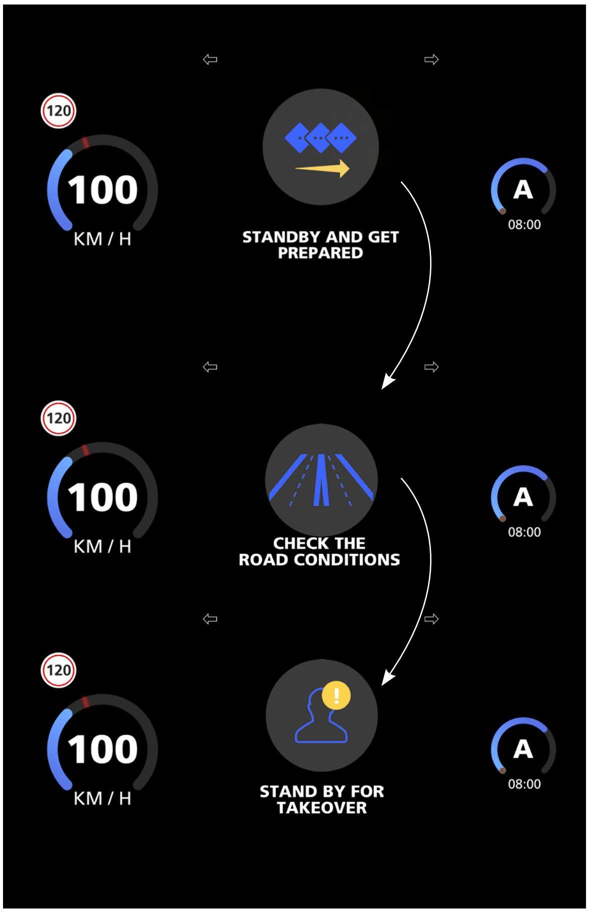


Figure 41. Information on HUD (step by step guide)

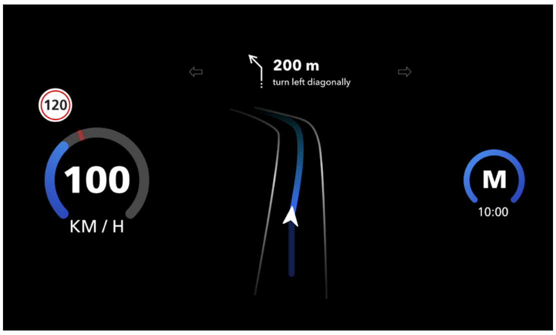


Figure 42. HUD during manual driving

With the step "wake up call", after being woken up from secondary tasks, driver becomes more alert and pay more attention to the surroundings.

However, according to insights from Chapter 4.4, participants were not aware that they need to prepare for takeover, e.g. stop STs and they were not aware of the priority of stuff to prepare either. In other words, it is very easy to lose attention in between wake-up call and takeover as shown with yellow line in figure 43. With the Step by step guidance, it supports drivers to remain attentive, regain situational awareness gradually and ultimately become fit for takeover as shown with red line in Figure 43.

CONCLUSION

Final design is concluded in the redesigned journey map.

