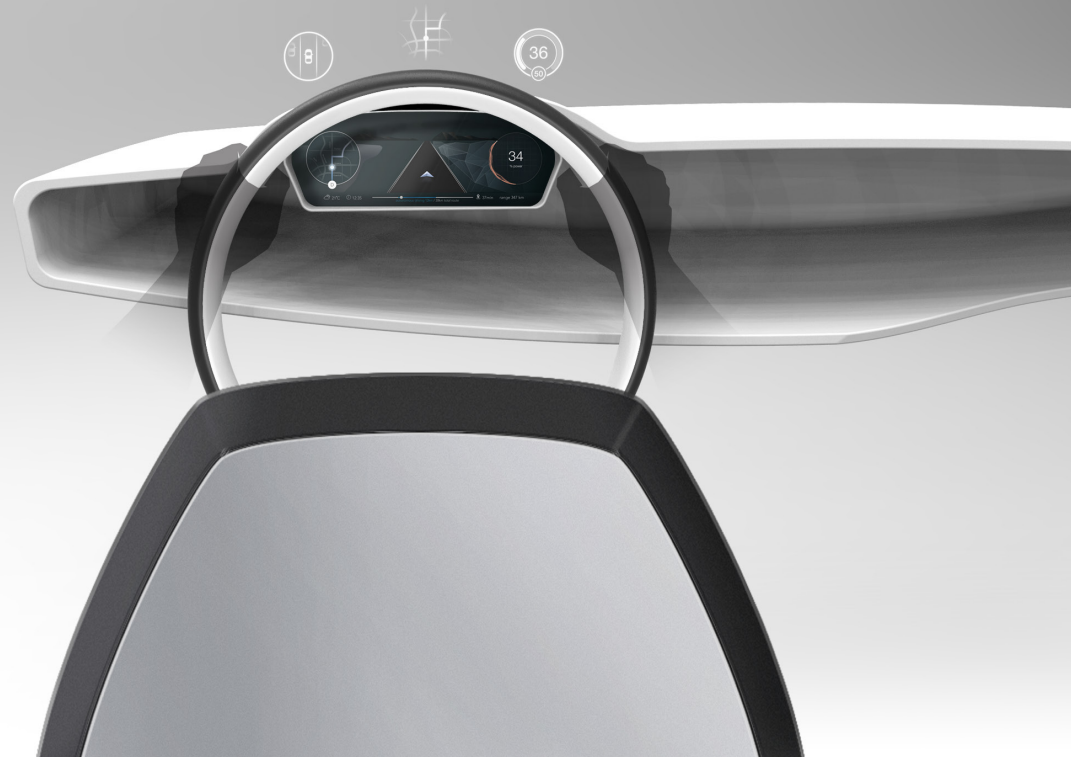


AUTHORITY TRANSITIONS

in highly automated vehicles



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TABLE OF CONTENTS

Video & Audio reference	4		
List of definitions	5		
Executive summary	6		
1. Introduction	9		
1.1 The problem	10		
1.2 Approach	16		
1.3 Project setup	17		
1.4 Concluding	18		
2. Highly automated driving	19		
2.1 Driving	20		
2.2 The road to autonomous driving	22		
2.3 Impact of automation on driver performance	26		
2.4 Mode transition	28		
2.5 Cognitive ergonomics	32		
2.6 Concluding	36		
3. Future design context	37		
3.1 Global trends	38		
3.2 Technological developments	40		
3.3 Megacities	44		
3.4 Customer segmentation	48		
3.5 Concluding	50		
4. Context of use	51		
4.1 Tesla autopilot	52		
4.2 Observing driving lessons	54		
4.3 Concluding	57		
		5. Problem definition	58
		5.1 Design goal and principles	59
		5.2 Experience map	62
		5.3 Interaction vision & qualities	66
		5.4 Concluding	68
		6. Designing the transition	69
		6.1 Ideation	70
		6.2 conceptualisation	74
		6.3 Head-up display	80
		6.4 Instrument cluster	83
		6.5 Steering wheel & levers	86
		6.6 Seat	88
		6.7 Design scenario	91
		6.8 Concluding	108
		7. Evaluating & optimising the design	109
		7.1 design evaluation	110
		7.2 Optimisation	120
		7.3 Concluding	122
		8. Conclusion	123
		8.1 Conclusion	124
		8.2 Recommendations	126
		8.3 Evaluation	128
		References	129

VIDEO & AUDIO REFERENCE

Video A

Explanation of the Head-up display with the active safety features.

Video B

System during an action during autonomous driving.

Video C

The Head-up Display during the activation of automated features in assisted driving.

Video D

The take over sequence from autonomous driving to assisted driving.

Audio A

Wake up warning (three levels)

Audio B

Acknowledgement of a warning

Audio C

Attention on the road warning (three levels)

Audio D

Take over warning (three levels)

LIST OF DEFINITIONS

Active safety features

Safety features that aim to prevent an accident from happening rather than mitigating the damage.

Adaptive cruise control (ACC)

The speed is controlled by the system by sensing the environment in front of the car

Autonomous car

Self-driving car, a vehicle that is capable of sensing its environment and navigating without human input. This can be with or without a human being in the car.

Driver

The person that drives a vehicle, but in this report also the one behind the steering wheel when automated driving is activated

Driving mode

A type of driving scenario with characteristic dynamic driving task requirements (e.g., expressway merging, high speed cruising, low speed traffic jam, closed-campus operations, etc.).

Dynamic driving task

Includes the operational (steering, braking, accelerating, monitoring the vehicle and roadway) and tactical (responding to events, determining when to change lanes, turn, use signals, etc.) aspects

of the driving task, but not the strategic (determining destinations and waypoints) aspect of the driving task.

Feedback & Feedforward

In a product, information that addresses questions of execution (doing) is called feedforward. Information that helps understanding what has happened is feedback.

Lane Assist

When the driver is in control of steering and the car seems to depart from the lane without the driver intending to do so, lane assist will keep the car on the right lane.

Lane Keeping

The system keeps the car within the lane lines.

System

Combination of hardware and software components that receive input from, and communicate output to, a human user in order to support his or her performance of a task.

Usability

How easy & pleasant the features are to use.

Useful

Usability & utility.

User experience

All aspects of the end-user's interaction with the company, its services, and its products.

Utility

Whether it provides the features you need.

V2I

Vehicle to infrastructure communication

V2V

Vehicle to vehicle communication

V2X

V2I and V2V together

Vulnerable road users

Pedestrians, cyclists and riders of motorized two-wheelers (motorcycles, mopeds and light mopeds).

EXECUTIVE SUMMARY

Relevance

Autonomous cars can offer many benefits and potentially nullify the road accidents caused by human error (94%). One of the threats, however, is the mode transitions between the levels of automation. In a highly automated vehicle (level 4), the vehicle can drive completely autonomous, but only during a defined use case after which the user has to take over. This leads to sudden changes in workload which can be detrimental to driving safety. The current designs do not acknowledge these safety issues yet. Therefore the goal of this project is to design a system where the transitions to and from autonomous driving in a highly automated car are comfortable and safe. The project is executed in collaboration with the design agency VanBerlo.

Literature study

A literature study led to the identification of seven human-factors issues that affect the transitions between levels of vehicle automation, expected to emerge between 2020 and 2032:

- Vigilance decrements
- Complacency
- Manual skill decay
- Motion sickness
- Loss of situational awareness
- Predictability of the car
- Mode transitions

For automated driving, being a new development, it seems recommendable that the design should focus on building trust with the system and creating a built-in co-pilot that supports the driver in the new, more complex cockpit.

These different automation modes have been divided in assisted driving and autonomous driving with the difference being that in the latter one the system is responsible. In assisted driving, automated features like adaptive cruise control (ACC) and lane keeping can still be used making the system more complex. During autonomous driving, three measurable user states have been defined. Different studies show it takes 30-5 minutes from a sleeping state, 40 seconds from an inattentive state and 8 seconds from an attentive state to get back to the right driving performance level.

Field research

A test ride with a partial-automated vehicle (Tesla model S) shows minimal feedback from the automated features which leads to confusion. Also, trust was a reoccurring issue emphasised during this ride. Observing six students of a driving instructor during the lessons show unsolved issues in planning, traffic rules and communication. Calm, clear and structured feedback from the instructor was favoured. The driving instructor emphasises the importance of communication to other road users.

Design goal

The research concludes in the design goal: 'Make the transitions between fully automated and assisted driving safer by increasing the situational awareness when needed, re-engaging driver vigilance, avoiding mode confusion and establish trust with the system.'

Design

During assisted driving the HUD shows in combination with augmented reality what the status is of ACC and lane keeping and visualises their functionality to prevent confusion. Levers behind the steering wheel are used to control these features. Holding both activates autonomous driving. The steering wheel provides haptic feedback to indicate the take over after which it retracts as a strong symbolic message of giving the steering wheel to the system.

A framework is designed based on the literature research to facilitate the transition back to assisted driving where situational awareness and driver vigilance increase stepwise before a take over. Haptic feedback in the seat emphasises and pushes the user in the desired user state. If the desired user state is not met afterwards, auditive feedback is used to warn the user until the user state is met. These modalities are always combined with visual feedback to make the message clear. Holding both levers again initiated assisted driving. The steering wheel comes back as a symbolic message of taking the wheel and provides haptic feedback at the point

of take over.

Evaluation

A qualitative study with an interactive prototype, potential users and experts on automated driving is done to evaluate the design. It shows that the feedback modalities of the design work to facilitate the transitions. It is expected, however, that the steering wheel is presented back to the user in an earlier stage to initiate the take over. It remains unclear how the augmented elements work to facilitate ACC and lane keeping.

Next steps should be to evaluate the design further and design a system that communicates with other road users and add more functionality to the retracting steering wheel.

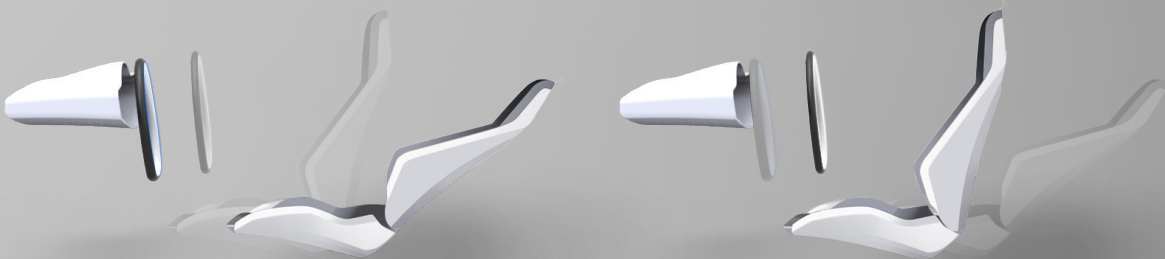


Figure 2. Retractable steering wheel to show the status of autonomous driving and smart seat system to facilitate the transition to assisted driving and provide comfort for the user. Autonomous driving left and assisted driving right.

Head-Up Display

Assists the driver with primary driving tasks on an operational and tactical level. It also shows the status of automated features.

Instrument Cluster

Assists the driver with secondary driving tasks on an strategic level during assisted driving. During autonomous driving it takes over the tasks of the HUD and shows messages related to the take over.

Steering Wheel

The steering wheel and levers are used to control the automated features and show their status.

Seat

During autonomous driving the seat guides the user through the user states of the take over procedure.



Figure 1. Design elements and their information hierarchy.



CHAPTER 1

INTRODUCTION

1.1 The Problem

The transitions between automated features while driving

1.2 Approach

A user-centred approach

1.3 Process & reading guide

A reading guide

1.4 Concluding

Concluding the introduction

1.1 THE PROBLEM

Autonomous cars can offer many benefits and potentially nullify the road accidents caused by human error, but there are threats too. One of these threats is the mode transition between the levels of automation. The project goal is to solve this threat for a level 4 highly automated car. Such a vehicle can drive completely autonomous but only during a defined use case. This project is in collaboration with the design agency VanBerlo.

The reality of automated vehicles

Since cars have become more advanced and smarter each year, self-driving, automated, autonomous cars are becoming a reality. It has already started with new functions and features as lane assist, park assist, adaptive cruise control and various media and communication features, which aim to make the driving experience better and/or safer.

Autonomous cars already exist e.g. the Google self-driving car. These cars have new sensory capabilities and can navigate themselves without human input by sensing the environment and analysing this information.

The emerging technology hype cycle (Figure 3) shows that autonomous cars are moved to the 'peak of inflated expectations' which means according to Gartner (2016) that: "Early publicity produces a number of success stories, often accompanied by scores of failures. Some companies take action; many do not". The movement is caused by the rising amount of automotive companies that are putting autonomous cars on their near-term roadmaps (see Figure 13) and the already existing autonomous cars. Even tech (non-automotive) companies are trying to

be ahead of the curve.

Potential benefits of automated vehicles

Human error and ignorance towards traffic rules are the main factors to most of the road accidents. The National Motor Vehicle Crash Causation Survey (NMVCCS, 2015) even states that 94% of the vehicle crashes was caused by human error (other causes were failure of the vehicle or the driving environment). They also state that most of the fatalities are vulnerable road users. Concerning the global situation of road safety, the WHO made a prediction that road traffic injuries will rise to become the fifth leading cause of death by 2030 (World Health Organisation, 2016). In 2012 it was the 9th leading cause of death with 2,2% (1.3 million). At the moment it is the leading cause of death among young people aged between 15 and 29 years old, second for people between 5 and 14 years old and cost governments approximately 3% of the GDP. Congestion and pollution are additional problems caused by vehicles, which especially occur in cities.

Most of the solutions for improving road safety lie with the setting of speed limits and other similar road regulations. These regulations then have to be

enforced strictly. These issues, however provide an enormous opportunity for autonomous vehicles. Theoretically and ideally the implementation of these self-driving vehicles could bring these numbers down to zero and create a safe driving environment. However, such an ideal scenario is not reality yet.

Controversy

Autonomous cars are despite their potential a controversial topic. Now self-driving cars are becoming a near future product, more questions and concerns are rising concerning the safety of these cars for both the drivers and other road users. Especially since the first fatal crash happened with a semi-automated car, the Tesla S (John Naughton, 2016).

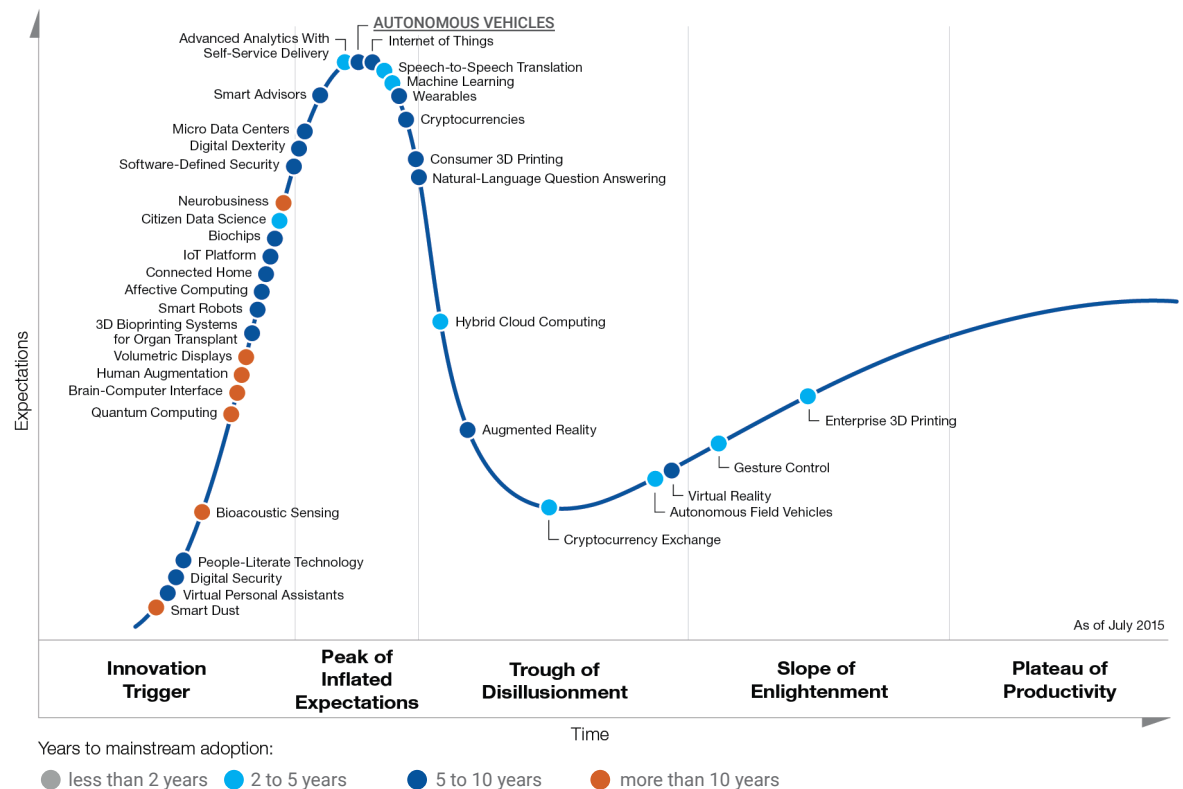
The solutions self-driving cars can bring are of great significance (Techtimes, 2015) such as reducing the amount of traffic accidents, increasing traffic flow and decrease congestion on the roads and saving fuel costs and thereby decreasing economics costs for both the government and user. However, people might consider high forms of automation in cars scary. When talking about autonomous cars, 75% of drivers say they wouldn't feel safe in such a vehicle. However still 60% would like to get some kind of

self-driving feature, such as automatic braking or self-parking. (AAA n.d.) Many drivers surveyed by the AAA say that they trust their own driving skills and they feel that the technology is (still) too new and unproven. One of the reasons people do not trust autonomous cars yet, is that they are still too unpredictable to people. Other reasons are that the misuse or hacking of the software, legal issues and privacy (Kyriakidis, M, 2015).

High automation cars

Since these next generation cars have new capabilities of sensing the environment, there is new potential in designing new active safety features (Appendix A). There are however different levels of automation which have been classified in six (some suggest five) levels (SAE, 2014) as shown in Figure 4.

This project will look at the context of level 4, high automation. A car is considered to be of a 'high automation' level when both the steering and the acceleration/deceleration can be done by the system using information about the driving environment. In contrast to level 2 the driver does not have to monitor the environment and in contrast to level 3, the driver does not have to be prepared to take



Years to mainstream adoption:

● less than 2 years ● 2 to 5 years ● 5 to 10 years ● more than 10 years

Figure 3. The emerging technology hype cycle (Gartner, 2016)

over the performance of dynamic driving tasks. This means the user is able to be fully engaged with non-driving related activities.

The difference at level 5 is there is no human intervention needed except for starting the system and/or setting the destination (or maybe no intervention at all in certain future scenarios).

At level 4 the system can take over the dynamic driving tasks of the driver on the user's command. It is still possible for the driver to drive like it is done at the moment, The new sensory abilities of the car, however can be used to design new features. To get a better grip on what a high automation car is, some typical (potential) level 4 features are given by the SAE (2014).

- Driver-less Valet Parking

The driver can deliver the vehicle to the entrance of a parking garage and step out and let the vehicle park itself.

- Highway Pilot

The vehicle will be able to drive on highways fully automatically. This includes overtaking manoeuvres and driving in highway junctions without driver

	SAE level	Name and description	Steering, acceleration, deceleration	Monitoring driving environment	Fallback performance of dynamic driving task	System capability (driving modes)
Human monitors 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				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				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				Some driving modes
system monitors 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				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				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				All driving modes

Figure 4. Automation levels adapted from SAE

monitoring.

- Urban robot taxi

“An Urban Robot Taxi accomplishes the complete dynamic driving task from origin to destination in a prescribed and limited urban environment. Maximum speed may be limited to e.g. 40 km/h. Area of operation is limited to cities or city centres. A typical example is the Google car.”

Limitations

Where does level 4 stop? What can't it do? The system can perform the dynamic driving tasks for the driver in all situations automatically, but only during a defined use case. This can be for example in a certain urban area. Whereas for the full automation cars the system can take over the tasks during the whole journey.

The car can bring the user to a certain point from which the user has to take over the dynamic driving tasks. From this point, the car can still assist the driver with certain actions, but cannot take full control, because the use case is too complex or not yet defined. A potential conceptual scenario is sketched in a storyboard (Delft Design Guide, 2014)

in Figure 5.

When human and machine (automation) share tasks there is a need for a human-machine interface (HMI). A good HMI should be able to lower workload, improve situational awareness etc. With human-machine interfacing however, there are two issues (D. Abbink 2016.) (1) Does the human understand the automation? (2) Does the automation understand the human?

Since the user is not required to monitor the environment, there are some issues (Kessel and Wickens, 1982) when a take over has to take place. These issues are yet to be solved (Endsley, M. R. 1995) which can lead to unsafe and uncomfortable traffic situations for both the user and other road users.

VanBerlo

VanBerlo, a Dutch design agency is currently focusing on human-system interactions taking place in car cockpits.

The agency was founded in 1982 and has since grown to be the largest design agency in the Netherlands. It is an all-round design agency ranging from branding to product engineering to UX design.

Currently, VanBerlo aims to reduce the complexity in automated car cockpits by introducing well-designed human-computer interactions and smart systems that aim for safer driving. In order to do so, VanBerlo tries to implement smarter solutions for safety features of the next generation cars. Although the safety problem with self-driving cars is globally relevant, VanBerlo is interested to first study the driving context with respect to added safety features and automated driving. The introduction of the design will start in 2020. This graduation project will be done in collaboration with VanBerlo as they will perform a similar project parallel to this project.

Aim of the project

A SWOT analysis (Delft Design Guide, 2014) of autonomous driving in Figure 6 shows an important threat which is described as the potential 'loss of driving performance'. The aim of the project is to tackle this threat.

The project goal is to propose an HMI solution for the take overs between the different modes of automation for a level 4 high automation car in the future context of 2020. The project will thereby help to solve the complexity of these kind of

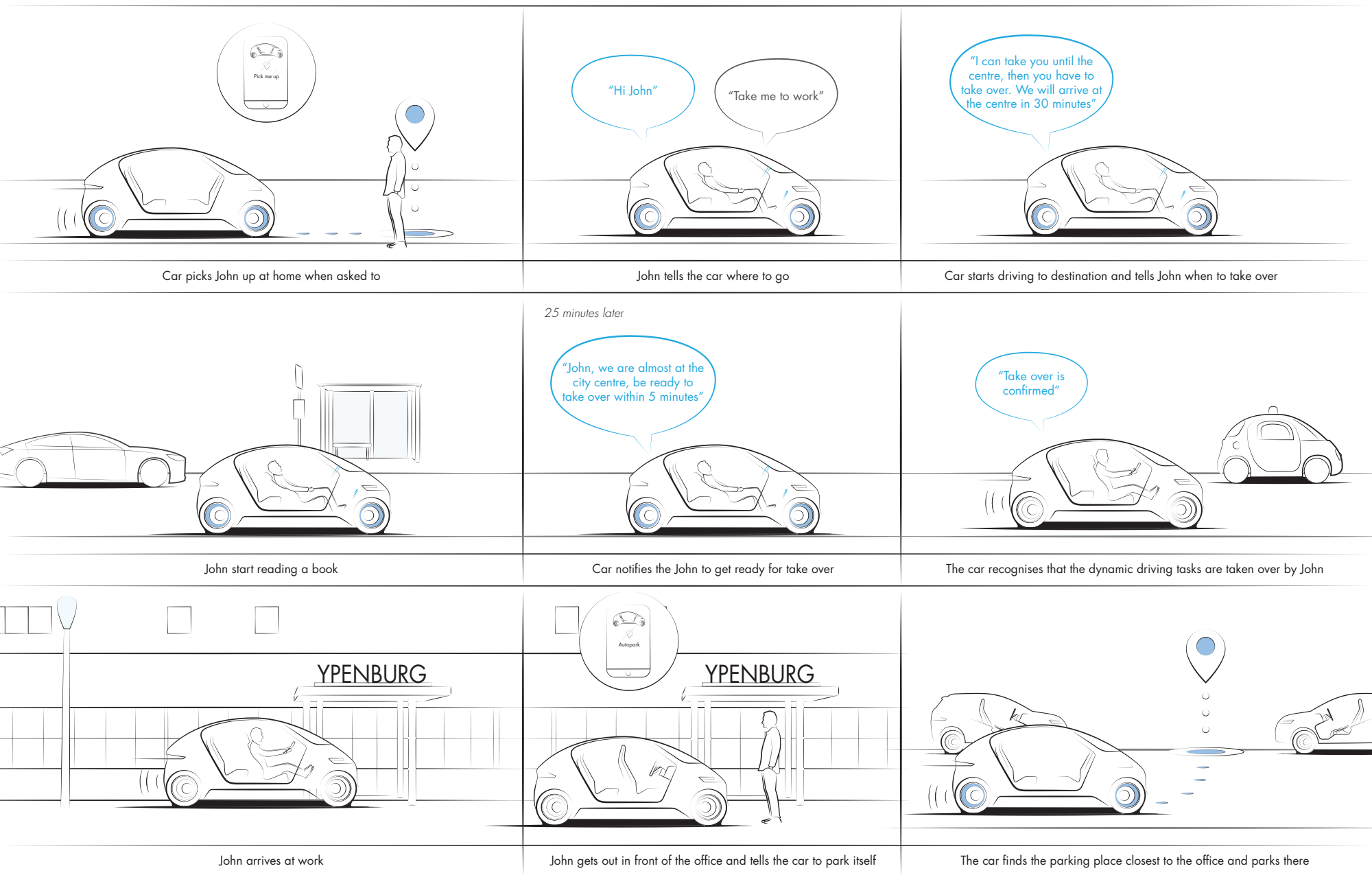


Figure 5. Potential (conceptual) scenario of a level 4 high automation car

Transition of automation

Level of automation X



Level of automation Y

Figure 7. Aim of the project

Figure 6. SWOT matrix of autonomous driving

Strengths	Weaknesses
Accessibility: Driving for non-drivers, young or old and physically impaired Energy saving: Efficient driving that leads to less pollution Reduce accidents: Can decrease the amount of road accidents Reduce space: Can decrease the amount of space needed on the road, parking space etc.	Costs: It is a new development which is still considered expensive Inadaptability: At the moment these technologies are still unable to adapt to different situations No Legislation : Not many countries have legislated automated cars yet Privacy: There is still uncertainty about what happens with all the data collected Liability: Who is responsible for potential accidents?
Opportunities	Threats
Increase road capacity: Less space is needed for cars Reduce congestion: Congestion can be reduced through multiple methods of smart cars Platooning: Platooning can minimise the space on the road needed Car sharing: Reduces the amount of cars needed	Deployment uncertainty: It is still not sure how automated cars will be implemented on the road Slow legislation: Legislation of these technologies will probably be very slow Hacking: It might be possible to hack the cars and misuse them Too reliant: People can become too reliant on self-driving car and start drinking or loose seatbelts Loss of driving performance: Because of automation the driving performance might decrease

automations and try to decrease or nullify the loss of driving performance. The project scope is likely to be expanded to the experience before and after the transition as this might influence the transitions themselves.

1.2 APPROACH

A user centred approach is chosen for the project. The user will be involved in the project on different levels and during different phases. Due to a future context, the project will be heavily leaning on scenario based design. The limitations to these approaches are however, that it might be difficult to find the right users due to limitations of resources and finding the right scenario might be time consuming, while uncertainty remains.

User-centred design is used when interactions with a product are important. It emphasises on involving the user in the design process and hereby designing for the user's need and experience (Design United, 2013). This project will have a dominant focus on product and user-centric design (see Figure 8).

The approach to the project is doing both literature and field research and combining the insights to sketch the future scenario and identify (potential) problems. This is done by both quantitative and qualitative research, which will provide detailed insights into the current use context, use problems and user needs. Figure 9 describes where and how the (potential) user is involved during the design process.

Since the project is in a future context, an approach is taken of scenario-based design. This will illustrate the envisioned context of the product use and help with reflection on product ideas. It will also facilitate the communication with the users.

These methods are used to gain tacit and practical knowledge.

Limitations

The limitation to this approach are among other things, finding the right users. The resource limitations (time and money) will make it difficult to find the right users.

Also, the number of possible scenarios can lead to time consuming process. The right scenario(s) have to be determined in limited time without it affecting the design in a negative way. Uncertainty, however can still remain with future scenarios.

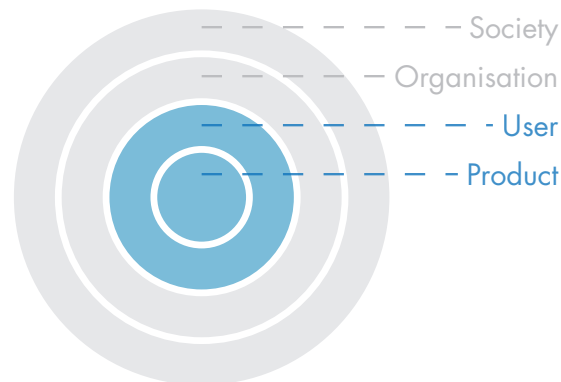


Figure 8. Model of design foci. This project will have a focus on product and user centric design. (Model adapted from Design United, 2013)

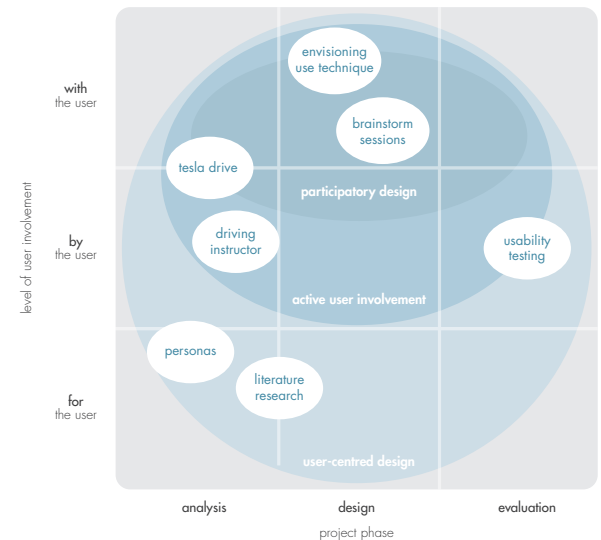
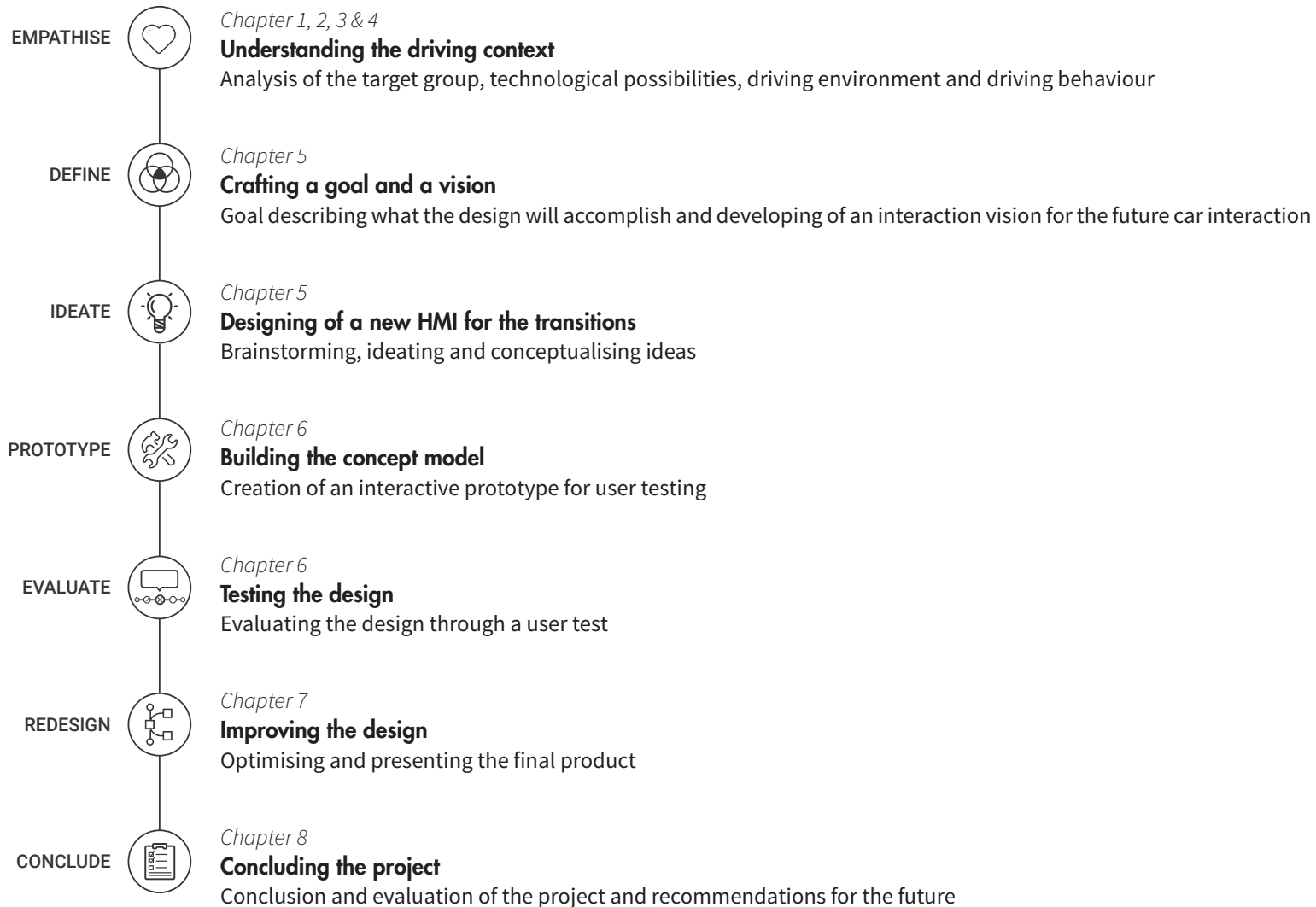


Figure 9. Where and how the (potential) user is involved during the design process. (Model adapted from Design United, 2013)

1.3 PROJECT SETUP



1.4 CONCLUDING

Autonomous cars can offer many benefits and potentially nullify the road accidents caused by human error. This project revolves around supporting design agency VanBerlo in the design of a level 4 high automation car. One of the unsolved problems with such an automated vehicle is that transitions between the levels of automation. The aim of the project is to propose an HMI solution for the take overs between the different modes of automation for a level 4 high automation car in the future context of 2020.

The next chapter will focus on the human factors that revolve around driving and mainly driving with automation. Also, research is done to sketch the development of such highly automated vehicles and where the focus of the design should be.

CHAPTER 2

HIGHLY AUTOMATED DRIVING

2.1 Driving

How can driving (behaviour) be explained?

2.2 The road to autonomous driving

How will the transition to automated driving develop?

2.3 Impact of automation on driver performance

How does automation change the driver performance?

2.4 Cognitive ergonomics

How can the different feedback and feedforward modalities be used?

2.5 Mode transitions

What is the framework around mode transitions?

2.1 DRIVING

Driving behaviour and driving tasks are researched in this section. Driving behaviour is based on an operational, tactical and strategic level. Especially on a tactical level innovation has not been greatly addressed yet. Also, three different kinds of driving tasks have been identified: primary (e.g. steering and braking), secondary (e.g. lights and windscreen wipers) and tertiary (e.g. music and eating). This offers a basis for the information hierarchy in the design.

Driving

Driving itself is characterised as consisting of three levels (Figure 11): strategic, tactical and operational (Janssen, 1979).

At the strategic level, a general planning of the trip is made including aspects like trip goals, route, costs, risks and comfort. This includes questions like: Where will I go? How will I get there? How fast will I get there? etc. Digital maps using GPS positioning information has been a great attribution into helping users at this level and decreasing their cognitive workload. (Sugie et al, 1984)

At the tactical level, manoeuvres are selected to achieve short-term objectives such as deciding whether to pass a blocking vehicle. (Sukthankar, 1997)

The operational level translates these manoeuvres into steering, braking accelerating etc. (Michon, 1985) Improvements at this level are for example cruise control, lane assist, power steering, which minimises the amount or intensity of manoeuvres necessary to perform a certain action.

The tactical level has not been greatly addressed

yet with new designs, but is getting more and more attention now by automotive companies. Providing useful information at the right time about the situation and advising the user with the right instructions for the situation could be a design that helps the user at this level.

Driving behaviour

The SRK (Rasmussen, 1983) model describes that the human behaviour can be classified into three levels: skill-, rule- and knowledge-based performance (see Figure 10). The novice drivers will mostly work on a knowledge and rule-based level which have the characteristics of slow execution of tasks and errors due to an overload of information or lack of knowledge and awareness. Drivers require skill to perform fast and the right execution of certain tasks and to be able to adjust to a continuously changing environment which provides tonnes of information. For a novice driver, these tasks can require a lot of cognitive workload.

When automated functions in cars become more common, people themselves will drive less and thereby be less practised in driving. This will lead to more knowledge and rule based performances and manual skill decay due to lack of experience.

The driver's mental state also has an impact on driving behaviour. Studies show (vanderHulst, 1999) that factors as attention, intention, anticipation, lack of preview and driving while fatigued result into an adapted driving style.

Driving tasks

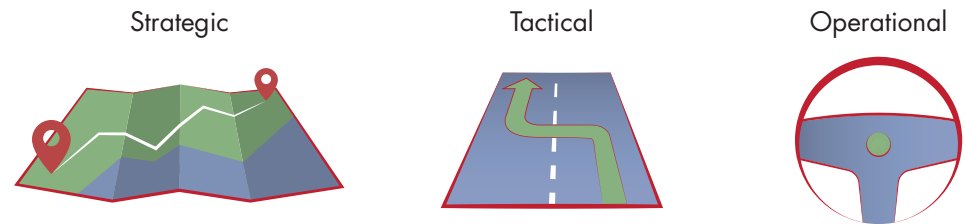
Driving tasks are divided into primary, secondary and tertiary tasks (Pfleging, 2015).

Primary driving tasks are basically all activities that are required to manoeuvre the vehicle. This includes the activities related to lateral and longitudinal control of the vehicle and the monitoring of the driving environment for potential hazards. The primary tasks are also divided into three tasks: navigation tasks (route and speed), guidance tasks (the exact path and adapting driving speed) and stabilisation tasks (the actual control of lateral and longitudinal movements).

The secondary tasks refer to functions that increase driving performance or safety. This can be for example activating the headlights or wipers.

The tertiary driving tasks refer to all other tasks

Figure 11. Levels of driving: strategic, tactical and operational



for example, operating comfort, infotainment and communication systems, or eating and drinking. These driving tasks will become a more important factor when autonomous driving comes into play. Other activities like sleeping, working etc. will become part of the driving routine.

The project will focus on making primary and/or secondary tasks easier, but will take the tertiary tasks into account as these become an important part of the driving experience.

Conclusion

There is new potential in designing for the tactical level of driving with the new sensory capabilities of the car. The automation of functions of a car will cause people to be less experienced in these actions and perform them more on a knowledge or rule based level instead of skill based. When designing a user interaction it is important to consider the driving tasks and their importance.

	Strategic	Tactical	Operational
Knowledge based	Navigation in a strange town	Controlling a skidding vehicle	Novice driver on first lesson
Rule based	Choice between familiar routes	Passing other vehicles	Driving an unfamiliar vehicle
Skill based	Home/work travel	Negotiating familiar junctions	Vehicle handling in curves

	Degree of conscious involvement	Speed of task execution	Amount of effort required	Types of error
Knowledge based	Novel situations performed completely consciously	Slow	Effortful	- Overload due to amount of info - Lack of knowledge - Lack of awareness
Rule based		Fast	Effortless	- Errors of intention if an incorrect diagnostic is applied
Skill based	Routine task performed highly practised with no conscious monitoring			- Attention diverted by distractions - Unfamiliar activities in familiar context - Slips where the intention is correct but failure occurs performing the task

Figure 10. Skill, rule & knowledge based classification (Adapted from Rasmussen, 1983)

2.2 THE ROAD TO AUTONOMOUS DRIVING

A lot of companies have already put their autonomous cars on the road map. It is suggested however that the implementation will happen gradually and in three stages that are guided by the technological development, social acceptance and the legal framework around it. During phase one (current Phase) establishing trust is of importance, during the second phase features that support the driver in a more complex cockpit become more important and during the last phase it is of importance for the design to also consider the user as a passenger. The design time-frame is between 2020 and 2032, which means the design should focus on phase 1 and 2.

It is not a question of if, but a question of when autonomous vehicles will happen. Figure 13 shows a timeline of when companies expect autonomous driving. This process of implementation will, however happen gradually and in phases. This process will be guided by the technological development, social acceptance and the legal framework around it (Irwin, 2016). As shown in the SWOT (Figure 6), the legal framework will, however most likely be developed slowly. It is expected that there are three (overlapping) phases of development which prioritise different aspects for the design for the introduction of automated features in cars (Hyundai 2012). An adapted timeline is presented in Figure 12.

Phase 1: Establishing trust

The first phase will focus on establishing trust with the user. For many users, this will be the first time they will let go of the steering wheel and give the control over to their 2000 kg moving vehicle. Building trust is, therefore, an important factor in building a positive relationship between the user and the car. It is also important to show capabilities of the features and maybe more importantly, its limitations.

Phase 2: Designing the co-pilot

More and more (automated) features are being

introduced in cars, which also makes the car cockpit more and more complex. Also, ambiguity becomes a problem. The opportunity of new hybrid models of shared control can pose a threat for the transitions between control of the driver and system. The collaboration between the driver, auto-pilot and car needs to be improved. V2I (vehicle to infrastructure) and V2V (vehicle to vehicle) can be a great addition for designing safety features which support the driver and can allow for the beginning of complete autonomous vehicles. The V2X technologies can also allow for car sharing option as presented with the BMW Vision Mini.

Phase 3: Embracing the passenger

When autonomous driving is introduced to the mass market, drivers will be considered more as passengers. The tertiary driving tasks will become more important and it allows the user to be engaged in new activities. The Rolls-Royce 103EX discussed in Appendix D is an example where there is no steering wheel anymore and the seat is not necessary facing forward. The car cockpit can become more of a living room than an environment ideal for driving.

Design time-frame

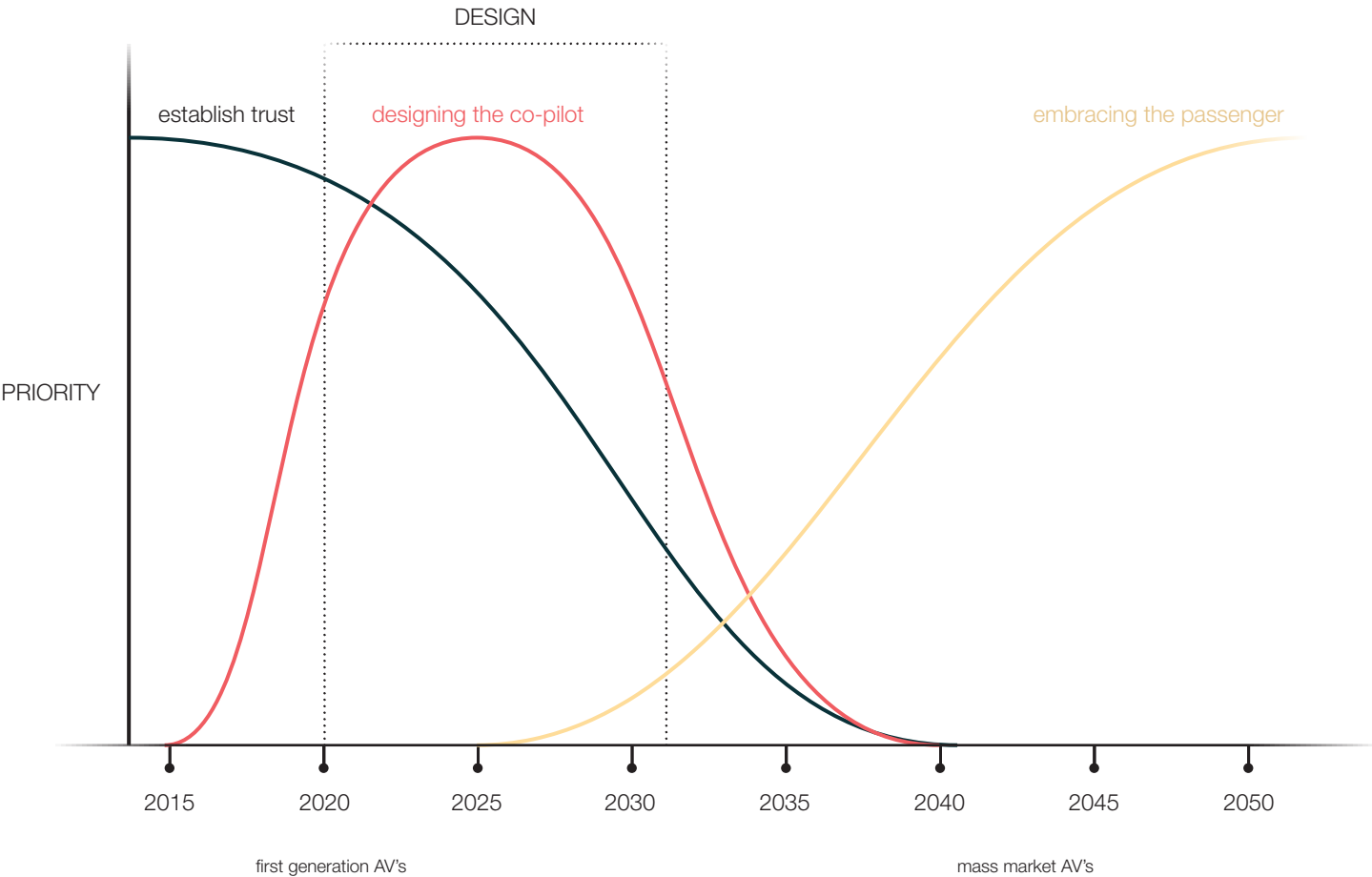
The proposed introduction of the design is in 2020.

The average use span of a car is 10 years (Cardeal, 2016). Expected is that this will be a little higher as cars will be updated and upgraded. This leads to a chosen time-frame of 2020 till at least 2032.

Conclusion

For the chosen time-frame establishing trust is an important factor, especially in the introduction phase. Solving the increasing complexity of the car cockpit and preventing confusing ambiguity will become a focus of the design. For this time-frame embracing the passenger has a low priority.

Figure 12. Timeline of priority in design adapted from Hyundai (2012)



PREDICTED TIMELINE AUTONOMOUS

2017

- Next generation Audi A8 capable of fully autonomous driving (Motoring, 2014)

2018

- Sergey Brin plans to have Google driverless car in the market (driverless-future, 2012)
- Elon Musk expects first fully autonomous Tesla (Elon Musk, 2015)
- NuTonomy to provide self-driving taxi services in Singapore (NuTonomy, 2016)

2019

- Volkswagen expects first self driving cars on the market (Focus, 2016)
- Baidu's Chief Scientist expects large number of self-driving cars on the road (Quora, 2016)
- Delphi and mobileEye to provide fully self driving systems (level 4) (The Verge, 2016)

2020

- First autonomous Toyota to be available (Wired, 2016)
- GM: Autonomous cars could be deployed (Wall Street Journal, 2016)
- Ford CEO expects fully autonomous cars (Autonews, 2016)

US DRIVING

Figure 13. Timeline autonomous driving, when companies are expecting autonomous driving.

2023

- 'True autonomous driving in Tesla' (announcement Elon Musk, 2016)

2025

- Driverless cars will be in use all over the world according to Daimler chairman (Detroit News, 2014)

2030

- Uber fleet to be driverless by 2030 (Mobility Lab, 2015)

2040

- IEEE predicts up to 75% of vehicles will be autonomous (IEEE, 2012)

** As a side note, the reader should understand that these predictions change rapidly over time and have probably changed drastically since this report was published.*

2.3 IMPACT OF AUTOMATION ON DRIVER PERFORMANCE

Seven new issues arise with car automation: vigilance decrements, complacency, manual skill decay, motion sickness, loss of situational awareness, the predictability of the car and mode transitions. Different levels of automation make this a complex problem. These problems (can) contribute to the complexity of mode transitions making them even dangerous. The problems could be mostly solved by using the right feedback and feedforward.

An overview of literature is made on system automation effects on user performance. New issues arise when looking at the driving context (Figure 14). Most of the issues contribute to the out-of-the-loop performance problem, which causes a loss of driver performance when the driver is not kept in the process (Kessel and Wickens 1982). It is researched how these human factor issues have an impact on the mode transitions.

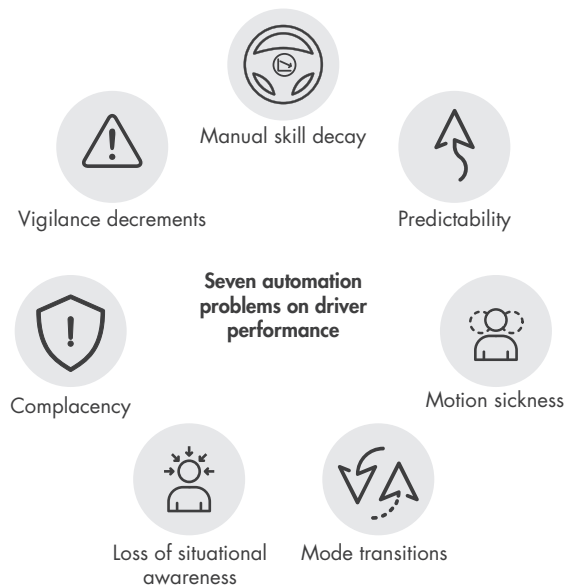


Figure 14. Seven automation problems on driver performance

Vigilance decrements

The automation of features can lead to vigilance decrements (Endsley and Kaber, 1999). This means the deterioration in the ability to remain vigilant for critical signals with time, which can result in a declining rate of the correct detection of signals. E.g. missing or incorrect identification of a collision warning.

Complacency

Complacency is a feeling of security while unaware of some potential danger or defect. An example of one of the consequences of complacency is when an error is indicated by the system however, the driver will assume that since the autopilot is on or the driver thinks it is on, the system knows what it is doing and hereby feel no alarming state for potential dangers. This happens frequently in aviation vehicles where a multitude of autopilots is available.

Loss of situational awareness

Situation awareness (SA) is “the perception of elements in the environment within a volume of time and space (1), the comprehension of their meaning (2), and the projection of their status in the near future (3)” (Endsley, 1995), which also describes

the three levels it consist. For vehicles, this concerns knowledge about navigation, environment and interaction, spatial orientation and vehicle status.

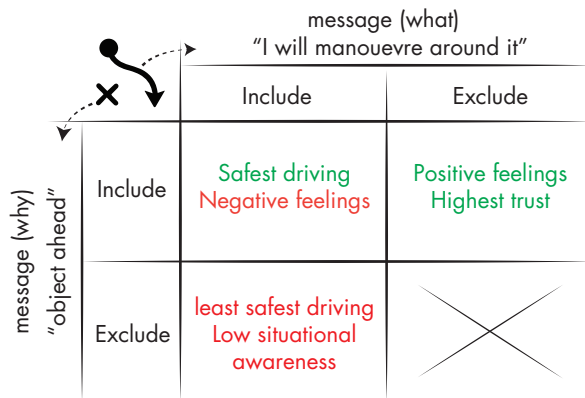
Since level 4 automation does not require the driver to monitor the driving environment, there will likely be a significant loss of situational awareness. Basically, the higher the level of automation will lead to a higher loss of situational awareness (Llaneras, Salinger & Green n.b.). However situational awareness is one of the most important things for drivers, because they need to react to a dynamic environment.

Manual skill decay

When performing certain tasks, normally the driver will improve in these tasks. When automation takes over people will be less experienced and as discussed in the previous subchapter these performances will be lowered to more knowledge or rule based performances.

Predictability of the car

People want to know what automated vehicles are doing, but also why they are doing this (Koo, 2014). If the car is going to perform certain actions, the driver and potentially passengers want to know what the



		message (what) "I will manoeuvre around it"	
		Include	Exclude
message (why) "object ahead"	Include	Safest driving Negative feelings	Positive feelings Highest trust
	Exclude	least safest driving Low situational awareness	

Figure 15. Results of providing ‘what’ and ‘why’ information of a semi-automated vehicle adapted from Koo (2014).

car is going to do, why it is going to do it and when it is doing it. This is not only important for the driver, but also for other road users.