REDESIGNED JOURNEY MAP

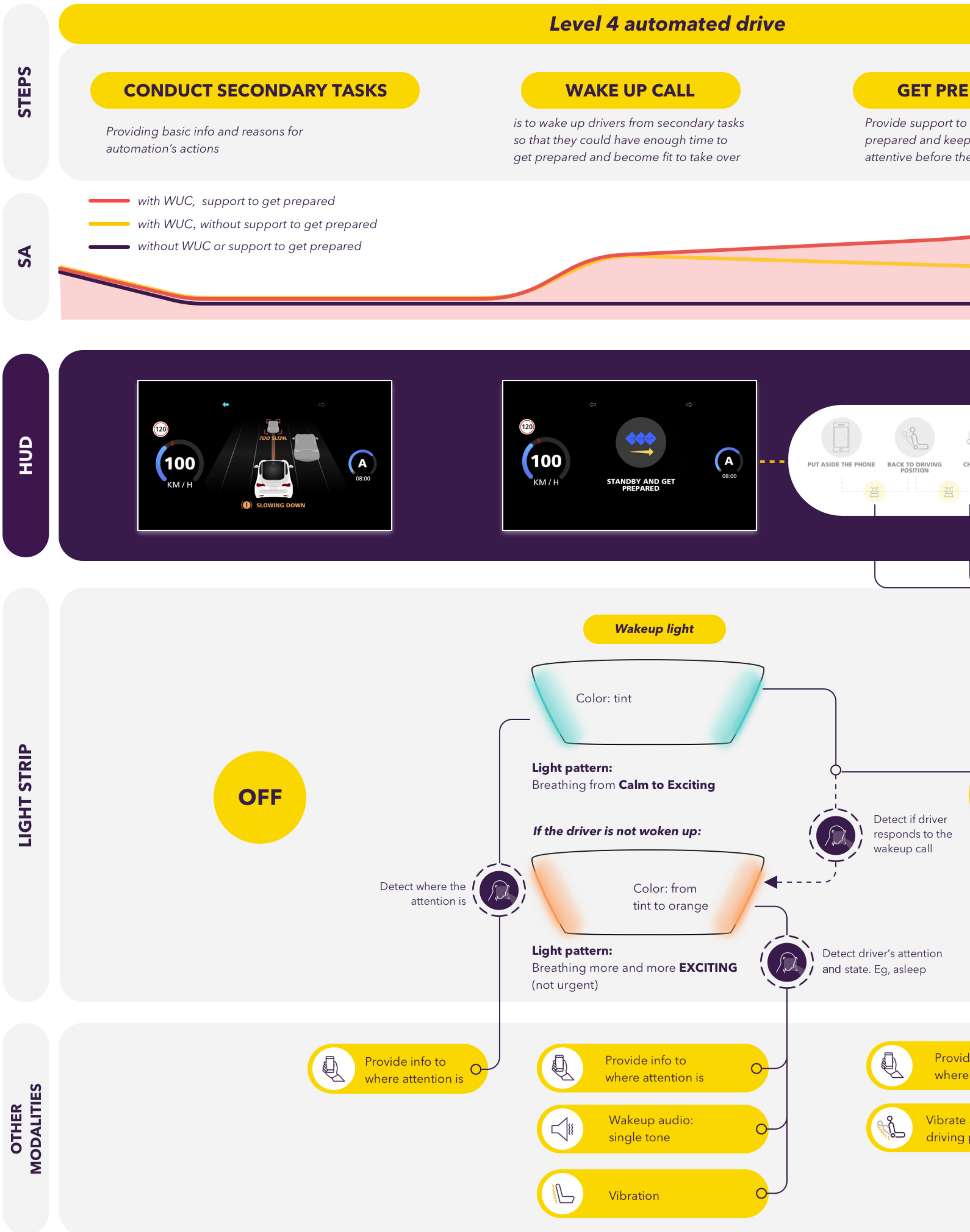


Figure 43. Redesigned journey map

Manual drive

PARED

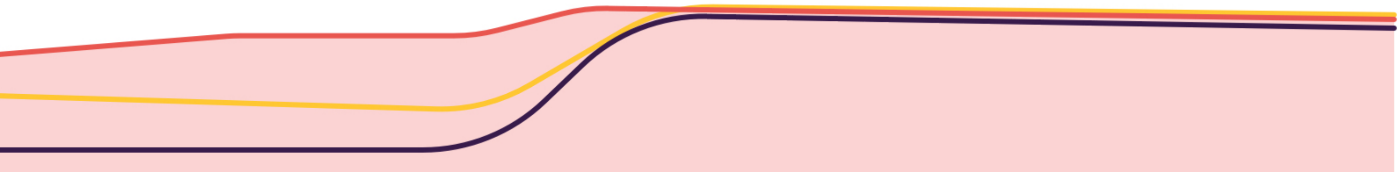
guide driver get
driver remain
takeover

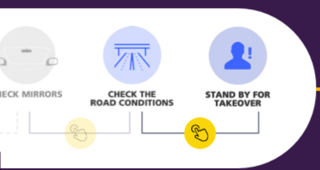
TAKE OVER REQUEST

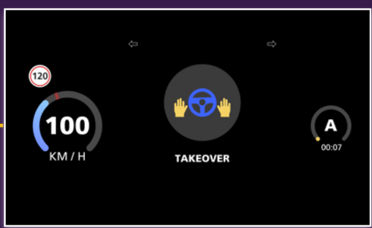
Dirver is requested to takeover the control by the automation system

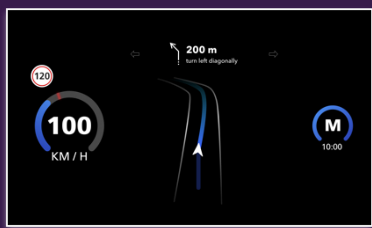
RESUME CONTROL

Driver successfully resumes control from the automation and back to manual mode



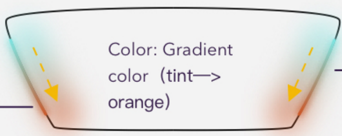






OFF

Takeover request



Color: Gradient color (tint—> orange)

Light pattern:
Countdown with gradient color

Grab steering wheel or touch the pedal

Affirmative of takeover

Light pattern:
Light bar on the steering wheel shows the deactivation process

e info to
attention is

and turn back to
position automaticaly

Alarm

Affirmative sound:
single tone

Final Design

CONCLUSION

ANSWERS TO THE INITIAL RESEARCH QUESTIONS:

"When is it needed to communicate what kind of information and how to communicate the information with the drivers during takeover?"

During automated driving - driver is doing secondary tasks (when):
During this period, drivers prefer to manage this time on their own without too much interference from the vehicle. Therefore, information about the automation should be displayed on the HUD, requiring only voluntary attention from the driver ***(how).*** In terms of the information on the HUD, first of all, it is suggested to only put the most essential info on the HUD. Secondly, regarding the content of simulation, to be more transparent or understandable, what the automation is doing, why it is doing so and the intention / next maneuver of the automation should be illustrated on the HUD ***(what).*** In addition, the car speed, how much time left before takeover ***(what)*** are essential to inform drivers.