When a car provides both the ‘what’ and the ‘why’ of the actions it performs, it results in safer driving performance, but also increases the negative feelings of the driver, which is probably caused by information overload (Figure 15). Only providing the ‘why’ information creates the least anxiety and highest trust. When only the ‘what’ information is provided it leads to the least safest driving and lowers the SA significantly (Koo, 2014).

Motion sickness

When the car is driving automatically, the user is not required to monitor the environment. This enables the user to do non-driving related tasks such as reading, watching movies, using the smartphone or other multimedia devices. This can lead to motion sickness.

Motion sickness causes dizziness, fatigue or nausea. It is caused by three main factors (Sivak and Schoettle 2015). The conflict between vestibular and visual inputs (1), the inability to anticipate the direction of motion (2) and lack of control over the direction of the motion (3). The people in the driver seat are able to experience motion sickness when performing non-driving related tasks. Since there is a high probability that the user has to take over the driving tasks at a certain point, motion sickness can be a problem for some users.

Mode transitions

One of the seven problems is directly related to the project goal. When the user has to take over the driving tasks, there has to be a form of take-over. During this time the user has to get aware of the driving situation (SA). What kind of roads is the car driving on, what are the rules, how are the other road users behaving

etc. Since there are no level 3 or 4 automation cars yet on the market, such take over systems have not been designed yet. Mode confusion is also likely to happen if feedback is lacking or insufficient.

Conclusion

Since the car is able to drive with different levels of automation, the solutions to cope with these issues will probably be more complex. The solution should be adaptable to the different level of automation to provide the optimal driving experience and safety. The six issues can all contribute to the seventh problem, the mode transitions.

Feedback and feedforward in the right manner can solve or minimise most of the presented issues. If the system provides both the ‘why’ and ‘how’ only when driving in the partial or zero automated mode it might improve safe driving. When the car is driving fully automatically, trust is an important factor and thus only providing the ‘why’ information can contribute to build trust with the system, give the highest positive feelings and still maintain situational awareness. In addition, outside HMI can improve the predictability of the car to outside users and thereby help to improve the safety on the road.

2.4 MODE TRANSITION

Different automation modes are defined to design the transitions. The assisted driving mode can have no automation, ACC or lane keeping (with ACC). During autonomous driving mode the car also takes over the responsibility. Also three (measurable) user states are defined to design the basic framework: sleeping, inattentive and attentive. It takes 5-30 minutes to get back to the right driving performance when sleeping, 40 seconds from an inattentive state and 8 seconds from an attentive user state.

Automation modes

With the new automated features, the cockpits become more complex and ambiguous which becomes a problem. Therefore it is important to define certain 'automation modes'. The definition of the modes is already part of the design and is a prediction based on the capabilities of the car within the time-frame. Figure 16 describes these modes.

The first mode is assisted driving. In this mode, the user controls the lateral and longitudinal movements of the car. Active safety features can still assist (or even override) the user's control.

In the second mode, adaptive cruise control is engaged, which means that the longitudinal movements are fully controlled by the system.

In the third mode in addition to the ACC, lane keeping is also engaged. This means both the longitudinal and lateral movements are controlled by the system. Noticeable is that lane keeping can not be activated without ACC, as this would potentially create dangerous scenarios.

The last mode is fully autonomous driving. This mode follows the definition of a level 4 car. Everything from

the primary to secondary driving tasks is controlled by the system and the system takes full responsibility (from the user) for what happens during this mode.

The most important difference is that in the first three modes, the user is fully responsible. Even if the features as ACC or lane-keeping are activated. These features should be considered as 'assisting' the driver.

The main reason features like ACC and lane keeping still exist in the to-be-designed car, is that fully autonomous driving won't be available everywhere and always. Where these other features can be. Also, it is very likely that autonomous driving can only be engaged when the navigation knows an arrival point.

As data learning is a big factor (see chapter x), it is expected that the cars will learn roads by driving and the software can be updated anytime. This means that in future (after or at the end of the chosen time-frame), most or even all parts where first only the ACC & lane keeping mode was available, fully autonomous driving will be available and can replace the mode fully. If the goal is to only reduce the complexity of the HMI this future scenario would be ideal as it would be possible to only have two modes (assisted

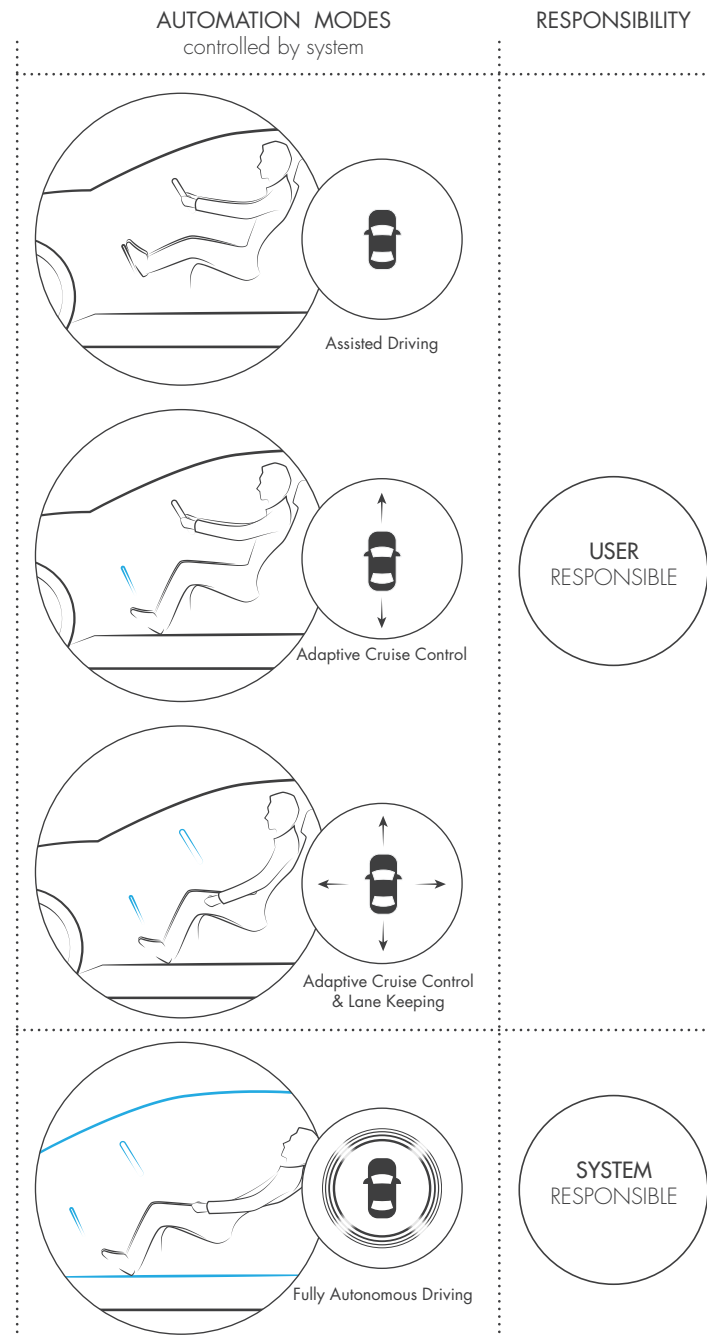
driving and fully autonomous driving) which have a hard and clear separation.

Authority transition

During the transition of control (also called an authority transition (AT)), there is a shift in the distribution of vehicle control between the driver and the system. Apart from the AT design itself, there are several factors that influence such a transition.

- The current and desired driver's state
The mental state of the driver is of major importance with factors (as described in the previous subchapter) as situational awareness, driver vigilance, complacency etc. Not only the mental state of the driver, but also the physical driver's state is of importance. This means especially the positioning of the driver. The movement from the current to desired state needs to be achieved by the design.
- The current and desired automation mode
There are major differences mentally and responsibility wise concerning the automation mode.
- The environmental situation
The environmental aspects such the road quality,

Figure 16. Different automation modes and responsibility share



the road traffic situation etc.

- The urgency level

Different situations and vehicle properties can impact the urgency level of a take over. The urgency level especially influences the timing of the initiation and the time it takes for a take over.

- The initiator

The possible scenarios for take overs from automation to manual can be classified into two categories.

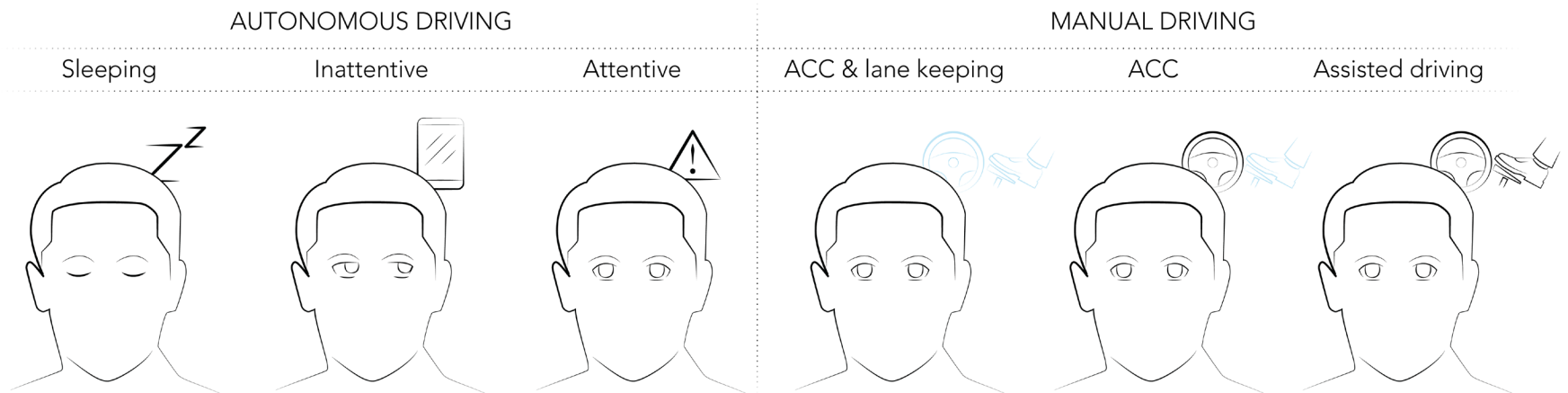
1. The take over is planned (and communicated) well before it has to take place and is known by both the user and the system. This is a typical level 4 approach.

2. A non-planned take over is initiated by the user. The system is not aware of this until the user provides the system with input suggesting a take over. For example when a bus is driving too slow for a long time in front of the vehicle and the user decides (s)he wants to drive in front of it.

User states

As mentioned before, when autonomous driving is active the driver can be engaged in other activities

Figure 17. Measurable user states



leading to different ‘user states’. These states are important to design a transitional framework which engages the driver back to the assisted driving mode. The user states which are actually measurable by the system are even more important. According to eye-tracking systems, (W. Horng, 2004)) it can be measured if a driver is non-attentive or sleeping.

This means three user states are defined which are measurable during autonomous driving (Figure 17). Sleeping, inattentive and attentive. When in a sleeping state it is expected that there is (almost) no income of contextual information SA and driver vigilance is extremely low. When the user is in an inattentive state SA is still low, but driver vigilance is higher. When in an attentive state both the SA and driver vigilance is high. This is dependent however, from the duration of the state.

Authority transition time budget

From the measurable user states, it takes different amounts of time get back on the right level of driving performance.

For sleeping, sleep inertia is an important factor. Sleep inertia is the period after waking up where people have a reduced level of capacity. There are three factors which can influence the duration of sleep inertia (Rosekind et. al, 1995). The depth of the sleep, the timing and chemical influences as drugs.

Tests (Tassi P. 2000) concluded that after 8 hours of sleep, sleep inertia is rarely longer than 30 minutes. Another test (Hofer-Tinguely et al, 2005) indicates that after sleeping 2 hours, no differences were measured in performance after 20 minutes. Other tests (Hilditch et. al, 2015) indicated that 5 minutes after a 10 minute sleep also no differences were measured in performance.

Research shows (Merat et al. 2014) that without a supporting design, it takes 40 seconds from the AT until the SA does not rise anymore from a conditional automated driving (level 3) transition to manual and stabilise the lateral control (this is better when the transition is expected by the user). Which is similar to the inattentive user state.

It takes 8 seconds (Endsley, M. R, 1999) from partial automated driving for the driver to regain SA fully (depending on which of the lateral or longitudinal control is activated).

These times are mapped in Figure 18 on a logarithmic scale. Noticeable is that the time never reaches zero seconds, as a take over (even best prepared as possible) will always take some time to get fully familiar with.

Conclusion

A clear distinction in the design is needed to make the user aware that there is a difference in responsibility between the combination of ACC and lane keeping and autonomous driving.

Combining the user states with the authority time budget can provide a time-framework for the authority transition to assisted driving.

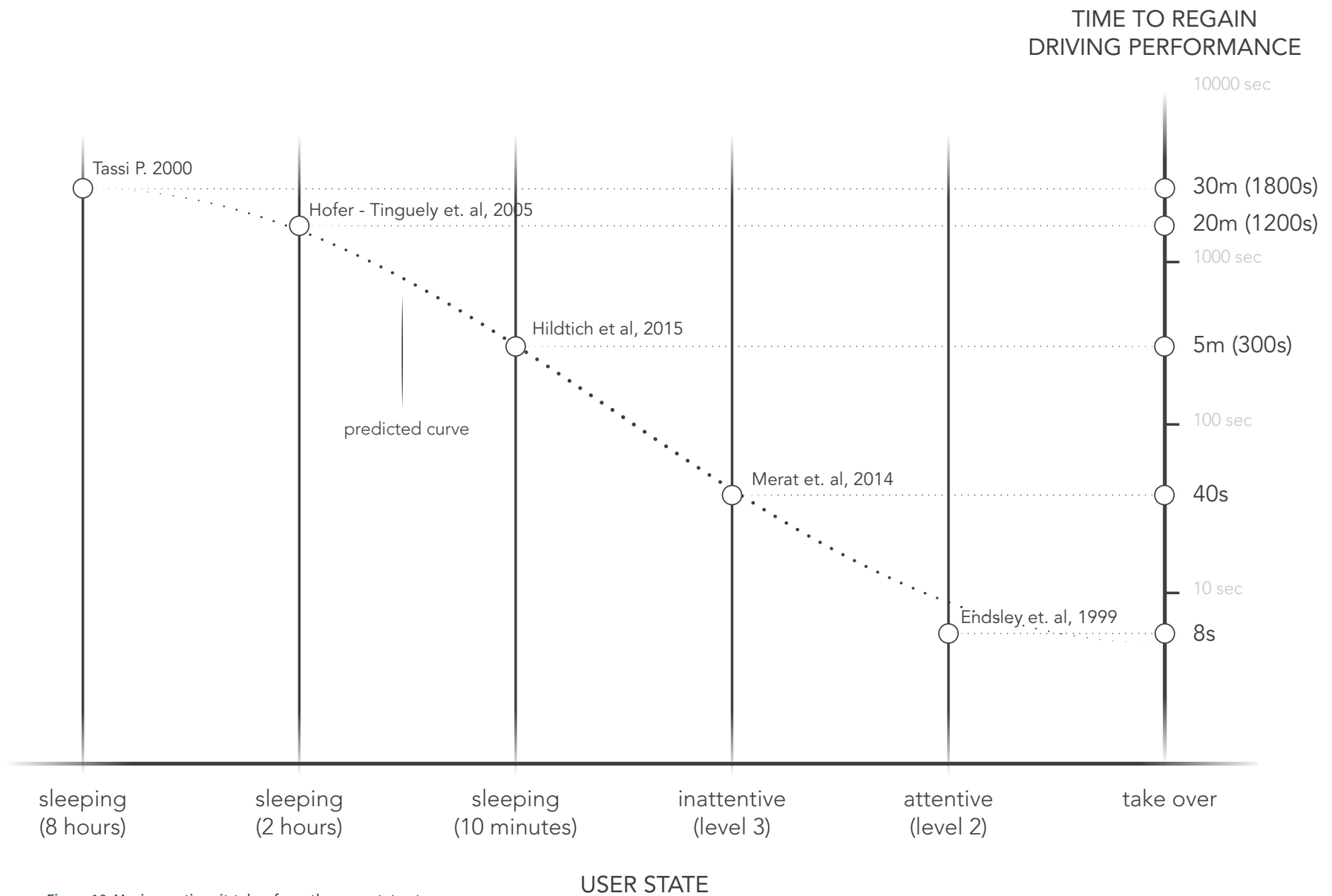


Figure 18. Maximum time it takes from the user states to regain normal driving performance level

2.5 COGNITIVE ERGONOMICS

Different types of feedback can be used to increase the driving performance and facilitate the transition between automation modes. Auditive (and haptic) feedback can be used for simple messages based on timing. Visual feedback can be used to convey complex messages. Combining these modalities can lead to the most effective feedback. The use of haptic feedback is best suited to provide the first set of information and auditive feedback as a warning to urge the user to action.

Section 2.3 concludes that the right feedback and feedforward could solve most of the problems concerning driving performance. Therefore it is important to look at the effectiveness of using different modalities for this.

Output

Outputs of the typical In-Vehicle Information System (IVIS) can be categorised as visual, auditory and physical (haptics) (C. Harvey, 2011). This is typically done through visual and auditory modes, although more creative ways of physical inputs are being experimented with (vibrating steering wheel or seats for example (General Motors, 2014)). The differences of when to use auditory or visual outputs (C. Harvey, 2011) are described in Figure 19. Generally, it is said to use visual outputs when the message is complex and use auditory outputs when the message is short and immediate action is required.

Visual

Feedback on the dashboard (instrument cluster) is one of the most used forms of visual feedback. New designs however, allow for different ways of visual feedback and/or feedforward. Head-up displays (HUDs) are fairly new in the automotive industry, however, they have been used extensively in aviation

vehicles, as it presents data in such a way that the user do not have to look away from their usual viewpoints. There have also been some experiments (BMW, 2016) with creative visual output in the steering wheel, which tells the user when to place the hands back on the steering wheel while driving with the auto-pilot on.

Auditory

Auditory feedback can be extremely effective, it as however a challenge to design the audio in such a way that the right relation is made between the different sounds and their meanings. A simple way to do this is to use speech form instead of the regular beeps. This has the advantage that it is generally easy to understand, the disadvantage however, is that the processing is rather slow relatively.

Some studies show that auditory output from navigation systems result into (Loomis, 1998) better driving performances. Also, performance increases when the auditive signal comes from the position it is referring to (C. Ho, 2005).

Physical

Also called haptic and tactile output. The advantage of physical output is that it does not require

(obviously) any visual or auditory attention. This advantage is mentioned especially for physical output, because it is not often used in IVIS, especially when compared to visual outputs. The difficulty with physical feedback in IVIS is that it is hard to convey complex information.

An example haptic feedback in IVIS is a concept of Citroen (2013) where the driver's seat vibrates when the driver moves across road markings without using turning signals. This also indicates which side the driver is crossing the markings. An experiment concerning a similar vibrating seat showed that users found this kind of haptic alerts less annoying and more appropriate than auditive alerts (J. D. Lee, 2004). Tactile warnings also show promise as effective rear-end collision warnings. (Scott and Gray 2008).

Figure 19 shows which modalities to use based on the kind of message that needs to be delivered. It does not include physical output, although it might be considered that the use of physical outputs to deliver a message can be comparable to the auditive ones for most of the characteristic.

Input

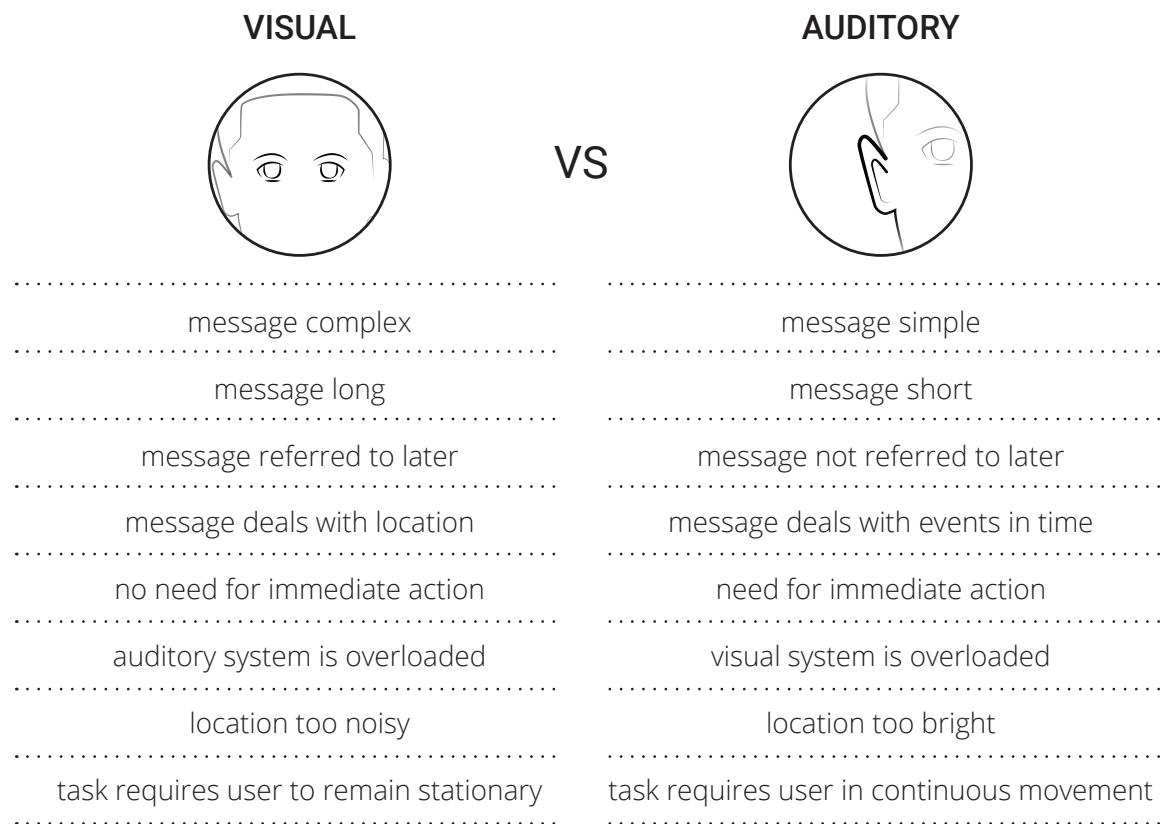


Figure 19. Visual vs. auditory modality for the use of messages adapted from C. Harvey (2011)

Inputs for an IVIS are typically either physical or auditory. The last one is mostly done by speech technology. Using speech is (or should be) easy to use, however it takes generally more time than physical interactions (depending on the task and interface) and it is still hard for systems to recognise the right message, which can lead to frustration.

Physical interaction in IVISs consists mostly of turning a knob or pressing a button. Touch-screens are a rather new development for IVIS, which allow for different interaction possibilities. The disadvantage of the touch-screens is that it requires a lot of the visual demand from the user.

Multitasking

Wicken's model (Wicken, 1984) assumes that tasks demand resources for their performance and that these resources are limited. The task performance will drop when these supplies are exceeded. It suggests that using different pools of resources for different tasks can benefit the task performance and allow the user to work more efficiently.

Multimodal outputs

Some studies have been done to the effect of using multimodal outputs, combining physical, auditory

and visual models. In relation to Wicken's model it should suggest better performances. Some results are that the combination of tactile and audio warnings produced the shortest reaction times to presented hazards (Murata, 2012, Ho Reed Spence, 2005 and Scott and Gray, 2008). The use of trimodal combining all three models, showed an improvement in performance and no increase in the mental workload (Oskarsson, 2011). When to use which combination of models is still unclear and probably depend a lot on the situation and context.

Urgency levels

Some situations require an immediate action from the driver (Kaufman, 2008). A signal of high urgency can help the driver alert to do this. Medium urgency signals provide an overall alertness and improve the lane keeping and steering behaviour during a non-critical situation. For auditory a higher fundamental frequency, higher speed and a larger pitch range increases the perceived urgency levels. Figure 20 shows which kind model of output is best used for different urgency levels. The reason physical and auditory models are used for high priority messages and not visual is that the visual demand is already high without these extra signals whereas physical and auditory models are not intensively used yet.

Also, these models can be used best to deliver a message that deals with events in time and which indicates a need for immediate action.

The outputs modes can also be related to the driver tasks. Especially the auditory mode has minimal

interference with the visual mode during the secondary tasks. This is both in the presentation of information related to secondary tasks and the execution of these tasks by speech (auditory) (Agah, 2000).

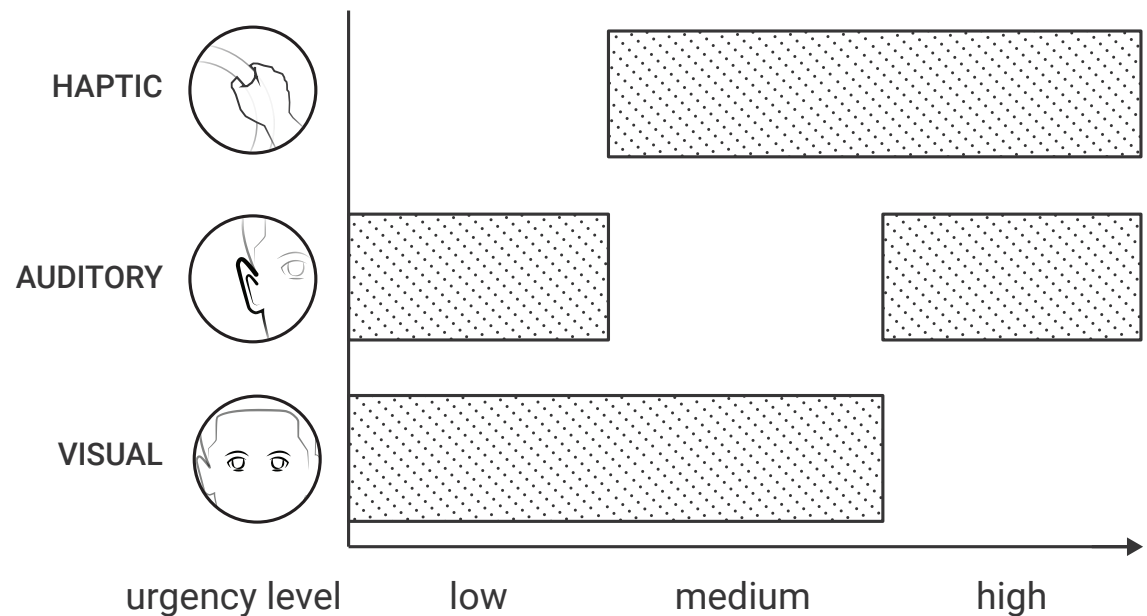


Figure 20. Modalities on urgency levels.

Perceived urgency vs. level of annoyance

For the user's experience, it is important that the feedback has the appropriate level of perceived urgency and also as minimal annoyance as possible. There is a general positive correlation between those two. Baldwin and Lewis (2013) tested this with auditory interpulse interval (IPI), auditory frequency, visual IPI, visual colour and tactile IPI. Tested were auditory interpulse interval (IPI), auditory frequency, visual IPI, visual colour and tactile IPI. In Figure 21 these perceived urgencies of modalities are mapped against the level of annoyance.

Conclusion

For more complex messages, using the visual model provide the best performance. For simple messages which deal with events in time or have a high urgency level, haptic or auditory feedback seems most effective. Multi-modal outputs lead to an overall better driving performance, this is however very dependent on the context and execution. Guidelines are that both haptic and auditory feedback can (and should) be combined with visual feedback for effective feedback. Combining haptic and auditory feedback will however have an insignificant increase in effect as their characteristics are fairly similar.

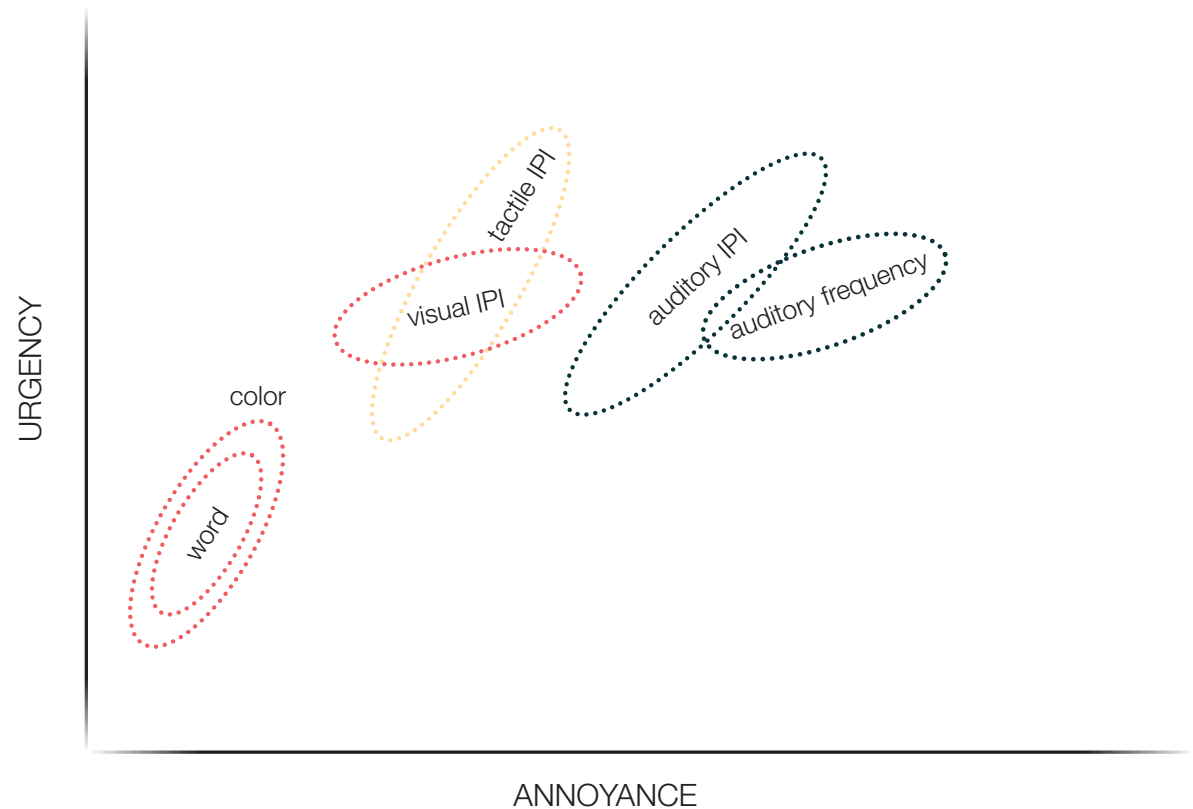


Figure 21. Perceived level of urgency vs. level of annoyance across different modalities adapted from Baldwin and Lewis (2013).

2.6 CONCLUDING

The distinction of the driving levels and driving tasks can be used to shape the lay-out of the design. Primary driving tasks should be more prominent in the view of the user as tertiary driving tasks. Also on an operational and especially on the unexplored tactical level the design can help the support the user. The automation of the vehicle propose some new issues. A lack of trust is important in the beginning stages of the introduction of the vehicle after which the increasing complexity of the cockpit needs to be solved by increasing the collaboration of the driver, autopilot and vehicle. With the design seven issues needs to be kept in mind: complacency, manual skill decay, motion sickness, predictability of the vehicle, the mode transitions themselves, situational awareness and vigilance decrements. Especially the latter two are of significant importance on the mode transitions. To design for the transition form autonomous to assisted driving three user states can be differentiated and used to indicate how long it takes from those user states to regain the driving performance.

The next chapter will sketch the future design context to get a better understanding of the environment and users of the design and where the technological opportunities lie.

CHAPTER 3

FUTURE DESIGN CONTEXT

3.1 Global trends

What are the relevant trends?

3.2 Technological developments

What is the current state of the art on active safety features?

3.3 Megacities

What describes megacities and how is their infrastructure?

3.4 Customer segmentation

Who are the potential users?

3.5 Concluding

What is the future design context?

3.1 GLOBAL TRENDS

A trend analysis is done to provide more relevant insights on the chosen context (2020) and user's needs. These trends show an increase in the numbers of megacities. Also, new technologies allow for constant connectivity and smart products. Trends like augmented reality, new interactions, HMI that adapts to the user and driving context and text messages shaped into visualisations offer potential for the design context.

To sketch the context in 2020 trend research is done. Most of the trends are visualised in an infographic in Appendix B. Figure 22 shows only the most relevant trends on interfaces.

Urbanisation has been a trend for many years now and this still continues (National Library of Medicine, 2015). The *continued urbanisation* is especially a strong trend among the young adults. This means there is a *growing number of megacities*.

Health, wellness and well-being will stay a trend until at least 2050 (Trendwatching, 2016). This is not only the health of the physical body, but also improving the wellness of the mind and soul. Especially within the mega cities *air quality* is a major health issue. One of the major causes is the rising amount of emissions from automotive vehicles. As discussed previously *traffic accidents are a global health problem* as they were the number 9th leading cause of death with 1.3 million deaths in 2012. These traffic accidents are most occurring in the urban environment. (VanBerlo, 2016)

Worldwide people spend an average of almost 4 hours per day on their smartphone (Trendwatching, 2016). One of the reasons is the *desire for constant*

connectivity. This trend can now also be found in automotive features: texting while driving even though it is prohibited. The *augmentation or blending of real and virtual* can be seen in video games with types of visions, but are now becoming a realistic option with new technologies as HUD-displays. (Trendwatching, 2016)

The internet of things is taking over the Western world. It is predicted by analysts that by the year 2020 each person in the UK will own and use 27 internet connected devices. These devices will be able to communicate with each other, which makes 5G networks necessary. It is expected this technology will start to appear in 2022/23 (Forbes, 2016). This trend can lead to the communication of vehicles for example, *V2V and V2I communication and car sharing*.

Computers will be learning rather than processing (memeburn, 2013). Recognising speech and objects will help systems to recognise complex patterns and adjust to them. The Google self-driving car knows how to drive using these kind of features. *Smarter products* than the ones consumers are now used to. These products become updateable and upgradeable. Save more time, money,

make it easier etc. also by using familiar interfaces. *Beneficial intelligence* is what the consumer now wants. Consumers desire new, more *intuitive and natural interactions with digital technologies*. (Trendwatching, 2016)

Innovation to Zero is a vision where products and technologies will be developed which achieve a zero concept. Cars with zero emissions, zero accidents and zero fatalities.

About 80% of consumers worldwide are willing to *share personal data* with companies, however only 8% of those consumers feel they are receiving better offers and services as a result of sharing their information.

A new form of exclusivity for consumers will rise which makes them *actively prove their worth to the brands* they want to buy from.

Conclusion

Following the trends, the context of the project will be in megacities. With new interactions and smarter products the goal of the project will tried to be achieved.

Figure 22. Most relevant trends on interfaces

Trends on interfaces efficiency



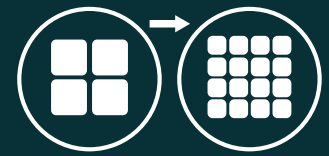
text, speech, numbers
to visualisations



new interactions



use familiar interfaces to
reduce driver workload



more controls to smaller
steering wheel

Trends on interfaces adaptability



user interface adapts to
driver context



HMI adapt to user



augmentation



upgradable &
updateable
(data learning)

3.2 TECHNOLOGICAL DEVELOPMENTS

Many car companies are experimenting with new features which show up in their new cars. To get an idea of what is already on the market and see what kind of possibilities there are, a state of the art research on active safety features is done, a technology map is made and concept and vision cars are studied. The studies provide inspiration for the design and show that technologies like a head-up display offer potential for the design.

Potential technologies

Since the context is in 2020 technologies could be used that are not yet available or still need to be improved. Some of these technological developments are providing a potential for the next generation cars. These developments are mapped in Appendix C. An excerpt of this is shown in Figure 24. It shows technologies which can be used in future cars categorised by user input, processing, input, output, connectivity and comfort with an estimation in which generation car they will emerge.

State of art study

Some of these technologies are already used for active safety features in the newer high-end cars. To show this current state of the art concerning active safety features, Figure 23 shows examples of active safety features which are already implemented in some of the newest cars. Most of these are further described on the next pages. The current state of features show the possibilities within the design for the take over.

Concept cars and vision

A study is done to three concept / vision cars. The Mercedes-Benz F015 "Luxury in motion", BMW vision and the Rolls-Royce 103EX. This study can be found

in Appendix D. These cars are the vision of major car companies on how the future cars will look like and interact with the user and environment.

The Mercedes-Benz emphasises on communication to the outside world. BMW uses alive geometry to provide intuitive assistance while driving and Rolls-Royce focusses on using artificial intelligence. Focussing on the mode transitions, the designs do not take into account the problems that come with automation. Simple take overs are used by grabbing the steering wheel and activating the manual/automatic driving mode with a single press. The design around the transition itself however, could provide insights or inspiration for design solutions.

Conclusion

Most of the technologies offer opportunities for the design of active safety features, but some can also be used to facilitate safe transitions between the automation modes. Especially the top view feature and collision warning combined can offer great improvement for safe driving and increasing situational awareness. Directional audio can act as a buffer to fill the gap caused by the loss of driver vigilance. The HUD developments offer a new ideal display for drivers. This potential can be increased with the use of augmentation.

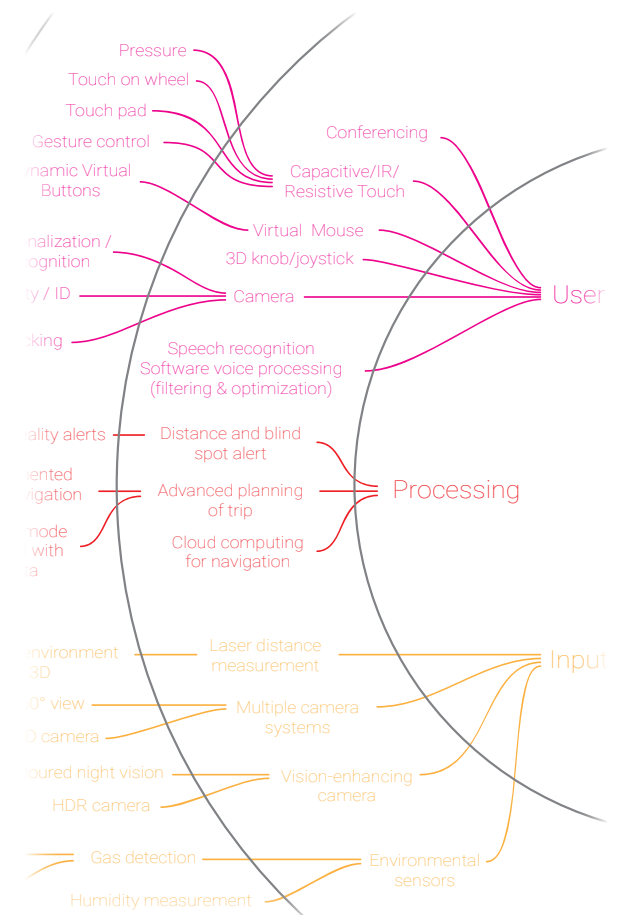
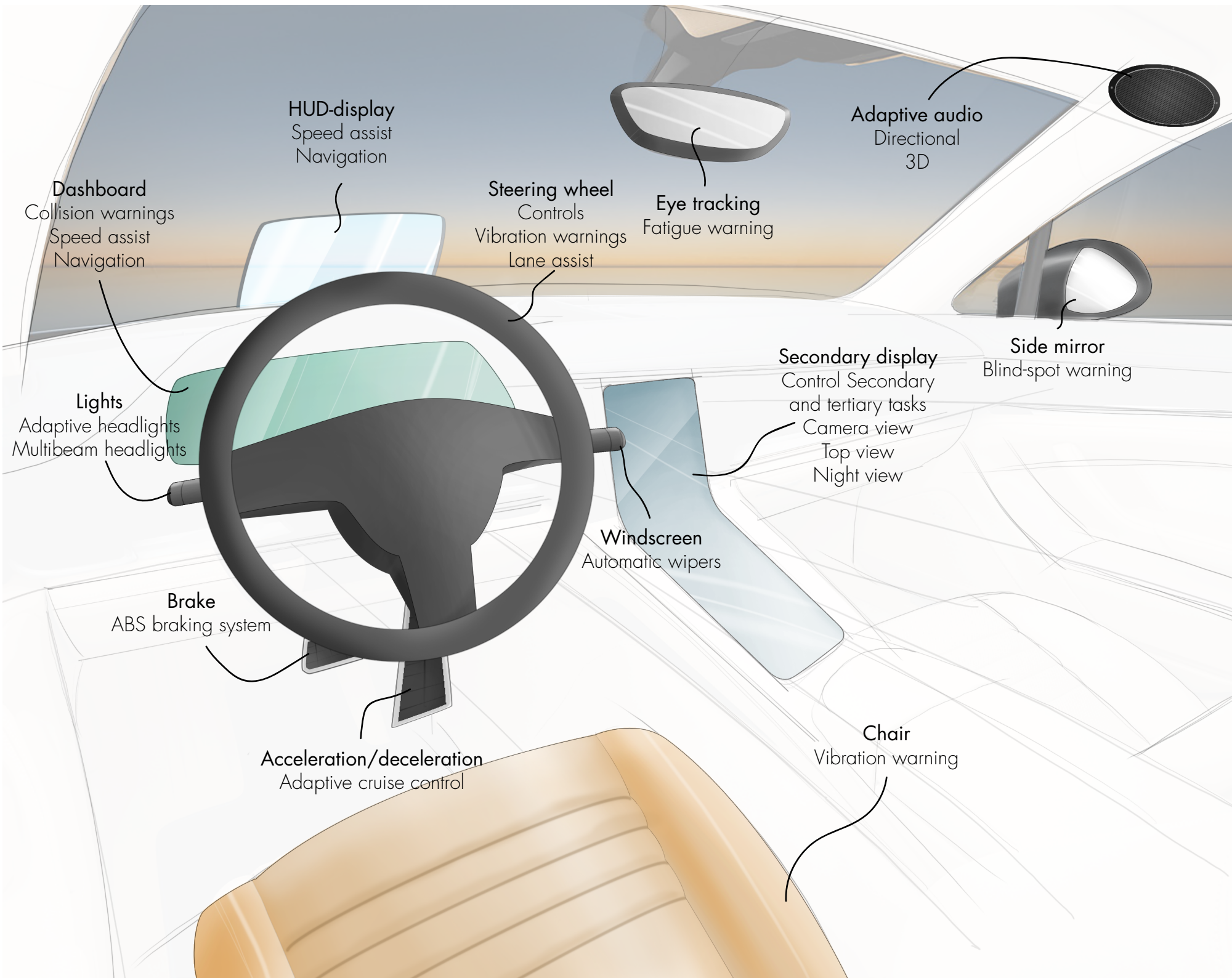


Figure 24. Excerpt of the technology map. The full version can be found in Appendix C.



HUD-display
Speed assist
Navigation

Dashboard
Collision warnings
Speed assist
Navigation

Steering wheel
Controls
Vibration warnings
Lane assist

Eye tracking
Fatigue warning

Adaptive audio
Directional
3D

Side mirror
Blind-spot warning

Secondary display
Control Secondary
and tertiary tasks
Camera view
Top view
Night view

Lights
Adaptive headlights
Multibeam headlights

Windscreen
Automatic wipers

Brake
ABS braking system

Acceleration/deceleration
Adaptive cruise control

Chair
Vibration warning



Adaptive headlights

Adaptive headlights are able to rotate towards the projected course of the car, which can be useful for turns in a dark environment. Also when a car approaches towards the Tesla the headlights will turn downwards.



Autosteer/Lane assist

Autosteer can keep the car within the road lines. In addition when activating the turning signal some cars will automatically change lanes when it is safe to do so.



Autopark

Autopark is a feature that can park the car automatically without input of the driver. This has some limitations however, based on the environment.



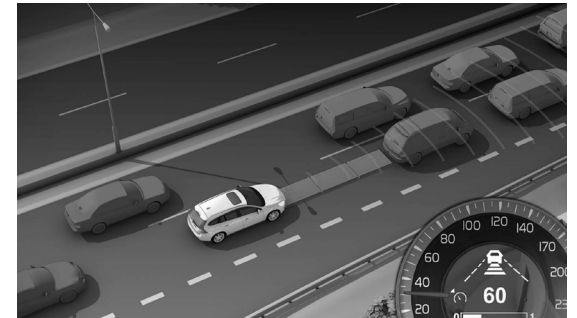
Collision warning

Collision warning will warn the driver when a collision is close to happening. The newer versions will have an all-round detection system and will brake automatically at the last moment.



Night vision

Night vision helps the users see the environment at when it is dark. In some versions these goes in combination with object recognition.



Adaptive Cruise Control

Most of the new cars already have some form of adaptive cruise control, these can however only be used within a limited speed range. The newer versions are in combination with stop & go function allowing it on (almost) all speeds.



Full-colour HUD

The adapted Heads-up display from aviation vehicles in full colour. It keeps the eyes on the road by projecting relevant driving information directly into the driver's line of sight instead of on Head-Down displays



Blind spot monitoring

The blind-spot monitoring system warns the driver when someone is in the blind spot of the car with visual feedback. The system is later merged into the newer systems of collision warning.



Break assist

Break assist helps the user by adding pressure to the brakes when it senses an emergency brake is happening



Fatigue-warning

Multiple companies are implementing fatigue warning which is mainly detected by driving style and will advise the drivers to take a break. New eye-tracking systems however allow for a more accurate detection and new design possibilities by detecting where the driver's visual focus is.



Top view

The cameras and sensors together generate a top view of the car. This view is shown on a display in the car and can be used for parking for example. The lines predict the movements of the car and warn for potential collisions.



Multibeam headlights

The multibeam headlights are designed to create visibility, but without dazzling. The multitude of leds will turn off individually when they would be aimed at other road users. This way it prevents that other road users would be hindered by these headlights.

3.3 MEGACITIES

The context are megacities with medium to high maturity level. A combination of literature research and watching dashcam videos of driving through megacities show that characteristics of a megacity includes a multitude of often crowded and congested lanes, drivers switch lanes often and there is a lot of sound coming from the environment. Also, switching between levels of automation can happen often at the transitions between different types of roads.

Figure 25. Megacities with a medium and high maturity level 

The complexity of driver behaviour is mainly determined by three classes of elements: (Li, 2013) driver personal, vehicle and contextual properties. The vehicle characteristics are unknown and not within the project scope. The personal and contextual conditions however, have some consistency. The contextual properties will be discussed in this section. The chosen context following the trends are megacities (Figure 25).

Maturity levels

A prediction (Allianz Risk Pulse, 2015) of Axel Theis (Allianz SE board member) is that “the course of how we will live in the future is being set in these megalopolises. This is where tomorrow’s trends are emerging ... the megalopolises show where urban development is headed and how transport, energy, culture, and economies can be organized”. This makes megacities one of the best places for an introduction of a new high automation car.

Since the autonomous car will still be a new development in 2020, the project will focus on megacities that have a medium (Shanghai) to high (London, New York) maturity level (Allianz Risk Pulse, 2015).

Characteristics of these megacities with a medium maturity level are a continuing growth with signs of an ageing population. A coordinated governance with a clear urban planning and an expanded mass transit. There is slightly improved infrastructure, however uncontrolled traffic is one of the main problems since more and more people are buying personal cars. This leads to congestion, a chaotic driving environment and air pollution.

The megacities with a high maturity level are distinctive by their wealth. This also means they have the means to invest in innovative solutions (for infrastructure). These megacities typically have a flat or negative growth in contrary to megacities with a lower maturity level. Their infrastructure is ageing, but provide opportunities for smart alternatives or improvements using coordinated urban planning.

Although these megacities differ a lot from each other, there are some similarities concerning the road context. Most of the time there is a multitude of lanes per road direction. The roads are crowded and congestion and traffic jams are not rare. Because of the multitude of lanes, there will also be a lot of lane switching which decreases the traffic flow. Also, a lot of sounds are coming from the roads: car engines,

honking, people talking etc. What is distinctive for a megacity is that they are most likely connected to one or multiple highways at multiple points.

Driving through megacities

By analysing dash-cam videos of people driving through three different megacities, tacit knowledge is gained. This analysis is shown in Appendix E and Figure 25. Tokyo has a clean and clear road environment. London has narrow streets and lots of congestion caused by parked or stopping cars. New York has clear roads, but there is a lot of congestion due to the crowdedness. Lane switching happens for three reasons: planning, finding the fastest lane and evading stationary objects.

TOKYO



Clear road and lane distinctions

Almost always multiple lanes

Speed limit on the road as markings, same goes for other traffic rules

Many large vehicles blocking the views

Almost no cyclists

LONDON



Narrow two-way streets

Broader roads outside of the centre

Switching lanes happens often due to movement from parking spaces

Clear road and lane distinctions

NEW YORK



Multiple lanes, the direction is divided by lines on the road

Many pedestrians and cabs

Almost no standing traffic signs, road markings are used for to indicate the traffic rules



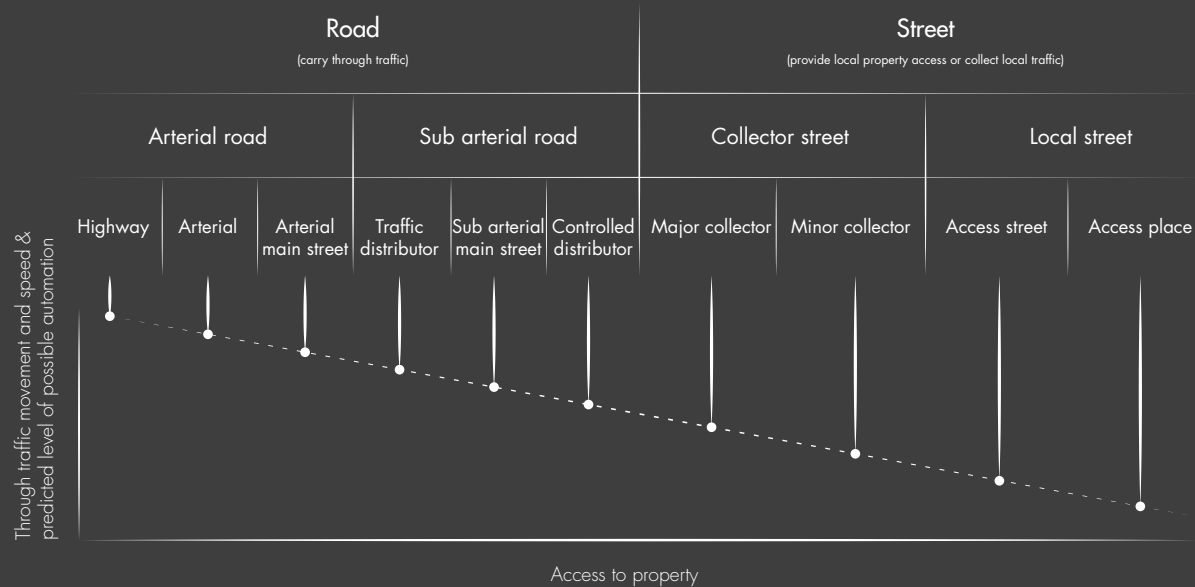


Figure 26. A typical road hierarchy framework. Access to property on the x-axis and through traffic movement and speed plus the predicted level of possible automation on the y-axis.

The journey of the target group

Figure 26 shows a typical road hierarchy framework (Eppell, 2001). This framework is mapped on a graph showing the road hierarchy and its characteristics related to access to property (x-axis) and through traffic movement and speed plus the predicted level of possible automation (y-axis). It shows a negative correlation between the access to property and traffic movement and speed, but also with the level of automation. With the years of development between the level 4 and 5 automation cars it is expected that the level of automation available will rise starting from left to right on the graph.