During automated driving - it is time to wake up driver(when):
When to wake up the driver depends on his/her state as mentioned in chapter 1.4, as time required to respond differs.

When in state B (Figure 38), wakeup driver 1.5 - 2 minutes before TOR. When in state C, wake up the driver around 5 minutes before TOR.

During this time, the aim is to awake drivers from STs, inform them mode change is about to happen and bring them gradually back to the loop ***(what)***. Design intervention at this time should not be too intrusive as the urgency is not high. In this design, ambient light is chosen to wake up drivers which is inspired by the Philips breathing light ***(how)***.

During automated driving, immediately after wake up call:
At this time, the main goal is to remain driver's situational awareness and guide drivers to get prepared. Therefore, guidance on what to prepare ***(what)*** should communicate to drivers through HMI (HUD) ***(how)***.

Takeover request:
At this moment, it is rather short and the urgency level is high. Communications should be effective, simple and strong ***(how)***. So intrusive means are deployed. Takeover request ***(what)*** shows up on HUD along with audio warning sound and countdown ambient light strips ***(how)***.

After resuming control:
After drivers successfully back to the loop, affirmative should be given clearly. Mode change should be stated very clearly too. In the design, deactivation is communicated through the light bar on the steering wheel. After switching back to the manual drive, road simulation is no longer needed. Instead, a simple and clear navigation should be there. Also, the speed, current mode and duration should still be kept ***(what)***. The above information is demonstrated visually on HUD ***(how)***.