Figure 27 visualises the relation between the road types and geographical scale of it (Marshall, 2004). Typically a journey to a megacity starts from an access place and then moves to the roads where the through traffic movement and speed gets higher (from right

to left in Figure 28). When the megacity is reached on the highway, the infrastructure gets inverted until the destination within the megacity is reached (Figure 29). These graphs help to sketch the journey of the target group to and in the megacities and when during the journey what level of automation will probably be available. Such a journey is sketched as a transitional map in Figure 29. The transitional map shows two insights: (1) It shows that different levels

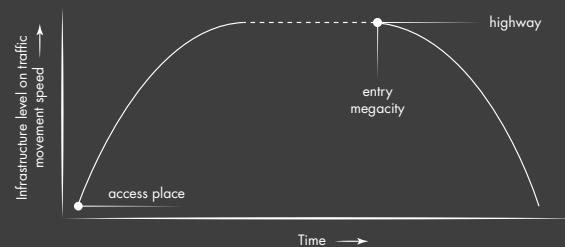


Figure 28. Journey to a destination in a megacity based on infrastructure level.

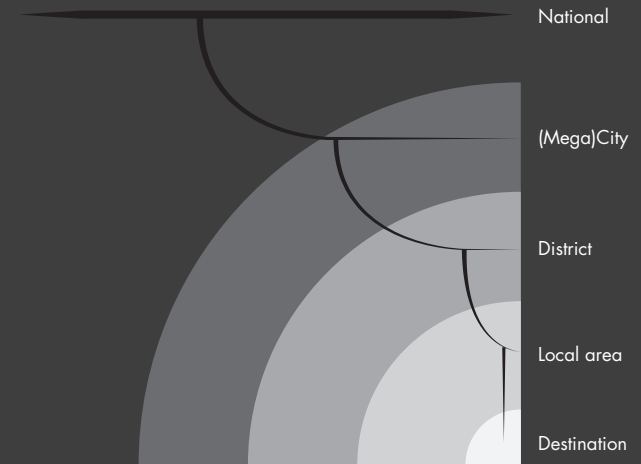


Figure 27. Road hierarchy and geographical scale.

of automation are likely to occur on different types of road and (2) it shows that the transitions between the levels of automation are likely to happen during or nearby the transitions between the type of roads.

This illustration is however limited to a static environment. In reality, the driving environment is dynamic and includes unexpected situations. The level 4 automation is able to cope with these kind of situations, the other modes however (probably) not. Also, the illustration shows a preplanned scenario for when which mode of automation will take place. Scenarios that are not included within this illustration could be for example an accident that happens near the vehicle or when there is construction work.

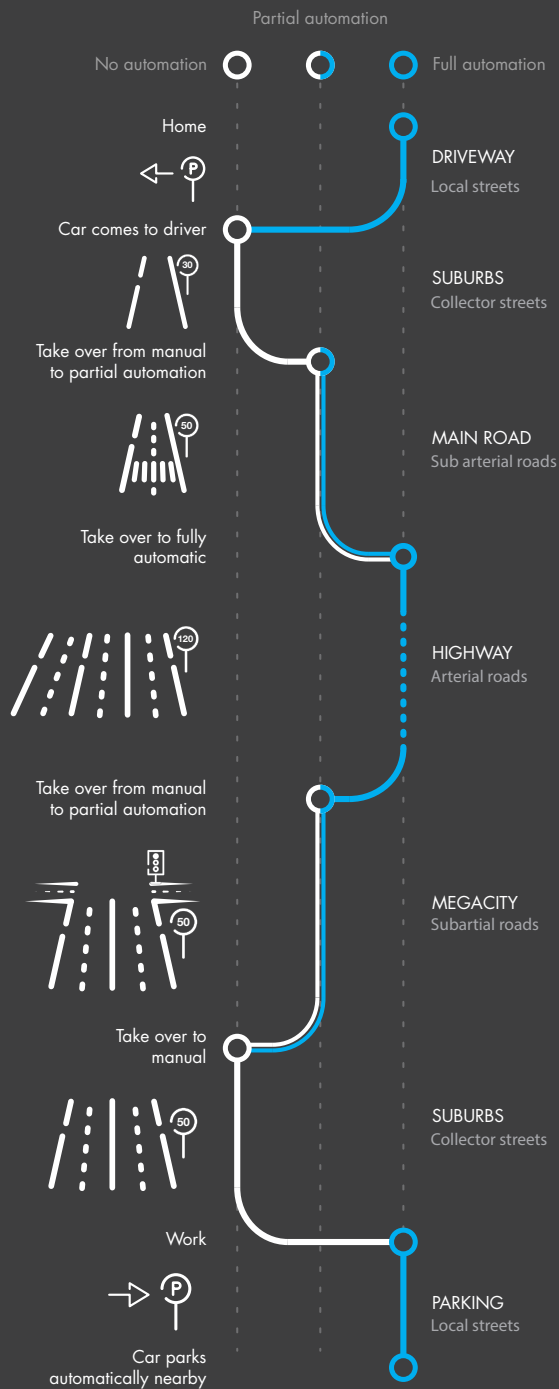


Figure 29. A transitional map of a typical journey for the target group driving a level 4 personal car to a destination in a megacity.

Conclusion

Megacities with a medium to high maturity level have certain characteristics which have to be taken into account when designing for the context. A multitude of often crowded and congested lanes, drivers switch lanes often and there is a lot of sound coming from the environment which can limit auditive feedback from the car.

The car should be able to read the many road indications in order to understand the rules and be able to provide the driver with the right information on ahead of time. Lane switching will happen often, but for different reasons depending on the city. One reason is planning, another is simply finding the fastest lane and another is to evade stationary objects.

Switching between driving modes (levels of automation) will potentially happen often depending on the road types and can be initiated by the system, user or both.

3.4 CUSTOMER SEGMENTATION

A survey showed what people would do in a car that drives autonomous. The worst case scenario for the transitions would be when someone is sleeping. Three potential target groups are described: Taxi/Uber drivers, people engaging in car sharing and users of personal cars. The latter is chosen as target group. A balance in the design have to be found between focussing on first time use and long time use. The others target groups might have more potential in later stages, when the cars are further developed and cheaper.

Figure 31. Three potential user groups for automated vehicles described

The personal properties that affect driving behaviour are discussed in this chapter. Since this project revolves around automated driving, it is not only interesting to see what the driving behaviour is but also, what kind of activities people will do in a self-driving car. A survey is done on this subject by Schoettle B. (2014). The results of this survey are illustrated in Figure 30. The best case (safest) scenario is where people will watch the road even though they are not driving (41%). The worst case scenario however, is when people will go to sleep (7%). It is expected thought that these numbers do not represent the actual use of such cars in the future

as trust in these cars will increase over time.

Target group

Figure 31 described three potential target groups. Uber / Taxi drivers (Chafkin, 2016), people engaging in car sharing (Carsharing.org, 2016) and people using personal cars. For each target group, a different HMI is most likely desirable. For the car sharing group the first time use will most likely be most important with an extra emphasis on building trust with the automated features, whereas for Uber / Taxi driver who will drive the most on the same roads. Here comfortable and quick transitions might be more

important with a focus on the long time use. The user group of personal cars are between these other two user groups.

The chosen target group are people using personal cars. Since this system will be designed for the first generation of level 4 automated vehicles, it might be quite expensive. Car sharing is not used extensively yet (although of use an increase is expected with autonomous driving cars) and might have a larger support group a few years later. For taxi driver's it might be an expensive investment for the first generation. When the autonomous cars allow for more flexibility with the automated features, it could be an ideal investment for taxi drivers. It is expected that mostly people with a higher income will use such system in the earlier years, until the investment costs become lower and it becomes a feasible option for people with a medium income.

Conclusion

The worst case scenario is that users will sleep in the car. The chosen target group are people using personal cars. This might require a focus on the longer use period with a smaller focus on the first time use.

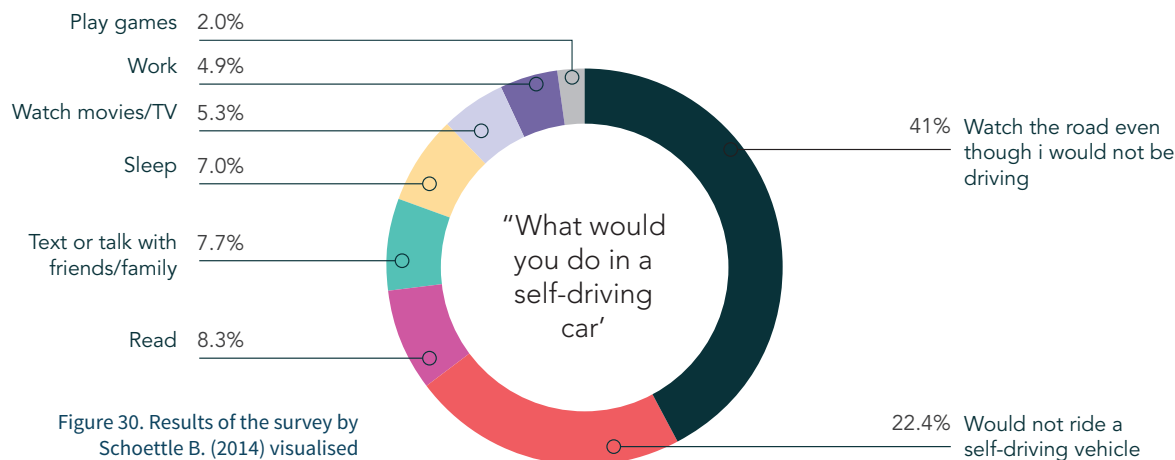


Figure 30. Results of the survey by Schoettle B. (2014) visualised

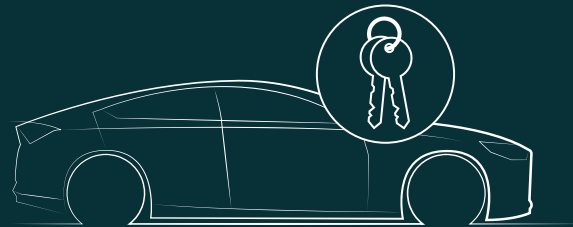


Uber / Taxi Drivers

Car to drive people to specific places with or without a designated driver

Uber and other similar taxi-like companies are already introducing self driving cars on a conditional automation level (level 3). The eventual goal would probably be to exclude to taxi drivers completely and make it easier and cheaper for the user to use the service.

Users can reserve one of these vehicles in certain time slots and use the vehicles more efficiently without waiting.



Car Sharing

Multiple people using a single car (service)

Car sharing is an already existing concept where user's do not own a car, but rent one for short periods of time. It is mostly used by customers who make use of a vehicle occasionally. Car sharing is a rising business caused by the congestion in cities, shifting mindsets of ownership and convergence of business models.

The ideal scenario is that the user reserves a car and it will drive itself to the pick-up place and drive itself back to the company.



Personal Cars

One person or family owning a single car

Most people still desire to own a car as they frequently use one and want to stay flexible using a vehicle. Many car companies (see Figure 13) are already designing level 3 or higher vehicles. The potential of autonomous vehicles is enormous not only for the comfort of the user, but also for the decrease the congestions and increase the safety on the road with a width range of users.

Users can have the option themselves to use the automated features or not.

3.5 CONCLUDING

The context of the project is personal cars in megacities with a medium to high maturity level. The characteristics of these megacities are a multitude of often crowded and congested lanes, drivers switch lanes often and there is a lot of sound coming from the environment which can limit auditive feedback from the car. The switching between different levels of automation will likely happen between the transitions of road types. To facilitate the transitions between the levels of automation new interactions and smarter products can be used with a focus on the use of a longer period of time. One of these smarter products that offer great opportunity is the augmentations in head-up displays, as they are within the peripheral view of the driver.

The next chapter focusses on gaining knowledge about the experiences while driving. This is done by testing with a Tesla and its automated features and through observing driving lessons.

CHAPTER 4

CONTEXT OF USE

4.1 First hand experience of the Tesla autopilot

What is the experience of driving with automation?

4.2 Observing driving lessons

What are the relevant safety issues and situations?

4.3 Concluding

What is the context of use?

4.1 TESLA AUTOPILOT

The Tesla S is one of the cars which has currently the highest automation level (2). A test ride is made to experience the levels of automation and gain inspiration for design. The autopilot can be turned on/off by using a special lever for the autopilot. The feedback the user gets is minimal and can lead to confusion. Data learning however offers potential for future design. Building trust with the system seems more important than anticipated as it was a reoccurring issue.

The highest level of automation car on the market is currently level 2: partial automation. The typical level 2 car is the Tesla S, as this includes for example, adaptive cruise control (longitudinal movement) and lane assist (lateral movement). Also, there are a lot of extra features in this car compared to the average car (Teslamotors 2015). Some of these features stand out, Especially the autopilot (also called Traffic-Aware Cruise Control), because it basically takes over the primary driving task from the user in certain situations. These features and others were tested during a test drive with a focus on the mode transitions and an interview with someone from Tesla. The extensive version of the research can be found in Appendix H.

Dashboard display

The dashboard display is basically divided into three sections: left, middle and right (Figure 32). The division is related to the driving tasks. The middle (most important) section is related to the primary tasks. The left and right sections are related to secondary and tertiary tasks.

Autopilot features

The autopilot is basically a combination of two active safety features: adaptive cruise control (ACC) and

lane keeping. There is a separate lever near the steer which controls the autopilot. To activate the ACC a switch on the lever needs to be pressed.

The feature 'speed assist' can recognise the current speed limit by detecting speed limit signs and using GPS data and displays it on the dashboard. This feature can be combined with the ACC to set the maximum speed. When however a new speed limit is detected by the speed assist it does not adjust the speed accordingly. The user has to reset the ACC in order to set the speed to the new speed limit.

To activate the 'lane keeping' the autopilot lever needs to be pulled towards the driver. When activated and the user wants to switch a lane, the car can do this automatically when the turning signal is turned on. The Tesla uses the sensors (in combination with the blind spot monitoring) to determine when the time is right to switch lanes.

Feedback & feedforward of the autopilot

When the ACC and/or lane keeping is available for the user, the corresponding indicators show up grey next to the current speed indicator on the middle section of the dashboard (a speedometer for ACC and a steering wheel for lane keeping). Tesla uses the colour blue to

indicate that these features are activated. In addition when the lane assist is activated the lane lines will also turn blue when activated. When the user tries to steer when lane assist is activated, the steering wheel will resist a little at first before the lane assist is being overridden.

Data learning

What makes these features strong is that the Tesla uses data learning. Every Tesla will record data while driving about the road (bumps, turn, traffic signals etc.) and send these to a database. The collected data is analysed and send back to the Teslas. Through these updates, the Teslas are learning to drive the roads optimal.

Experience

There are still many situations where the functions do not (officially) work yet, So Tesla warns the users to not solely trust on the system and always monitor the environment and be ready to intervene when necessary. The functions are expected to improve a lot through data learning and will be available in more situations the coming years.

When switching to the autopilot there was still uncertainty concerning the actual confirmation

that the car is taking over the primary driving tasks. Just a small colour change on the dashboard is not sufficient for such a major transition of control.

Conclusion

Each of the safety features contribute to the safety and comfort level of the car however, they are especially effective in combination with other active safety features.

Tesla put all the feedback related to primary

driving tasks near the steering wheel. However the feedback for the autopilot is minimal considering the importance of the tasks. These need to be improved to ensure the user that the autopilot is activated. Physical forms of output by the system are rarely used and allow for opportunities for improvements. Also, the data learning has great potential for improvement of both current and future features.

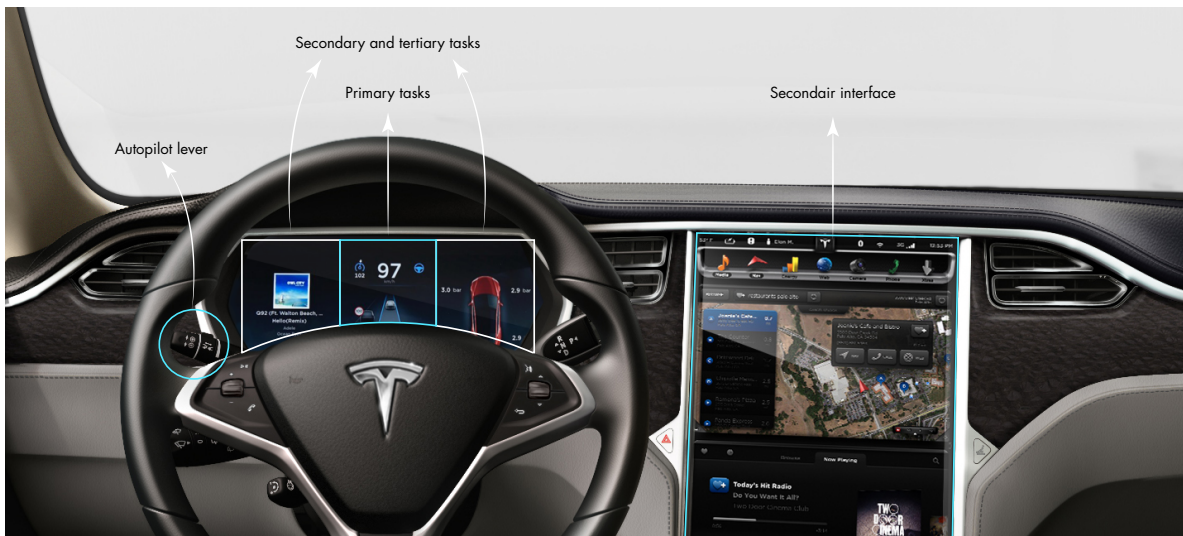


Figure 32. Tesla S interface



The User Interface of Active Safety Features

- When the car goes faster than the speed limit, the speed sign increases in size in order to alert the driver.
- 'Lane departure warning' will warn the driver when the car is crossing the markers on the lane (if the associated turning signal is off), by vibrating the steering wheel three times.
- The 'forward collision warning' warns the user when a collision is likely to happen unless immediate action is taken. This is done by both a visual signal on the middle section of the dashboard display on the and an auditory signal. This feature can be customised by choosing to warn late or early or turning it off.
- The 'park assist' feature helps the user with parking by warning the driver for collisions and the 'rear view camera' will show what is behind the car on the secondary interface in combination with guidelines which indicate the car's movements.

4.2 OBSERVING DRIVING LESSONS

To identify safety issues and gain inspiration for interactions, qualitative research is done by observing while driving with a driving instructor and six students and interviewing afterwards. The results show unsolved potential issues in planning (22), traffic rules (15) looking (10), communication (19) and skill (6). Calm, clear and structured feedback from the instructor was favoured. The driving instructor emphasises the importance of communication to other road users. The research concludes that there is space for improvements in the categories planning, traffic rules looking and communication.

Research with the student of a driving instructor can be seen as speed up process of driving with already experienced drivers. Although this is not a completely comparable study it is sufficient for this project.

Goal

The goal of this research is to identify safety issues/situations while driving and understand how the driving instructor interacts with the student before and during those situations as inspiration. Also to understand what variables influence the driver (Dutch Design Guide, 2013)

Method

The research was done mostly by observing the behaviour of both the student and the instructor (and the environment) during the driving lessons. The students had at least 20 hours of driving lesson experience. Since talking was not allowed, the student was asked to wear the Apple watch to measure their heart rate. The heart rate can be used to identify stress points for the student (Mybasis, 2013).

While driving, the student's and instructor's behaviour were observed and notable events were noted on a timeline on paper (video or pictures were

also not allowed for the student's comfort). The timeline was later linked to the heart rates of the student. Afterwards, a short interview was conducted with the student. Six participants are used for this research. After this part of the research, an interview was conducted with the driving instructor.

The car of the instructor was provided with a navigation system, but no other safety features than the basic car nowadays.

Results - Perceived issues

The results are presented in a graph showing the heart rates (y-axis) over time (x-axis). Within the graph situations are described in black, instructor's comments in blue and student's comments in red. These graphs can be found in Appendix F.

The stress points mostly occurred within the planning' categorisation. Especially when performing special operations there was consistently a significant rise in heart rate. These were also found when the lane indications were not clear (or complex), there was a complex intersection and during the planning of a take over.

The issues found within the research are categorised

in five sections (Figure 33): planning (22), traffic rules (17), looking (14), communication (20) and skill (21). Within these categories, themes were identified.

Some of the issues found during the study can already be solved/nullified by the state of art features mentioned in chapter x. Figure 33 describes the quantity of issues which cannot be solved with the currently existing features.

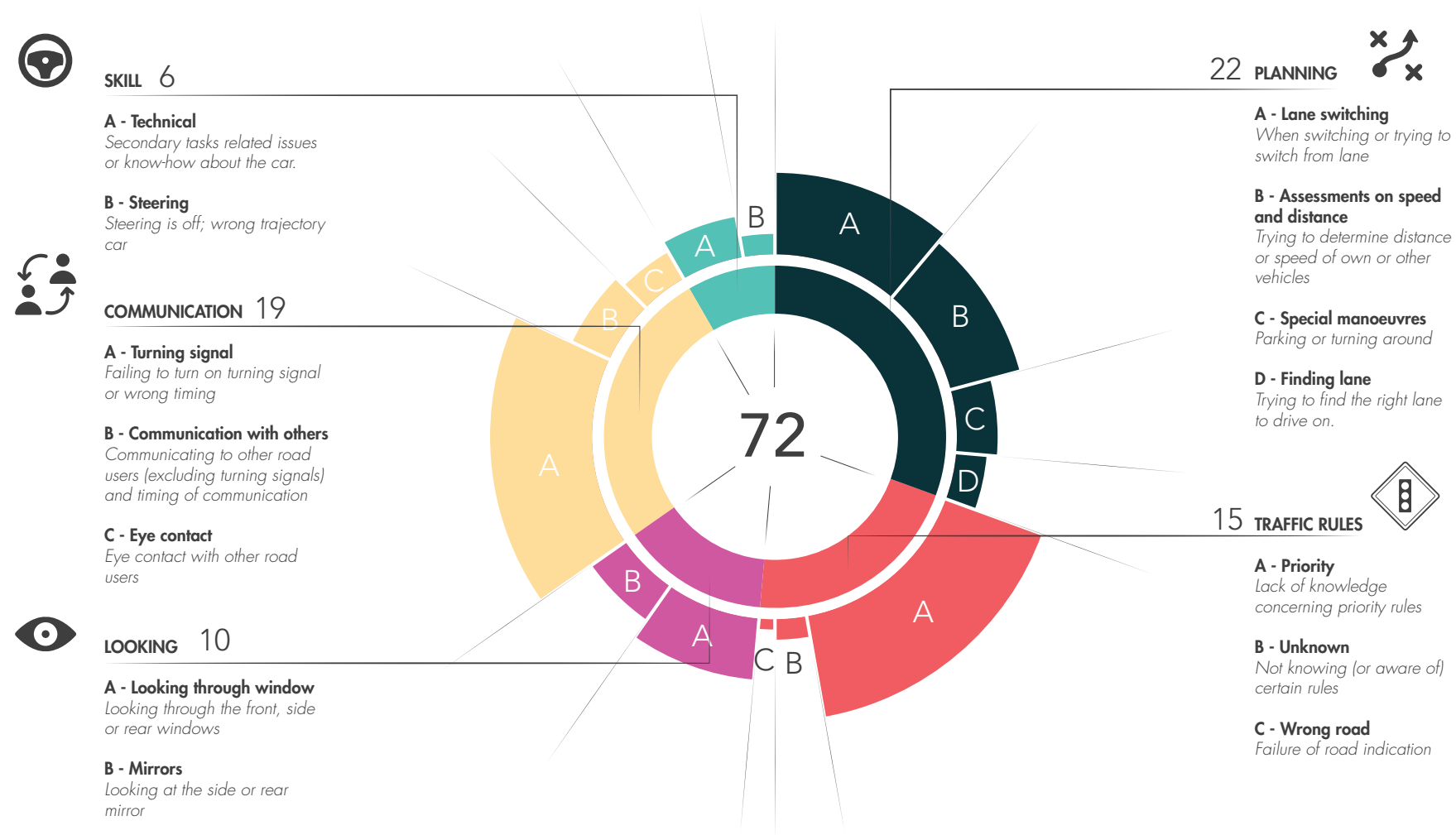
From the category 'skill' many (15) issues could be solved by existing features whereas in 'planning' none of the issues could be solved. The themes blind-spot, gear, hill, speed and lights could be completely solved by them. Within the theme 'steering' just a few issues could be solved.

Results - Interviews students

During the interviews, it was mentioned often that driving instructor was calm and clear, which was experienced as nice and comforting. Also he helped with a structured approach to situations.

Some people wanted more guidance concerning the blind-spots. One suggested it was more important to gain situational awareness than to perform the right execution during special manoeuvres.

Figure 33. Issues found within the study and which of those issues could not be solved by the current active safety features. The issues are categorised and themes are identified within them.



It was mentioned by one participant that her stress leads to a decrease in alertness and an increase of distractions.

Results - Interview driving instructor

Blind-spot is still a problem with most students. Communicating to other road users is important, because this allows for predictable behaviour. Making eye-contact with other road users is one of the ways to do this. Also using the turning signals and the warning lights in the right manner, but at the right time is key to good communication. It is also important to look ahead of time instead of during the execution to anticipate on the coming situation.

Discussion

Since the heart rates were measured with an Apple Watch, these results are not precise and thus might be considered not reliable enough. Using experienced driving students are still lacking experience for an accurate comparison with the target group. It will however, allow for a research with a lot of input within the time frame of the project. It was rather difficult to find driving instructors willing to participate in the research so only one has been used for this research.

Conclusion

The research concludes there is still space for improvements in the categories planning, traffic rules looking and communication. Within communication however, most of the issues revolve around the use of the turning signal, which might be a difficult issue to solve. Looking through the windows and to mirrors remains an issue. For traffic rules, the theme priority provides great potential for improvements in the new sensory capabilities of cars. The most potential lies in the category of planning where none of the issues could be solved with the current solutions. Until now most of these solutions improve issues revolving around the skill category.

Using a calm and clear interface is desirable from a user perspective. As the students (users) experienced as nice and comforting. Especially when it is done in a structured way for guiding.

4.3 CONCLUDING

The feedback from the automated features of Tesla is lacking or misleading. Also, Tesla did not grab the opportunity of using a HUD or haptic feedback. The research with the driving students show that there is still space for improvements for planning and traffic rules in the standard personal cars. With the addition of active safety features these issues can be (partly) solved. Solving these issues could simplify the transitions between automation and thereby reducing stress and increasing the safety. A calm and clear interface can contribute to a nice comforting experience.

The next chapter will conclude the research into a design brief. The goal and vision of the design is described.

CHAPTER 5

PROBLEM DEFINITION

5.1 Design goal and principles

What are the problems and what is the design goal?

5.2 Experience Map

Where is the design needed and why?

5.3 Interaction vision & qualities

What is the interaction vision and what qualities go along with it?

5.4 Concluding

What is the problem definition?

5.1 DESIGN GOAL AND PRINCIPLES

The goal of the design is defined as: 'Make the transition between fully automated, partial automated and assisted driving safer by increasing the situational awareness when needed, re-engaging driver vigilance, avoiding mode confusion and establish trust with the system.' Eight design principles are explained and statements are made which define the specifications of the car.

The problem definition does not only limit itself to simply designing only the transitions themselves. What happens before, during and after are part of the problem. The design is aimed at a personal car that is used often by a limited amount of people (only people within a family for example). This design is therefore aimed at longer periods of multiple uses. In contrary to a car-sharing system where first-time use is crucial.

Availability of automation modes

The fully automation mode will most likely only be available on arterial road and maybe even only highways in the introduction phase of such a highly automated vehicle. The partial automation mode will have a higher availability. The design is responsible for indicating which of the modes are available and when.

Mode confusion

The differences in the automation modes lead to a problem pilots are experiencing: mode confusion. Especially when the user thinks the system is responsible for the lateral or longitudinal movements of the vehicle this can lead to dangerous situations. There is also a crucial difference between being in control of lateral and longitudinal movements

(partial automated driving) and being responsible for the movements. The system might perform the same actions, but depending on which mode it is the responsibility belongs to either the user or the system. A clear distinction has to be made between them.

Trust

While driving in the partial or highly automated mode, trust seemed to be an issue. To make people feel secure with automated driving and build a positive relation with the car establishing trust with the system is an important factor, especially since the state of autonomous cars is still in the introduction of phase two.

Authority transition

The transition from manual to partial and highly automated driving is part of the design. The transition to manual however, is the most crucial aspect of the problem definition. There has to be a large transition both physically and mentally for the driver to create such a safe and comfortable transition between automation modes. Especially the lack of situational awareness and driver vigilance that comes with automation is a problem which hasn't been solved yet. From the transition, it takes 40 seconds until the

SA does not rise anymore when the transition starts from highly automated driving. It takes 8 seconds from partial automated driving (depending on which of the lateral or longitudinal control is activated).

Scenario definitions

Fully automated driving will only be possible on highways. As the definition of a level 4 high automation describes, fully automated driving does not need the user to be involved in monitoring the environment or be ready for fall back performance of dynamic driving tasks. The system can cope with every possible scenario and unpredictable road situations do not play a part for highly automated driving for the predetermined use cases where highly automated driving is possible. The end of a highway is a typical example of the transition to manual.

Partial automated driving can consist of either only ACC (longitudinal) or both ACC and control of the lateral movement (a form of lane keeping). This will be available on most of the (sub)arterial roads. Unpredictable road situations during partial automated driving are included in the problem definition as the driver is responsible for monitoring the environment and fall back performance of dynamic driving tasks.

DESIGN GOAL

‘Make the transition between fully automated and assisted driving safer by increasing the situational awareness when needed, re-engaging driver vigilance, avoiding mode confusion and establish trust with the system.’

Goal

The design goal is as follows: ‘Make the transition between fully automated and assisted driving safer by increasing the situational awareness when needed, re-engaging driver vigilance, avoiding mode confusion and establish trust with the system.’

8 Design principles

1. Clear limitations of the HMI

The design of a highly automated vehicle is still a new development with which the target group has most likely no experience with. It is important for the user to understand the system’s capabilities and more importantly, its limitations. A clear design can facilitate the understanding of the system and the right responses of the user. It can also create trust with the system and thereby reduce stress levels and improve the relation with the car.

2. Adaptive HMI

An adaptive HMI can simplify the complexity of the interfaces, as they are aimed to provide information for all driving modes. Only providing relevant information to the driving mode can decrease

information and cognitive overload and emphasise the mode transitions. A structured hierarchy is needed to enable such interfaces while remaining easy to comprehend. Also offering too many options and warnings can result in complacency. The HMI should also be adaptive to the state of the user and the urgency in order to be able to provide the right feedback to the user.

3. Perceived affordances / use cues

To facilitate a safe and intentional transition between the different automation modes, perceived affordances should be key to the design. These affordances are both physical and digital and allow for intuitive interactions.

4. Providing information in the right places

The right feedback and feedforward can solve or improve most of the problems that come with automation. If these are placed in the right places it makes them easier to comprehend and relate them to the right actions.

5. Sufficient time to get back into the loop

The driver should have sufficient time to prepare for a

take over and get back into the loop. The time needed for this is 40 seconds, but should be decreased by the design by increasing SA and driver vigilance.

6. Providing the right information of automated actions

Only providing information that explains the ‘why’ of the actions of the automated features of the car, can increase SA, create a positive relation with the car and prevent cognitive overload. Also providing the ‘what’ will increase the safety. Since there are different levels of automation. Only providing the ‘why’ when the car is driving autonomously and providing both the ‘why’ and ‘what’ during assisted driving would be best.

7. Efficient use of different modalities

By using the strength of the different modalities and combining them in the design, it should become effective without creating cognitive overload. A cascade of different warnings for example which adapt to the user’s state and urgency.

8. Dynamic interface

It is preferred to use visualisations rather than text,

numbers or speech as these take more time and cognitive load to process. These visualisations need to be designed well to implicate the right meaning. A dynamic interface can allow the use of more complex icons by labelling when needed.

Design statements

To create a clear and structured start for the ideation, some statements are made which are part of the design.

‘There are four automation modes’

There four available automation modes are as follows:

- Assisted driving - no automation
- Assisted driving - ACC
- Assisted driving - ACC & Lane keeping
- Autonomous driving - fully automated

Adaptive Cruise Control and Lane Keeping should be considered added features to assisted driving as the responsibility stays the same. Therefore, from here on ‘partial automation’ will not be mentioned anymore and ACC and Lane Keeping are considered part of assisted driving.

‘Hands on steering wheel with Lane Keeping’

While Lane Keeping is engaged, the user must have the hands on the steering wheel, to prevent the user from getting engaged too much with non-driving tasks and prevent liability issues for the car manufacturer.

‘From autonomous driving to Adaptive Cruise Control’

From autonomous driving, it should not be possible to go back to assisted driving with ACC and Lane Keeping activated directly. This can be dangerous as (almost) only the responsibility shifts from the system to the user and not the control.

‘The user can always initiate a take over’

Since this design is for the first generation of cars which can drive autonomously, but have not been proven yet, trust is still a big issue. Therefore it is important for the user’s mental comfort that a take over can always be initiated by the user (interview nu.nl). Even though (assuming the car will function correctly) this might can be considered less safe. The system will only take control of the car without the

consent of the user if an accident is about to happen or will inevitably happen.

5.2 EXPERIENCE MAP

The experience map visualises the complexity of the issues with a scenario based approach by linking the emotions, quotes, stress level and situational awareness (SA) to the key activities. The data is collected from both the literature and field research. The results show multiple switches between levels of automation. During complex situations, there is a lowering in trust and joy, rise in stress levels and a lack of SA. With a high level of automation comes low levels of trust and SA, but a high level of joy. It is concluded that when a high SA is needed, it leads to cognitive overload and stress. The lack of SA becomes a problem when there is a sudden high need of it, which happens after the transitions to a lower level of automation.

Introduction

The experience map (see Figure 34) visualises the issues found in both the literature and field research. It helps to understand the user and visualise the complexity of the issues. The experience map shows a typical scenario for the future target group in megacities with a level 4 high automation car. The scenario is linked measured or predicted data showing the emotions, quotes, stress levels and situational awareness of the driver. It is assumed that this car has the active safety features described in the state of art subchapter.

1. Phases and automation level

The journey starts with the preparation of the departure. This is followed by driving at different automation levels and ends with the arrival.

2. The key activities

The key activities show more specific what the actions of the user/car are.

3. Emotions driver

Two emotions are visualised with their counter emotions: trust. vs. fear and joy vs frustration. These emotions are chosen as they are considered to be important factors for an automated car design.

Trusting the system is still an issue with these kind of automated functions and joy can make a journey more pleasant. When the data is visualised above the neutral line the positive of the two is indicated and the other way around.

4. Stress level

These levels indicate when the driver is stressed during the scenario.

5. Driver vigilance

The driver vigilance level of the driver. Driver vigilance is one of the important factors according to the literature research.

6. Situational awareness

One of the most important issues as shown by both the literature and field research. This includes both the situational awareness the driver has and the situational awareness the driver needs at that point.

Data collection

The data of the visualisations are based on literature, field research and indications by potential users.

1. Phase and automation level & 2. Key activities

Within this journey the assumption is made of when

certain levels of automation are activated based on the probability of where these automated features are available. The activities are based on a typical route the target group takes.

3. Emotions driver

The emotions are based on literature the experiences of driving of other people.

4. Stress level

The stress levels based on the heart rates measured of the students of the driving instructor for the non-automated parts. The partial automated stress levels based on the heart rate measured during the Tesla drive. The levels for the fully automated activities are a prediction.

5. Driver vigilance

The levels are an indication which are derived from the experience during the lessons of the driving instructor and the Tesla drive

6. Situation awareness

The levels are an indication which are derived from the experience during the lessons of the driving instructor and the Tesla drive

Results

The activities show multiple switches between levels of automation. Also special manoeuvres are made in each of them.

Overall the joy of the driver is mostly linked to the level of automation and the complexity of the situation. The higher the level of automation and the lower the complexity of the situation, the higher the joy. For trust it is opposite concerning the level of automation. The higher the level of automation and the higher the complexity of the situation, the lower the amount of trust is with the system.

During complex situations, the stress level rises. The automated functions are lowering them however, especially when these are activated over a longer period. Almost no stress is found in the preparation and arrival phase.

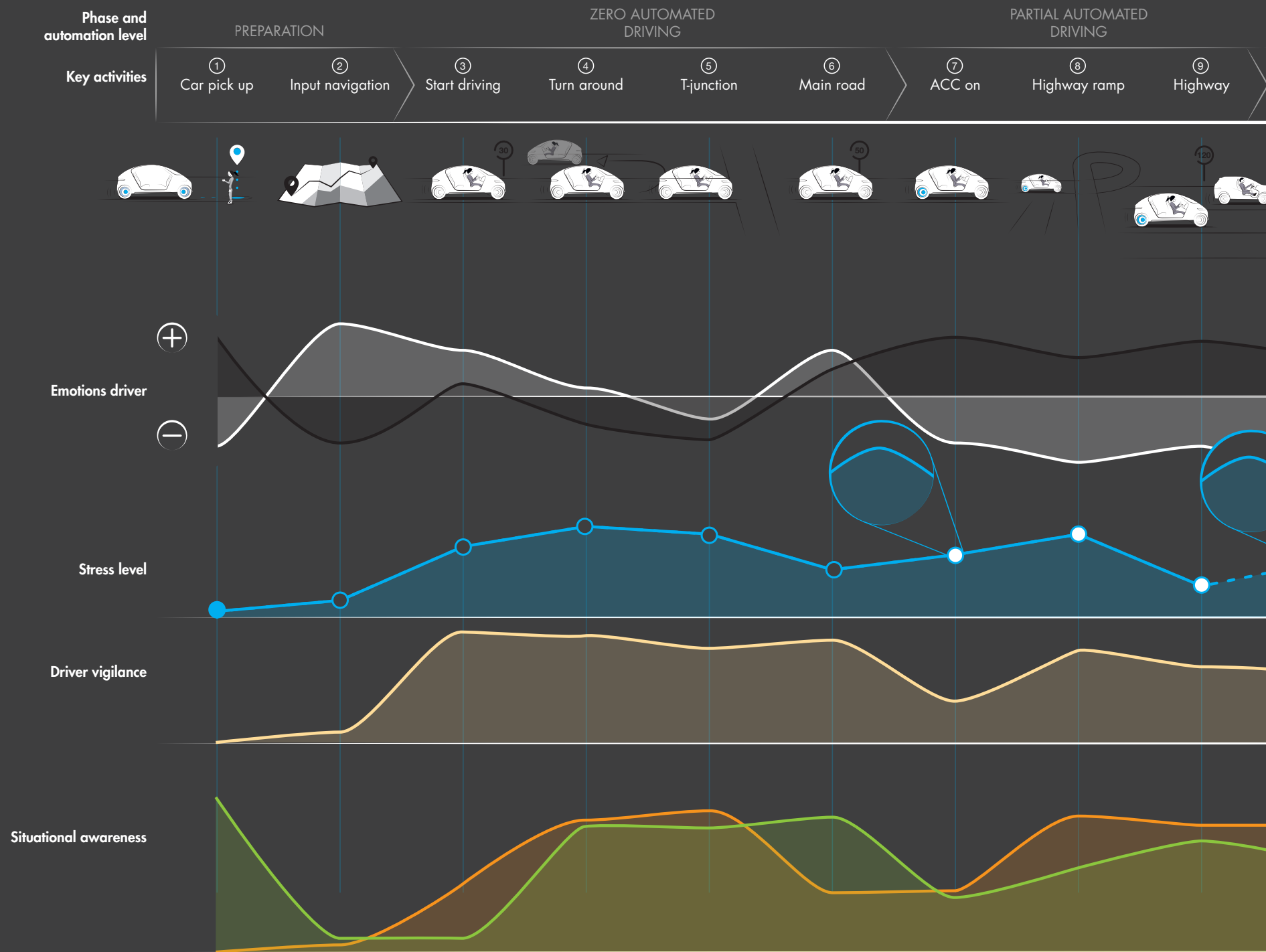
During the preparation and arrival, there is more awareness than needed. The opposite is happening just before and during partial automated driving. The situational awareness is almost none when driving fully automated.

The rising stress levels are most likely caused by the situational awareness that is needed and the actions the driver has to perform. This leads to cognitive overload and with it, stress.

The higher the level of automation, the lower the situational awareness. This self is not necessarily a problem. It becomes one however, when the driver has to take over these automated features.

If the cognitive overloads during complex situations where to be lowered, it would probably also lower the stress the driver experiences.

Conclusion

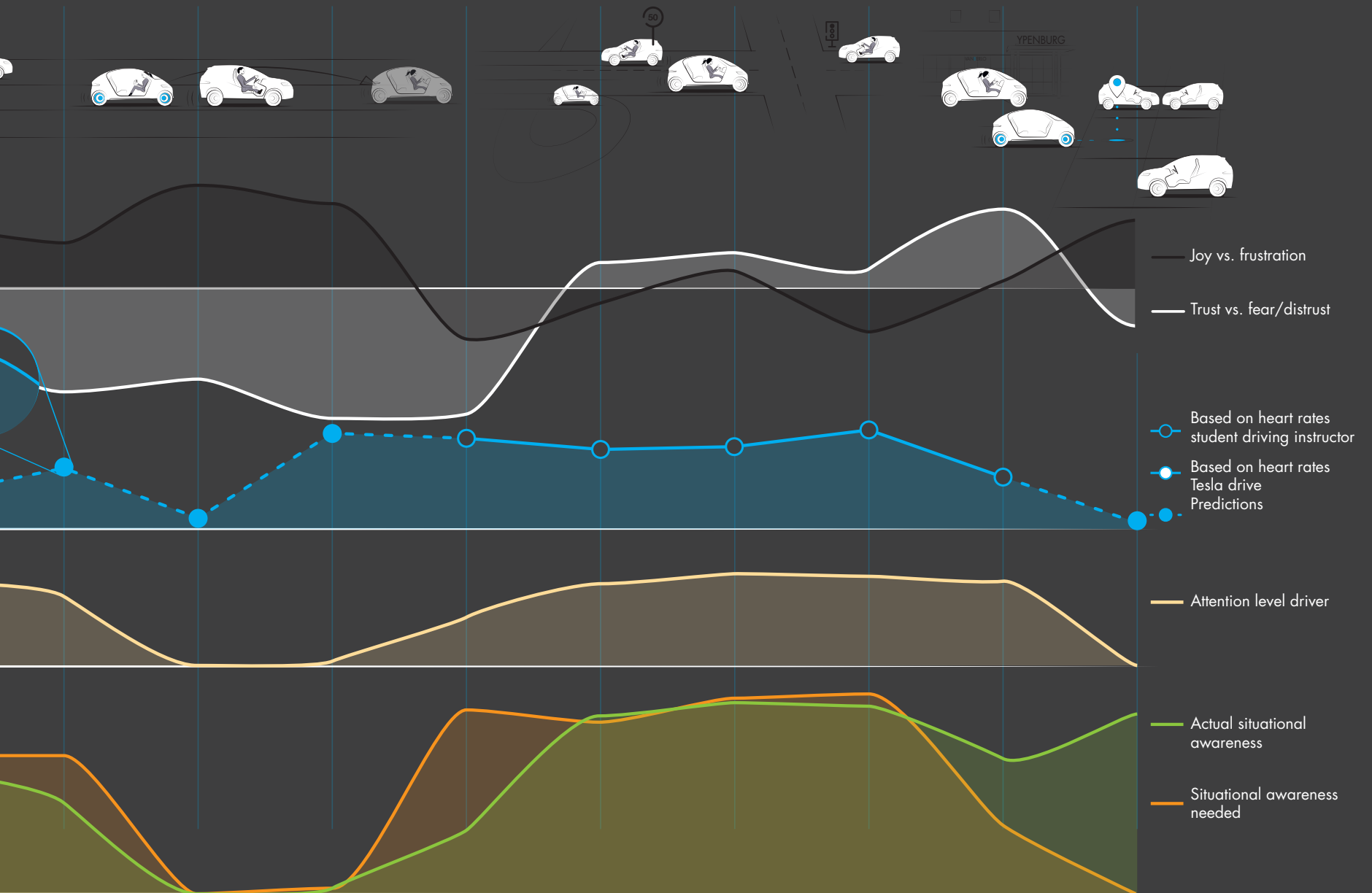


FULLY AUTOMATED DRIVING

ZERO AUTOMATED DRIVING

ARRIVAL

- ⑩ Take over of full automation
- ⑪ Sleeping, working etc.
- ⑫ Overtaking other vehicle
- ⑬ Take over to manual
- ⑭ Highway exit
- ⑮ Road megacity
- ⑯ Intersection
- ⑰ Stopping car
- ⑱ Sending car to park



5.3 INTERACTION VISION & QUALITIES

Co-pilot

A co-pilot the first officer is second-in-command of the aircraft to the captain (the pilot/user), who is the legal commander. The control of an aircraft is shared between the pilot and co-pilot. Both are either designated to 'pilot flying' (PF), 'pilot not flying' (PNF) or 'pilot monitoring' (PM). The roles between the user and the HMI design will change depending on the mode of the car. In this vision, the characteristics of the co-pilot change, however, depending on the situation.

Assisted driving

During assisted driving, the co-pilot (HMI design) will be attentive but on the background giving subtle guides and supporting when necessary. The co-pilot allows for the pilot (the user) to keep its freedom while confirming the actions of the pilot. The co-pilot becomes more attentive when the pilot is not paying attention when the pilot should.

Transition to automation features

While activation automated features the interaction with the co-pilot is effortless and fluent. The co-pilot guides the user through the process while assuring the pilot of its actions.

Driving semi-automated

When the automated features are active the co-pilot comes to the foreground. It will still be supporting the pilot, but becomes it becomes more a collaborative interaction where the pilot is still responsible for the plane, but the co-pilot supports the pilot by controlling some flying tasks.

Driving autonomous

During autonomous driving, rather than the co-pilot taking over, the co-pilot becomes the pilot as the pilot is responsible for the plane. When the pilot wants to give back the pilot hat to the user, the pilot does this first in a subtle way where the user still feels flexible. Then the pilot conveys the message in an explicit and structured way which can end in strictly and annoying if ignored.

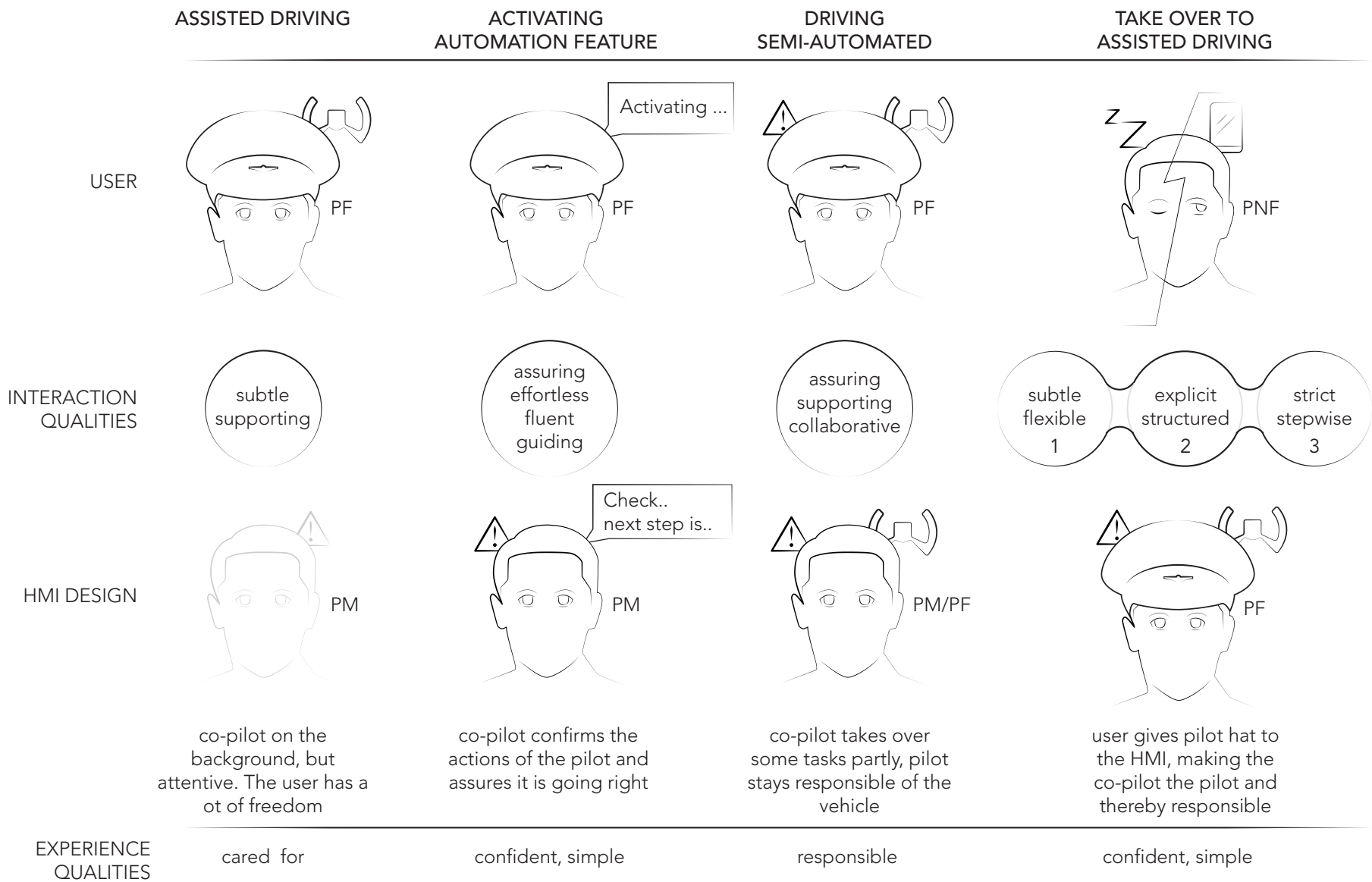
Qualities

Fluent, confident, trust, attentive, intuitively, clear and effortless

The pilot trusts the co-pilot blindly and can interact with him/her intuitively and doesn't have to think much about the actions. The actions are fluent and conscious and the pilot feels confident doing so. The pilot starts in a state of serenity, but when needed

the co-pilot helps to change the state of the pilot to attentive and focussed. There is no feeling of ambiguity.

Figure 35. Interaction vision for different stages in the design.



5.4 CONCLUDING

The issue addressed in this project is the loss in driving performance that comes with the transitions from manual to partial and highly automated driving. Therefore the design goal is to 'Make the transition between fully automated, partial automated and assisted driving safer by increasing the situational awareness when needed, re-engaging driver vigilance, avoiding mode confusion and establish trust with the system.' A metaphor of a co-pilot is used to describe the interaction and their qualities.

This sketches the setting for the design phase of the project which is discussed in the next chapter.

CHAPTER 6

DESIGNING THE TRANSITION

6.1 Ideation

How broad and deep are the ideas explored?

6.2 Conceptualisation

What are the frameworks for the design and how is it developed?

6.3 Design refinement

What is the design?

6.1 IDEATION

During the ideation, brainstorm sessions were held and an envisioning use workshop with VanBerlo. The ideation scope was set on designing active safety features, the use of automated features, the transition to autonomous driving and the transition to assisted driving. The design should be where these four aspects are integrated in one system.

Brainstorm sessions

The ideation phase started with multiple brainstorm sessions with four participants. One session took about 2 hours where the participants were asked to brainstorm on different 'how to's'. The results of the sessions were used as input for further ideation.

Envisioning Use Workshop

The 'Envision Use Workshop' (Delft Design Guide, 2014) was used share and align not only ideas among the team member of VanBerlo, but also to align our visions around the context of the product. This is especially important since it is a (uncertain) future context. Use scenarios were defined and usability and user experience issues were identified and emphasised around these ideas and context.

Methodology

Further ideation is done through a form similar to a morphological chart in combination with 'how to's' (Delft Design Guide, 2014). This can be found in Appendix K. It shows the broad and depth of the exploration for ideas.

Ideation scope

The ideation could be categorised in mainly four categories (Figure 36). The activation and use of

the automated features (ACC & Lane Keeping) during assisted driving (1), active safety features (2), the transition to autonomous driving (3) and the transition back to assisted driving (4). The first category finds it additional bases on the field research with the Tesla drive as it has the similar features. The second category finds support on the field research with the driving instructor to provide help during assisted driving. The third and fourth category are mostly based on the literature research.