LIMITATION

Restraints on final experiment
A significant limitation is that in unexpected corona situations, the duration of the thesis is limited while when everything can go

back to normal is uncertain. Physical/offline experiments are no longer possible after the first user test. But fortunately, in the first user test which is focusing on the wakeup call and takeover request, the light signals and takeover request (audio/visual) were tested with a simulation of real interactions. The step by step guidance is the main testing objective for online tests. Since the step by step guidance is presented on the HUD, online testing is sufficient to collect insights in terms of users' feedback for the interface. However, for the final evaluation of the overall experience, it is conducted by providing an online animation to let participants experience in a virtual way. The online experience can be biased:

1. The screen is too small to simulate the car interior. Visual messages on the HUD are therefore too small to read;
2. The online interactions can be biased. Regarding the feedback of light signals, results from the first user tests (offline) and the online evaluation are very different.

In the offline test, the change of shades of light enables participants to perceive the light signal very quickly. However, in the online test, not only the light bars are smaller but also the shades of light are not well-perceived from the digital screen. But in terms of the visual messages and audio messages, the online evaluation produced useful and less biased insights. Last but not least, the haptic element has to be left out from the final experiment. Instead, only describing the haptic effect like "the seat starts to vibrate now" can be very ineffective. If the corona situation still continues for a long time, how to best conduct an efficient, unbiased online experiment would be a big challenge for the mediator group.

Here are my several tips:

1. Bigger screens: Try to recruit participants who have big screens instead of a pc;
2. Simulate the set up: Provide a set up guide for participants: for example, put the screen on a higher place (e.g on top of some books) to simulate the fact that for instance, if you look down on your phone then your vision is off the road;
3. Instead of observing, listen and dig: Since for online evaluation, it's hard to observe the interaction. It's suggested that the moderator should ask the driver to think out loud and carefully listen, ask questions accordingly and dig into the real problems that participants encounter.

Restraints on participants

Moreover, for qualitative tests, test samples with 5 - 7 participants are good. It's not about how many users are being delayed. Once several people are stumped by the same design element, the design element needs to be revised. However, for quantitative research, around 20 test samples would be appropriate as it's all about data and it's easy to end up with misleading data without enough sample numbers (Nielsen, 2016). So it is suggested for the future experiments, if it will be quantitative, try to recruit around 20 participants.

Restraints on scope of the project

Due to the scope of the master thesis, one important element in automated driving is not covered. Looking back to the research insights, there are many interesting findings about the passengers' interaction with drivers and automation. For example, passengers normally know little about automation and therefore even less trust in autonomous driving, more surprises and even worries. For the future projects, it is highly recommended to take the passengers into consideration.

RECOMMENDATION

Since there will be further iteration of the project, recommendations are proposed for the later projects.

Talking to specialists

Autonomous driving is a topic that contains much technical knowledge behind. If researchers or designers do not have much knowledge in this area, after conducting a massive literature review, it is recommended to interview specialists who have years of experience in AD. It helped me organise the knowledge that I learnt from the literature review and position the key painpoints in a very efficient way.

Target groups require further clarity

In my project, I only considered who would be the user of future automated vehicles? As the project progresses, in the user tests that I conducted before, participants' experience can vary according to how familiar he/she is with the system. Neville also proposed that for beginners, intermediate and advanced drivers, the HMI is expected to be different. So for later projects, it is recommended to analyze the user group more clearly.

Ethical issue

Some participants said they worry about the fact that in the future automated cars, there will be eye trackers or cameras. They are afraid that this might affect their privacy and result in participants stepping backwards. This is definitely something interesting and valuable to look into.

Don't forget passengers

As I mentioned, passengers' experience also plays a vital role. For example, passengers normally know little about automation and therefore even less trust in autonomous driving, more surprises and even worries. Also passengers have direct interaction with drivers, therefore their experience can have great impacts on the driver. However, due to the limited scope of the project, not much research has been done

REFLECTION

This section delivers the reflection on the project and personal experience.

PERSONAL REFLECTION

Executing the graduation project was a challenging experience for me. Not only the topic autonomous driving is new to me but also I need to do the project individually from the start to the end, in charge of literally everything: planning, communication, interviewing, analyzing, facilitating, and ideating etc. This is also challenging for me because in the previous projects, I would possibly lay back from the parts that I think I am not good at and let other teammates do it. I can still remember vividly, in my first project here in Delft, I was not familiar with the methods / design process here. So managing the direction and progress of the project was sometimes very challenging. Throughout the graduation project, I am able to apply and validate the user-centered design methods that I learned from my master courses and projects confidently on my own. I could say I am satisfied with the end results and the process towards it. It's very proud to see how much I learnt and grew from the "me" two years ago with my study here in TU Delft and also my internship in Alibaba. I definitely become more confident in planning and leading a project and start to get excited about starting my career as a UX designer soon. In this project, I also see my potential in tackling complex topics like autonomous driving. It's more and more clear for me that my goal is to be a UX designer who can bring the user-centered mindset into tackling problems behind cutting edge technologies, follow the digital transformation and update myself with the future developments.

PROJECT MANAGEMENT

As I personally would like to finish the project on time, the project in the end, time wise, does not have much delay. But still, managing an individual project is highly depending on self discipline. From this perspective, I personally prefer to work in teams so that we could help, motivate and strengthen each other along the journey.

WHAT COULD BE IMPROVED

Look back to the project, if there was a second chance, I would work more closely with the Mediator team. Before the start of my project, I would like to have a meeting first with the Mediator group and have someone from the team discuss the strategies, scope, direction, ambitions etc more thoroughly. In this way, this project can be more practical and valuable for the Mediator group.

Also, in the end, the plan of the project had to be adjusted and I was not able to build the final offline experiment. This was something completely unexpected. It was super tough to not be able to follow the original plan and complete the project in an ideal way. However, I am also glad to see how I utilized my technical background and flexibly adapt my project to the unexpected situation. I definitely learned a lesson for future projects.

Last but not least, I hope this project gives valuable insights in how user-centered design methods can be deployed in tackling the automous driving issues. And more specifically, Mediator team can hopefully gain inspiration from the HMI design on optimising driver's takeover experience as well as leading to a better takeover performance.

ACKNOWLEDGEMENT

Reaching the end of the journey, I would like to express my sincere gratitude to everyone who gave me support during the process.

To the supervisor team
First of all, I would like to thank my coaches for supervising me, inspiring me, supporting me and offering me a lot of trust and flexibility throughout the project. Without you, the project would definitely not have been a success. Elmer, thank you for that you believed in me at the beginning and gave me this great opportunity. Your insightful feedback and a great sense of humor enable the coach meetings to always be quite positive and pleasant. Rene, thank you for your scientific point of views which always went right to the heart of the matter. Also, Wouter, thank you for offering help when I was looking for a project. You always pass very positive energy to me and your insights from being a practitioner really boosted the project.

To all the participants
For all of the participants in this project, people in the Tesla facebook group, participants in the user tests, Chenye, Soyeon, Jooyoung, Lars, Sum, Liangyi, Mediators, Reinier, Angelique, Michiel, I want to show my appreciation for your time and engagement.

To my family and friends
I would like to express my deepest thanks for my parents for their selfless support and care. I also would like to use this as a chance to honour my grandfather who left us during this project. Without you, I will never go this far. You will always be in my heart. To my friends, wherever you are, thank you for checking my physical and mental health from time to time during the corona times.

To my boyfriend
Last but not least, I want to thank my boyfriend, Jian. I am so fortunate to have you who always listen to my stories, ideas, complaints, cheer me up when I am upset, and give me confidence when I am in doubt.

Xinyi


WORK
FROM
HOME

REFERENCE

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