The ideal design is where the ideas in these categories can be integrated into a concept that works as one cohesive design.

Figure 37 shows a scenario where the user pushes the steering wheel in as a strong interaction and message that the user gives the steering wheel to the system. When autonomous driving is activated, the HUD disappears to provide to user with a clean panoramic view. The steering wheel turns blue with projected hands on the steering wheel of the system which shows how the system is steering.

Conclusion

Part of the conclusion of the ideation is visualised in Figure 38. It shows the potential of certain design

aspects. The heads-up display, instrument cluster, directional audio, steering wheel and seat are used for further development in the conceptualisation.

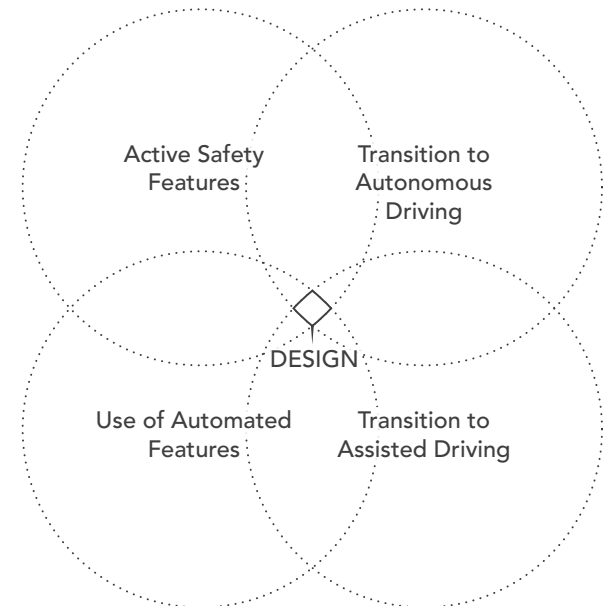
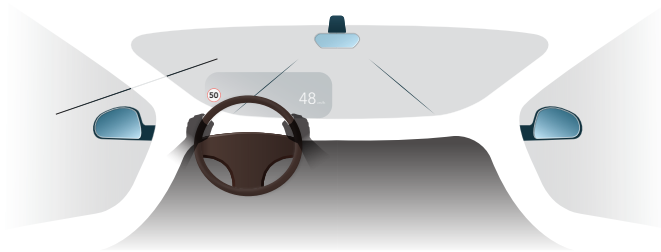
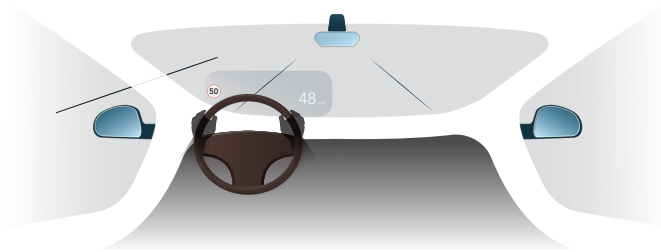


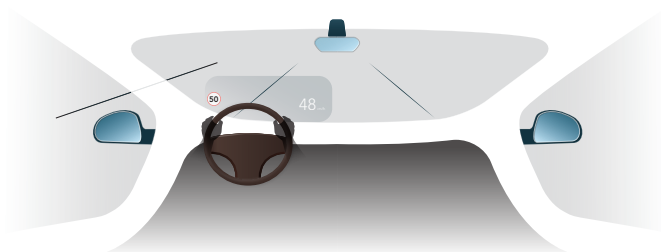
Figure 36. Ideation categories, the goal is to integrate the ideas into a concept that works as a one cohesive design.



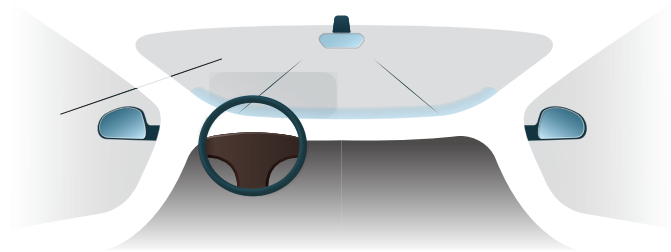
1. Driving in assisted mode with the HUD activated.



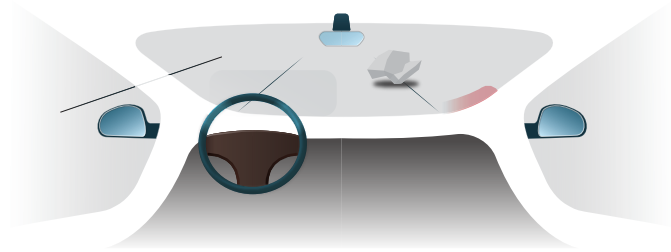
2. User activates autonomous driving by pushing steering wheel in.



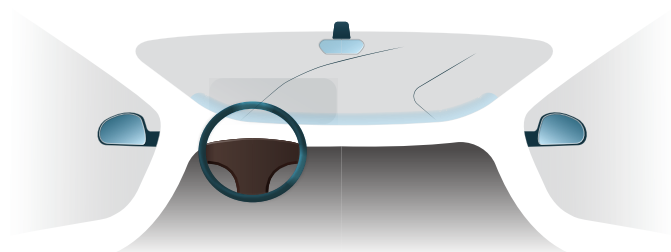
3. Steering wheel moves back, which shows a metaphorical interaction of giving the control to the system.



4. Steering wheel turns blue means take over is confirmed HUD not needed anymore. LED strip turn blue to indicate autonomous driving mode.



5. Red light on windscreen shows danger and the direction it is coming from within the peripheral view.



6. Extreme blue light visualises the steering. Can help with predictability of the car.

Figure 37. A scenario form the ideation describing the transition to autonomous driving.

HEAD-UP DISPLAY

HUD can act as a primary display during assisted driving, supporting the driver with the primary driving tasks on a tactical level.

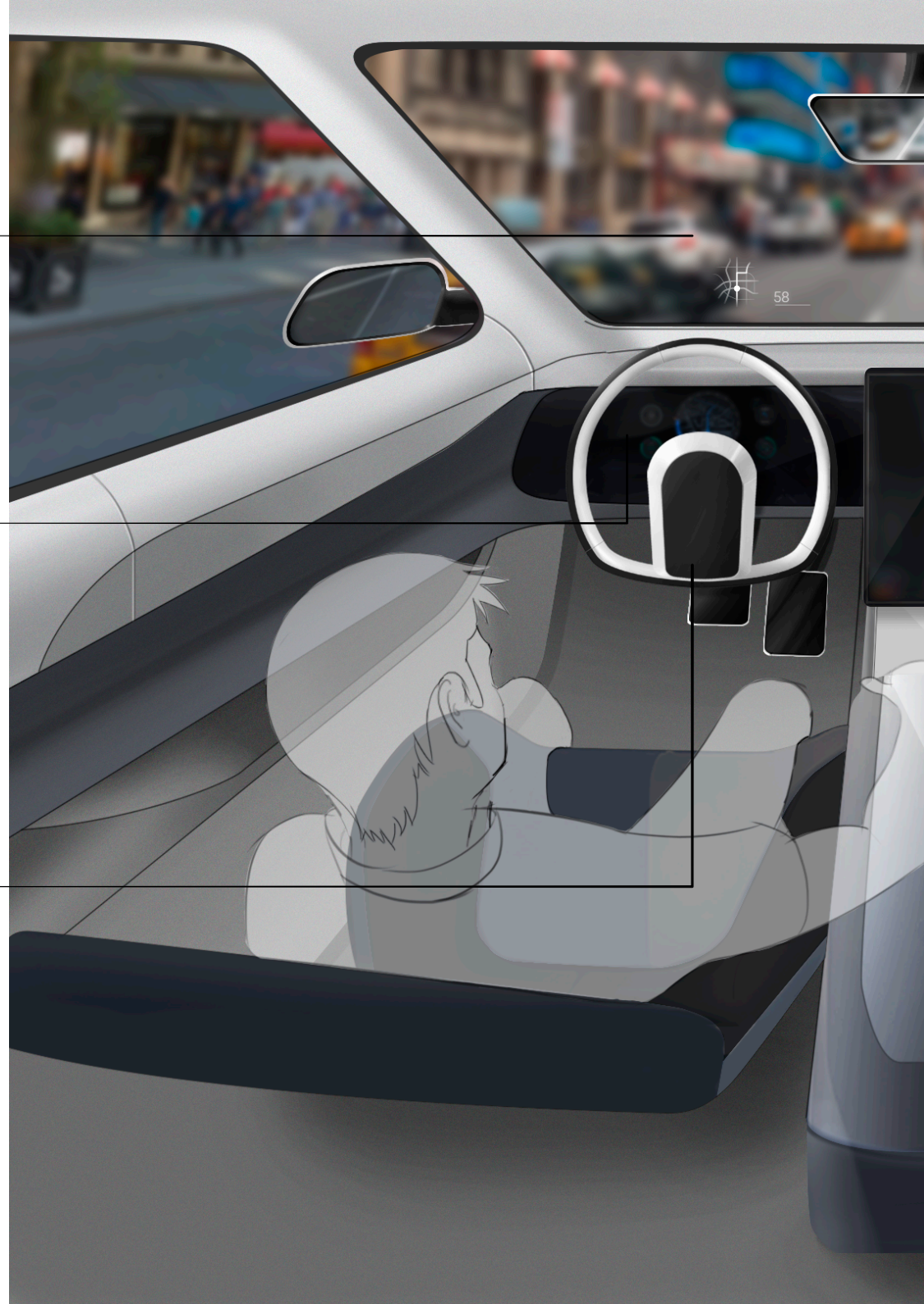
HUD can become ineffective if the user changes the seat position while in autonomous driving mode

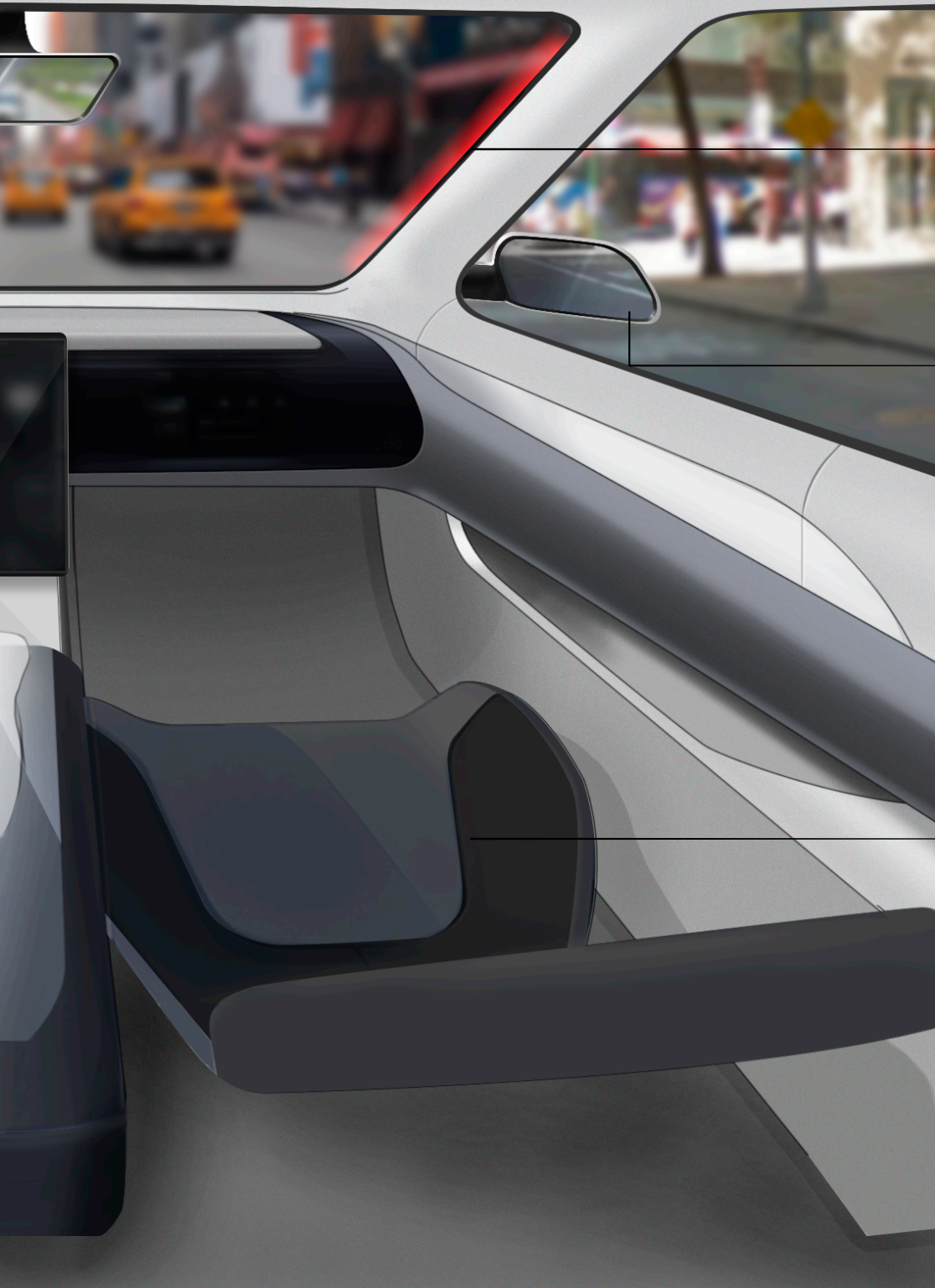
INSTRUMENT CLUSTER

Instrument cluster can act as a secondary display during assisted driving, supporting the driver with the secondary driving tasks and on a strategic level. During autonomous driving, it can take over tasks of the HUD more effectively.

STEERING WHEEL

The steering wheel is under used and can provide a lot more feedback than the current steering wheels. It can metaphorically be used to indicate the status of the automated features.





LED STRIP

LED strips around the wind shield can be used as effective collision warnings. Using them in the bottom might, however, interfere with the HUD.

MIRRORS

Mirrors can be used as an additional display if they are designed as smart mirrors. They can support the driver mostly through active safety features on a tactical level.

DIRECTIONAL AUDIO

Audio can be used as an effective feedback modality when timing is important.

SEAT

The seat has new flexibility with autonomous driving. During autonomous driving, it could provide feedback and feedforward to the user about the desired user state.

6.2 CONCEPTUALISATION

A basic framework is designed based on the literature research. It shows five stages in combination with the user states and how situational awareness and driver vigilance should increase. The design consists of four design elements, which are layered and have a structural information hierarchy. The elements are the head-up display (primary driving tasks on a operational and tactical level and status of automated features), instrument cluster (secondary driving tasks on a strategic level), steering wheel (control and status of automated features) and the seat (guiding through user states).

Structure take over to assisted driving

The literature research sets a basic framework for the design of the take over from autonomous driving to assisted driving (which is considered to be the crux of the project). The stages of this framework are shown in Figure 39. It shows that the design aims for a gradual increase in both driver vigilance and situational awareness before the take over takes place.

Thirty to five minutes (depending on how long the user has been sleeping) before the take over the design will wake the user up gradually until the user actually wakes up. During this stage, the user should be at least vigilant to other warnings. If the user is awake, it will increase the user's situational awareness gradually on a basic level (where am I, what is the weather etc.).

Forty seconds before take over the design will bring the user to an attentive level. The user should now not only be vigilant for alarms, but also monitor the environment.

Eight seconds before the take over the design will warn the user to take over the control. The

contribution of designing active safety features, in addition, can significantly support the user after the take over. Appendix L shows the interaction framework used to describe required actions of the system and the potential actions of the user. This framework is used during the ideation as a sort of checklist and to define stages during the take over.

Stages

A design framework is made based on Figure 39. The framework defines different stages in the design and shows what type of feedback modalities are used. Figure 40 visualises this framework.

There are five stages defined within the framework.

1. Pre-care

During the pre-care stage, no actions are required of the user, only the system will perform actions. As chapter 3 concluded, the system will come to its limitation most likely when the car has to make a certain lateral movement (e.g. taking the exit of a highway). To make the transition as smooth as possible for the user, the system will position the car on the right lane in advance, so minimal lateral movement is required of the user right after the take

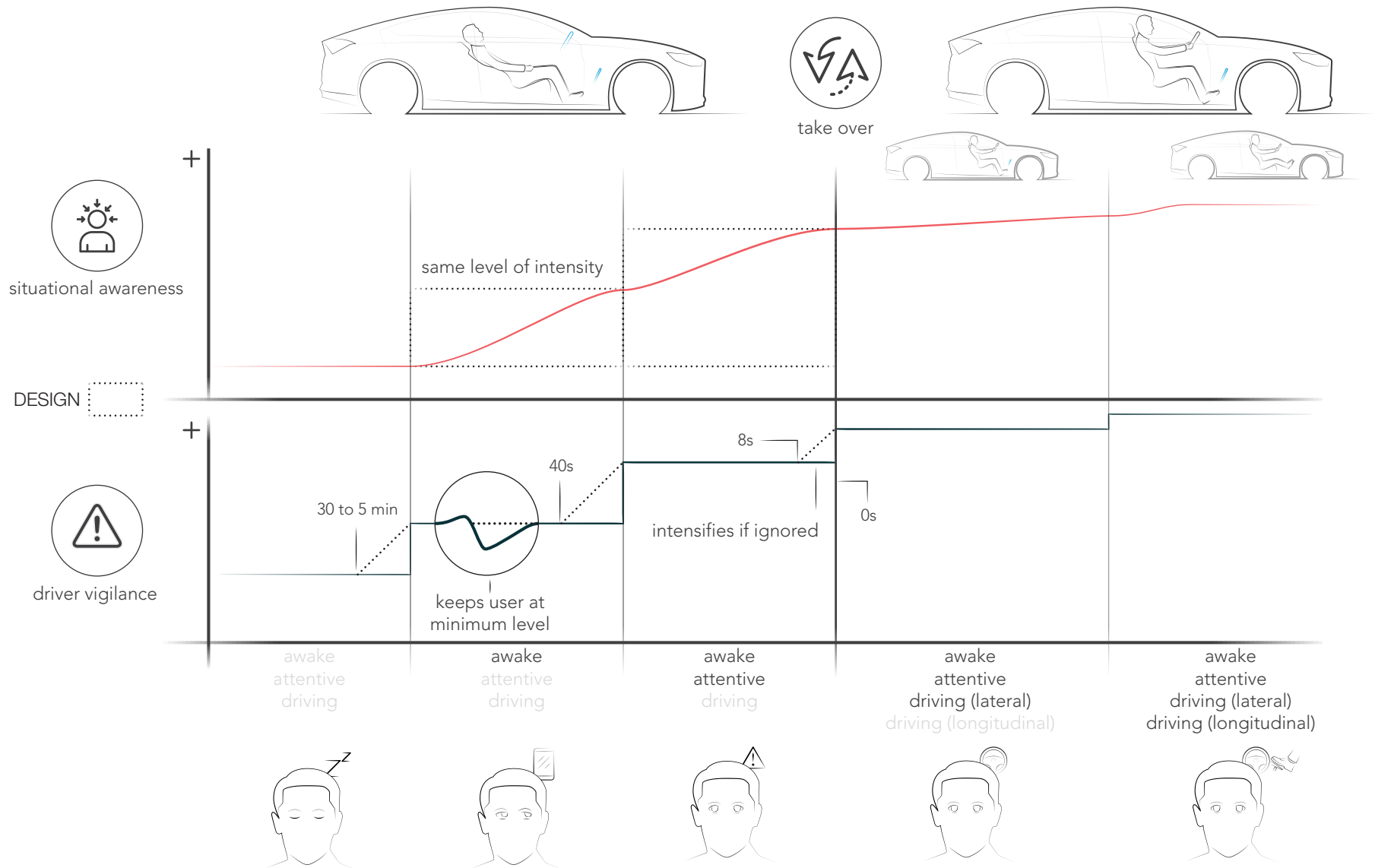
over.

When the car is driving autonomously the car can theoretically drive closer to other vehicles (especially when these cars are also driving autonomously). This is however not advised for two reasons.

The first one is for the experience of the user. Figure 12 showed that the developed car would be in the phase where building trust still has a high priority. The first users might feel uncomfortable when the car is driving closer to other cars than the user would even though the reaction time of the system is significantly shorter. Something similar is also indicated from user research with the Google Car (Google, 2014). It indicates that when overtaking a truck for example it is more comfortable for the user when the Google Car puts extra space between itself and the truck.

The second reason is for the other road users who cannot react as fast as automated cars and also since the first generation of level 4 might be behaving unpredictable for others (Google, 2014). If for some reason (e.g. every car is autonomous) the car will drive closer the others vehicles anyway. The system

Figure 39. Framework of the take over to assisted driving with time and user states on x-axis and situational awareness and driver vigilance on the y-axis.



will at this stage drive slowly make more space between itself and other cars so the user has extra space to regain control after the take over.

It will also plan the take over in such a way that after the take over there is still some time left to drive at least 8 seconds in the same lane. This acts as a buffer to increase driver performance before another action is required by the user. E.g. taking an exit.

2. Sleep inertia

The first interaction the system has with the user is waking the user up. This is between 30 to 5 minutes before the actual take over depending on how long the user has been asleep. At first, this is done with haptic feedback. If the user does not wake up or falls back asleep, a combination of auditive and visual feedback is used to make sure the user wakes up.

Since the design does not allow the user to be asleep anymore during this stage, working (see Figure 30) could be the 'worst case' scenario during this stage as this could mean people are sitting with their laptop, papers, pen etc. Therefore a notification is needed two minutes before the take over so the user can prepare for the next stage of paying attention to the road. The message is shown visually in combination

with a subtle sound to give the user a recognisable time indication.

3. Preparing take over

Forty seconds before take over, the design will make the user attentive. This is done in a quite similar manner as waking the user up. It starts with haptic feedback and if the user does not pay attention on the road, a combination of auditive and visual feedback is used to make sure the user will pay attention on the road.

4. Taking over

Eight seconds before the take over, auditive and visual feedback is given to the user as a notification that the user should take over. The take over itself will be confirmed with all three modalities. Ideally, the user is encouraged to hold both hands on the steering wheel. This is important just after the take over for a safe, comfortable and stable transition of control.

5. After care

As described by the definition of a level 4 car, when the user has not taken over, the system will take the car to a safe place to stop.

Even if the take over goes perfectly there is always a small drop in driver performance. This can be increased to a sufficient or even better performance by the use of active safety features. In this project, some of these features were developed.

Feedback modalities

Sound feedback has some similar characteristics as haptic feedback (chapter 2.4). Sound feedback, however, has an overall higher annoyance rate than haptic feedback. Therefore haptic feedback will mostly be used to guide the user into the right user state for the first time. When the user is not performing the desired behaviour after the haptic feedback, sound feedback is used to warn the user to get back in the desired user state. Auditive feedback is also used when the user is required to perform a certain action. Haptic and auditive feedback are always combined with visual feedback to clarify what the feedback is referring to and thereby preventing confusion or misreading the feedback.

New paradigm: status of automated features

A new paradigm is designed during the project and applied consistently and multiple times in the design. This paradigm concerns the status of automated features (adaptive cruise control, lane keeping and

autonomous driving). Three statuses are defined: off and unavailable (1), off and available (2) and on and available (3). To indicate the status of the automated features colour symbolism (Color-Wheel Pro, 2016) is used.

No colour (or no visual) is used to indicate that the feature is unavailable. To show that the feature is available and off, the neutral 'colour' white is used. This reduces the changes to confuse it with activation, error, danger etc. The colour blue is often associated with stability and symbolises trust, intelligence and truth. This can emphasise the trustworthiness and intelligence of the system.

Design elements and structure

As concluded from the ideation the heads-up display, instrument cluster, directional audio, steering wheel and seat are the design elements used to facilitate the transitions between the levels of automation. The information provided by the design is layered based on these features.

Head-up display

The HUD is in the peripheral view of the driver and has potential to become the main display for the driver. For the main display, it is important to show

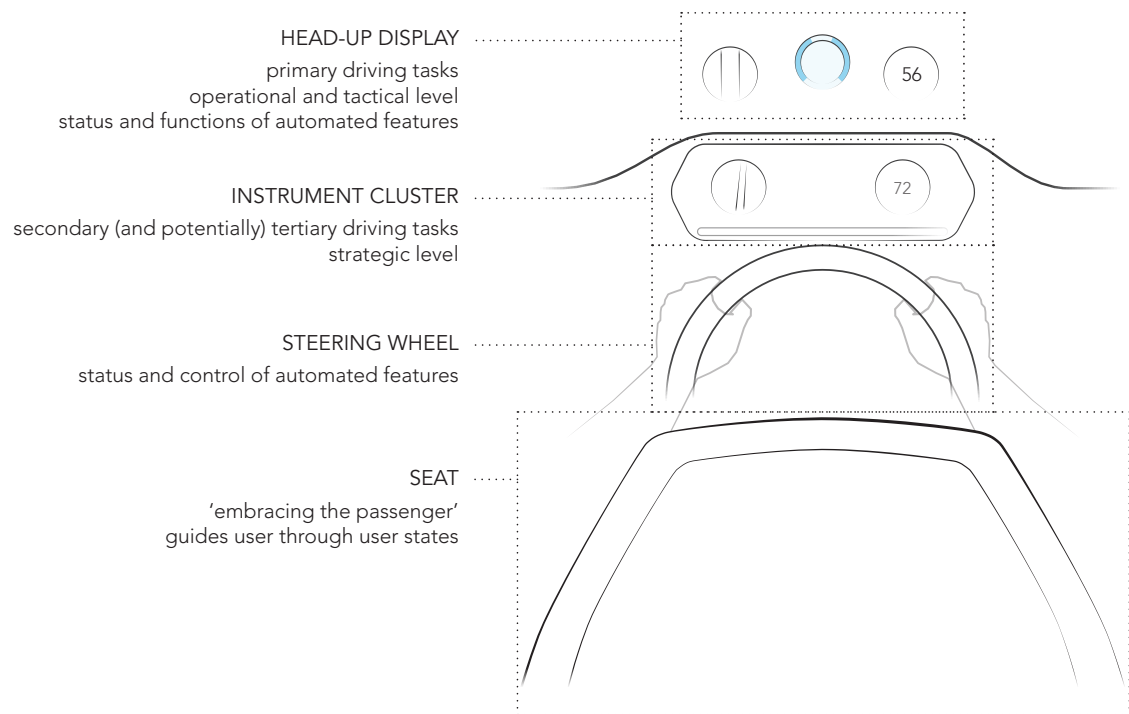


Figure 41. Design elements and structure existing of the head-up display, the instrument cluster, the steering wheel and the seat.

information regarding the primary driving tasks (e.g. speed and steering trajectory). In addition, it can support the driver on an operational and tactical level as these have most frequently a higher priority than the strategic level. The status and function of automated features are also displayed on the HUD as these are important messages.

Instrument cluster

As the secondary display, the instrument cluster is used to support the user with the secondary driving tasks. This can potentially also support the tertiary driving tasks, but these are not developed in this project. The advantage of the instrument cluster over the HUD is that there are more possibilities for visual detail and brightness.

Steering wheel

The control for the automated features can be done with levers on the back of the steering wheel so they can be controlled while having both hands on the steering wheel. Since the control of the features is within the steering wheel section, the status of them will also be displayed on the steering wheel or levers depending on which automated features is active or available.

Seat

The seat is used to guide the user through the user states, but also to put a small emphasis on ‘embracing the passenger’ (Figure 12)

Conclusion

The frameworks provided in this chapter lay the foundation for the lay-out of the design. The lay-out describes which features of the car are being used for the design and for what purpose. It should be designed in such a way that the features are layered and the user gets an idea of the information structure. For this, four design elements are used. The HUD is used as primary display whereas the instrument cluster becomes the secondary display. The steering wheel is used to control and show the status of the automated features and the seat guides the user through the user states.

Sections 6.3 to 6.6 will go into depth about the four design elements. Sections 6.7 and 6.8 will explain the transitions between the automated features in a dynamic manner.

6.3 HEAD-UP DISPLAY

The HUD is the primary display during assisted driving. On the right, the speedometer is shown with the current traffic rules, on the left a radar of the surroundings with collision warning and in the middle navigation and messages. Augmented reality is used to emphasise the messages of the automated features. Active safety features are used to increase the driver performance especially just after the take over. During autonomous driving the HUD becomes less effective due to the unpredictable position of the user.

In regular cars, the HUD is an assisting display on top of the primary display of the instrument cluster. It is expected that further technological developments will increase the effectiveness of HUD's and increase their potential as a display for cars.

In this design, the HUD is the primary informative display when in assisted driving mode since it can be displayed in the peripheral view of the driver and thereby helps the driver to keep the eyes on the road. Due to the limitations of a HUD, a bold visual style is needed with ideally high values for blues, greens and reds. The higher values, the less translucent the visualisation. So white would be the optimal colour.

Assisted Driving

During assisted driving, the HUD is focussed on supporting driving on an operational and tactical level. It assists the driver with performing the primary driving tasks. Based on the results of the research with the driving instructor, the HUD will also assist the user in the suggested categories of 'planning' and 'traffic rules' (which account for more than 50% of incidents found) and thereby increase the overall driving performance. This is done by the designing active safety features, which are part of the stage 'after care'. Figure 42 shows the HUD layout

and video A and Figure 43 explain the functionalities of the HUD during assisted driving.

Autonomous Driving

In autonomous driving mode, the HUD becomes very minimal and shows the only non-essential information. This conveys a message that these tasks are taken out of the hands of the user. It will also support a nicer view as the window stays clean. When driving in autonomous mode the user is allowed to change the seat (modes), this could render the HUD useless as the position of the eyes changes. Video B shows the HUD during autonomous driving.

Distance

The HUD actually consists of two HUDs. One projected on a distance of 3 meters and the augmented visualisations are 12 meters. This is more comfortable on the eyes and this way it can actually project on the roads better.

Speedometer

The speedometer is displayed on the right side of the HUD. It visualises the speed in a shape that is recognisable as a traditional speedometer. The current speed large in numbers in the centre of the

speedometer. At the bottom, the maximum speed is visualised as a traditional speed limit traffic sign. It is positioned on the same vertical central axis to indicate it is related to the speed.

Speeding

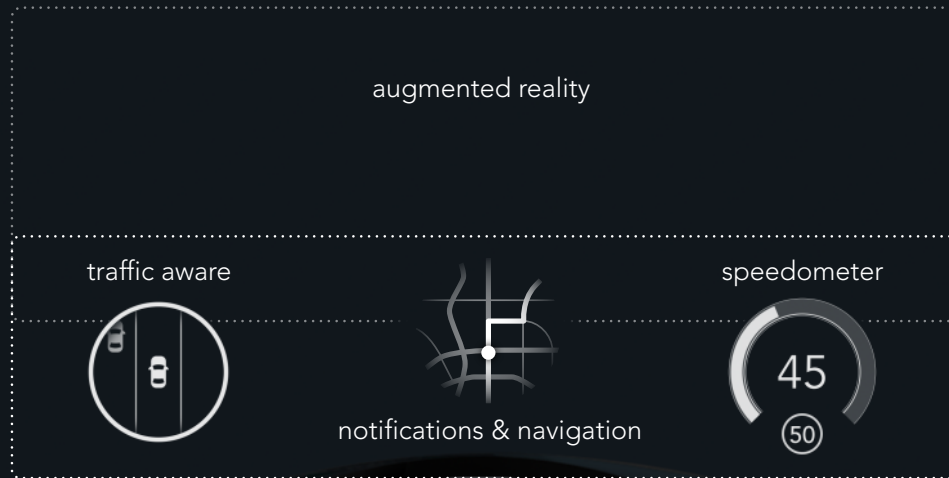
When the user is speeding, the amount of km/h past the speed limit is displayed in red together with the speed limit indicator which also increases in size. The user can notice without really looking that (s)he is speeding and estimate by how much.

Traffic signs

The system can recognise (source) traffic signs and displays the sign in a similar way on the HUD next to the speedometer on the same height as the max. speed limit indicator. This way all the traffic rules are displayed on the same level (height). Informing the user of traffic signs is of significant importance when a car has a (SAE) level of 3 or higher. The user does not have to monitor the environment anymore while certain automated features are active. This means the user will miss certain traffic signs and hereby not be aware of the traffic rules during the take over to assisted driving. When the user is violating one of these traffic rules, the corresponding signs will increase in size to notify the user

HUD projection at 12 meter

HUD projection at 3 meter



Traffic aware

The left side of the HUD it shows a radar view of the surroundings of the car. The system can differentiate (Google self-driving car project, 2014) trucks from cars and recognises cyclists and pedestrians. These will be visualised accordingly, so the user gains relevant information and can estimate the size and trajectory of the different road users (a truck is larger than a car and a cyclist is often slower than a car).

The traffic aware section zooms in or out depending on the speed of the car. At a low speed, it is more relevant to see close up information (e.g. for parking). When driving at a high speed, visualising a large area around the car is preferable (e.g. driving on a highway). When lanes are recognised, they are also projected on the HUD in this section.

Displaying this kind of information should not only improve the driving performance (as an increased and effective way of relevant information is displayed within the peripheral view of the driver), but also create trust by displaying that the system

can recognise the important objects.

Collision warning

Since the car is displayed in the middle and shows the environment it also allows for an effective collision warning. It shows different levels of urgency and the direction of the warning in reference to the car in the middle. It will also show what object the collision warning is referring to.

Notifications/navigation

The middle of the HUD stays mostly empty so the view of the driver is not disturbed. Only notifications can pop-up in the middle to grab the attention of the driver. The navigation can be toggled on or off if the driver wishes to use it on the HUD.

Augmented Reality

Using augmented reality in HUDs is already done by PSA (2016) and shows potential for augmenting the road or other vehicles. This design will use these augmentations to support the feedback of ACC and lane assist. This will be further explained in section

6.7.

Conclusion

The HUD is in the peripheral view of the user and is thereby best used as the primary display, by assisting the user with the primary and secondary driving tasks. The active safety features like visualising speeding, showing the current traffic rules and when they are violated, showing the road users in the environment adaptive to the needs and the directional collision warning can all increase the safety especially after a take over from autonomous driving.

Figure 43. Details of the HUD during assisted driving



6.4 INSTRUMENT CLUSTER

The instrument cluster is the secondary display during assisted driving showing the navigation, power usage and a bird view of the surroundings to create trust. During autonomous driving these sections are replaced by the HUD sections and a zoomed out version of the navigation as it changes to the primary display. The route and driving modes are always displayed together with the information bar.

The instrument cluster has two different modes which correspond to the driving modes. One for assisted driving and one for autonomous driving (Figure 44). The instrument cluster is not limited as the HUD and thus allows for a more detailed visual style.

Assisted Driving

During assisted driving, the instrument cluster is the secondary display as the HUD is the primary display. The focus of the cluster is aimed at assisting the driver on a strategic level (with navigation and power) and providing extra information in addition to the HUD, as the cluster allows for more detail on the screen.

Navigation

On the map displayed in the navigation (left) section, it shows the position of the user and the route it should take to the destination (strategic level). It also displays where and when autonomous driving is available. The roads that are available for autonomous driving are highlighted. Since data learning will be a major factor for the availability of automated features, the user will be updated through this navigation section. The user might prefer another road if it has the availability for

autonomous driving.

Driving states

On the bottom of the navigation is a circle in which the current driving state is displayed (Auto-Park, Park, Reverse, Neutral, Drive and Autonomous driving).

Power usage

On the right section is a circle which represents the power usage of the car. The power usage can support the user in adjusting its driving behaviour to get most of the battery and thereby positively impact the costs. (strategic level).

Bird view

The bird view in the middle is to support the driver on a tactical level. It is quite similar to the left section of the HUD and it supports this with more detail. Apart from actually helping the user with driving, by increasing situational awareness, it also builds trust with the user. Seeing that the car recognises other objects on the road can reassure the user that the car is able to manoeuvre itself without input from the user and hereby create trust.

Route

On the bottom is a line which is a visual representation of the route from beginning to the destination. On this line is a very basic visualisation of what parts of the journey are available for autonomous driving. Blue is an indication that autonomous driving is available there. The small circle on the line represent at what point the user is of the journey. To remain consistent with the design, the circle turns blue when autonomous driving is activated. Below the line, it says how much kilometres of the total journey is available for autonomous driving. Based on this information the user can choose a route which, for example takes longer, but has overall a longer availability for autonomous driving if the user desires this, which can be especially useful for longer journeys.

Information bar

The bottom section provides information about the time and weather, estimated time of arrival and the available range. This part is not fully designed and represents space for other information that cars need like which lights are on, is something leaking etc.

Autonomous Driving

Traffic aware & Speedometer

Figure 44. Layout (and default screens) of the instrument clusters during assisted and autonomous driving.



During autonomous driving, the HUD will almost become fully empty making the cluster the primary display during this phase. The functionalities of the traffic aware section and speedometer (from the HUD) are still important since the user can always initiate a take over. For this reason, those functionalities are placed on the instrument cluster during autonomous driving. This also includes the traffic signs.

Navigation

The navigation shown during autonomous driving is further zoomed out than during assisted driving. Small roads and when to turn become less important. A general positioning and the take over point are important at this state. The navigation will zoom out until the point of take over is visible on the navigation. The navigation will zoom in more when the car is closer to the take over point and more details become clear.

Information bar

The information bar stays the same (except for the circle which represent the position of the user in the journey that turns blue), so that the user does not have to search for the information. The other parts do change, since they are less relevant (or not at all)

during autonomous driving.

Conclusion

During assisted driving the instrument cluster is used as a secondary screen, helping the user with mainly the strategic driving tasks. When switching to autonomous driving it acts as the primary display, as the HUD might be unavailable, by preparing the user for the take over.

6.5 STEERING WHEEL & LEVERS

Two levers on the steering wheel are used to control the automated features (right for ACC and left for lane keeping). Using levers enables the user to keep the hands on the steering wheel. The steering wheel itself is used as a symbolic representation of autonomous driving. The led strip shows if it is available or active. The retracting of the steering wheel is a strong statement of a transition of both control and responsibility. By holding both levers for 2 seconds autonomous driving can be activated or visa versa. This also gives a small buffer to regain situational awareness when a take over is initiated by the user early.

The steering wheel is one of the most direct objects linked to driving, both literally and figuratively. 'Taking' or 'grabbing' the wheel can thus be a large gesture and starting point towards going to autonomous or assisted driving. Also, most of the control functions supporting the primary and secondary driving tasks are on or around the steering wheel. In the same manner, two levers on the back of the steering wheel are used to control the automated features.

In contrary to the trend of 'more buttons to a smaller steering wheel' the choice has been made to use levers instead of buttons. Using levers might be a more conscious action than using buttons and also more ergonomically comfortable.

Levers

Adaptive Cruise Control

The right lever corresponds to the speedometer on right side of the HUD and thereby providing a usecue that the right lever is related to control the speed. Therefore the right lever will be used to activate and control Adaptive Cruise Control.

Lane Keeping

The left lever corresponds to the traffic aware section

on the left side and will be used in the same manner to activate Lane Keeping.

Autonomous Driving

By holding both levers for two seconds, the user can switch between autonomous driving and assisted driving. A two second buffer is designed so it will be done with a conscious action and not on accident. It will also give the user a two second period of increasing the situational awareness when a take over is initiated by the user (Figure 46). The user will still have the feeling that they can take over (almost) instantly.

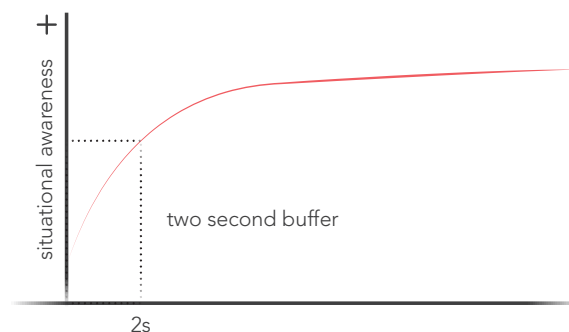


Figure 46. Two second buffer for situational awareness while initiating a take over to assisted driving. It is expected that SA will increase exponentially.

Steering wheel

Since the steering wheel is linked metaphorically to driving, it is used to indicate the status of the autonomous driving.

The steering wheel has a small subtle LED strip in the steering wheel for visual feedback and vibration motors for haptic feedback. Drive by wire system (Dickinson, 2008) is used to make it possible for the steering wheel to move back- and forwards while being able to still rotate it.

While in autonomous driving, the steering wheel will rotate with the movements of the car. This is done so the take over to assisted driving will go smoothly concerning the lateral movement of the car. Since the steering wheel is rotating, the levers should also rotate with the steering wheel so they are comfortably within reach of the user.

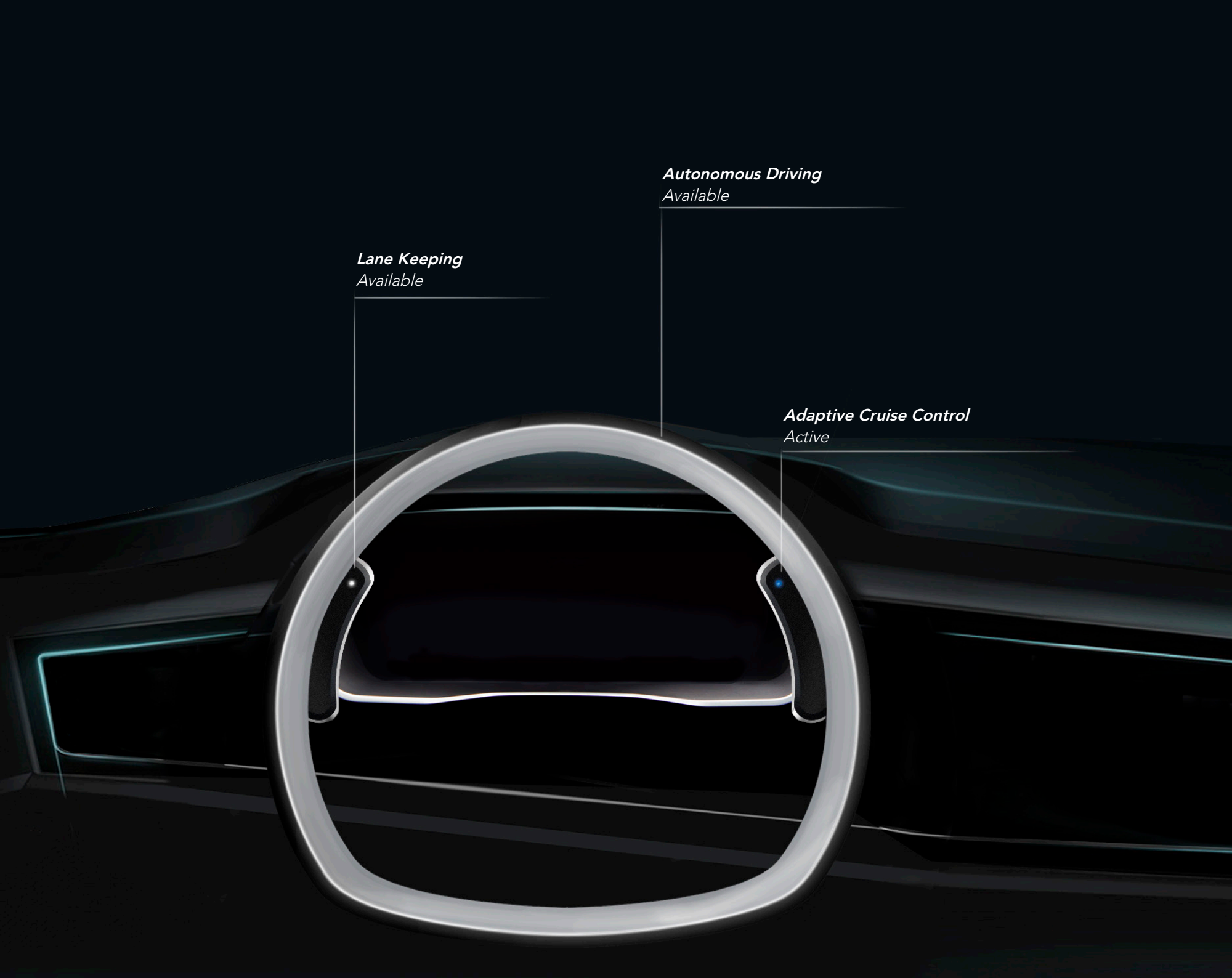
Conclusion

Controlling the automated features with levers can result in clear and conscious actions. The positions of the levers are linked with the HUD. The steering wheel is used to indicate the status of autonomous driving.

Autonomous Driving
Available

Lane Keeping
Available

Adaptive Cruise Control
Active



6.6 SEAT

Three seat modes are introduced for the user's comfort and to indicate the desired user states. 'Drive' mode is used for driving and when the user should be attentive. 'Relax' mode creates extra space between the seat and steering wheel to perform activities other than sleeping and driving. In 'sleep' mode, the user can sleep comfortable as the back of the seat is rotated backwards. Vibration modules in the seat are used for effective feedback.

The seat will have three optional modes (as an extra feature on top of manually adjusting the seat). These modes can be accessed through buttons in the armrest (which is not designed for this project). The three modes are: 'Drive', 'Relax' and 'Sleep' as shown in Figure 47. During assisted driving only the 'Drive' mode is available. Also during autonomous driving there is a limitation to what extend these seat modes can be used. These limitations are based on the framework provided in section 6.2.

There are two reasons for the seat modes. The first one is for the user's comfort and wishes. During autonomous driving, it might be desirable that there is extra space between the user and the dashboard to get engaged in other activities for example. The second reason is that it can put the user into a certain user state or at least push the user towards the desired user state. In addition, it gives a high-tech feeling where the car is taking care of you.

'Drive' mode

This mode is used for driving. It is the default state. The car measures while the user is driving what the seat settings are and saves this for future use. This way the system which controls the seat can be adaptable to different users. If it is desirable that

the user is attentive on the road, changing the seat to this mode will already give the user the mindset that the user should be attentive and take over to assisted driving soon.

'Relax' mode

In 'relax' mode the seat has extra space between the seat and the steering wheel, which lead to more comfortable experiences while performing the mentioned activities in Figure 30 except for sleeping. It can also give a feeling to the users that they are distancing themselves from the interfaces in the dashboard on both a literal and figurative way. This might put the user at ease and give an indication that the system can be trusted to drive.

'Sleep' mode

In the 'sleep' mode the back of the seat is rotated backwards which can make it comfortable for the user to sleep. In addition, this allows for features like lighting and sound feedback to be adapted to this mode.

Switching seat modes

Switching between these modes can be done manually (if allowed by the system) or automatically by the system. The switching between these modes

are done gradually and smoothly with an ease in and out motion (speed increases at the start and decreases at the end).

Haptic feedback

The seats are the only aspects of the car that will have direct contact with the user at all time while driving. The seats are therefore ideal for haptic feedback modules. In this design, they are placed in both the back and the bottom parts of the seats. These modules are used to provide haptic feedback to the user. Citroen (2016) showed that haptic feedback by vibration used in seats can be used effectively.

Conclusion

The positions of the seat can provide a clear indication for a basis of allowed behaviour by the user. Introducing these seat modes also provide the user with a feeling of luxury, ease and comfort, supporting the small priority on 'Embracing the passenger'.

SEAT MODES

DRIVE

Drive mode is either used while driving or will give the user an attentive mindset.

RELAX

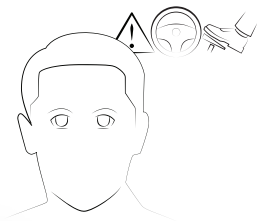
Relax mode makes extra space between the user and the steering wheel to create more comfortable experiences for other activities.

SLEEP

Sleep mode is ideal for sleeping comfortably as the back of the seat is rotated backwards.

USER STATES

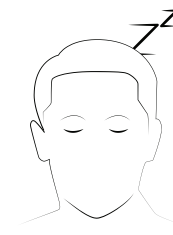
Attentive/Driving



Inattentive



Sleeping



SEAT

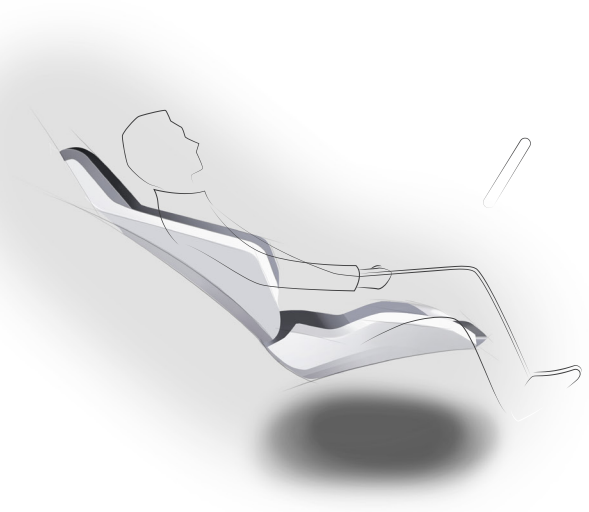
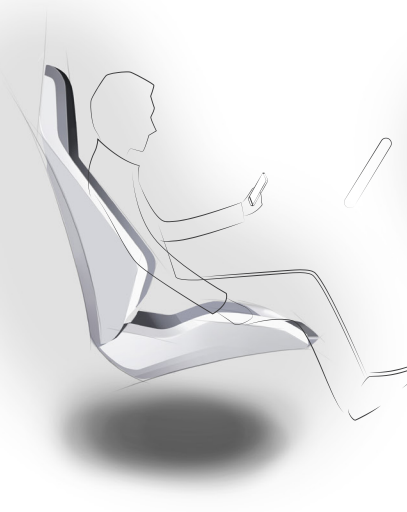


Figure 47. Seat modes with the user states

Figure 48. All elements of the design in context of assisted driving. HUD, Instrument cluster, the steering wheel and seat.



6.7 DESIGN SCENARIO

All the separate design elements are integrated into one system and explained through seven sections. Adaptive Cruise Control(1) and Lane Keeping (2) are visualised on the HUD in such a way that their functionality and limitations are clear. The steering wheel retracts and vibrates shortly to indicate that Autonomous Driving is activated (3). When an action is performed by the car (4) it is visualised on the HUD and instruments cluster to build trust with the system. To guide the user through sleep inertia (5), initially, haptic feedback from the seat is used. If the user does not comply, auditive feedback is used. A similar is used to make to user attentive (6). The take over to assisted driving (7) is also facilitated by the steering wheel moving towards the user and ending with a short vibration.

Now the design elements are clear, the design will be explained by means of a scenario consisting of seven sections (Figure 49). This shows how the design elements are integrated in one system and how they work

- Activating Adaptive Cruise Control and the system shows while Adaptive Cruise Control is activated.
- Showing the availability and activating Lane Keeping and the working of Lane Assist.
- Detailed description of the transition to autonomous driving.
- Explanation of what happens when a special action is performed by the system during autonomous driving.
- How the user guided through getting through sleep inertia.
- The user is made attentive as a preparation for the take over.
- Detailed description of the transition to assisted driving.

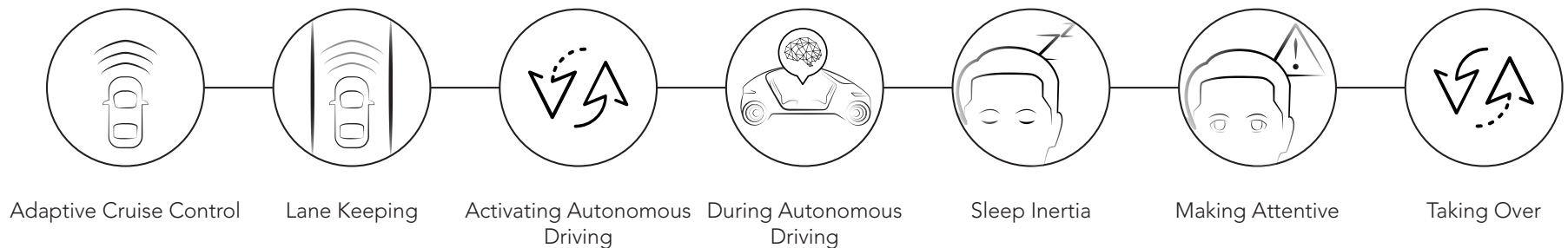


Figure 49. Seven sections of the scenario

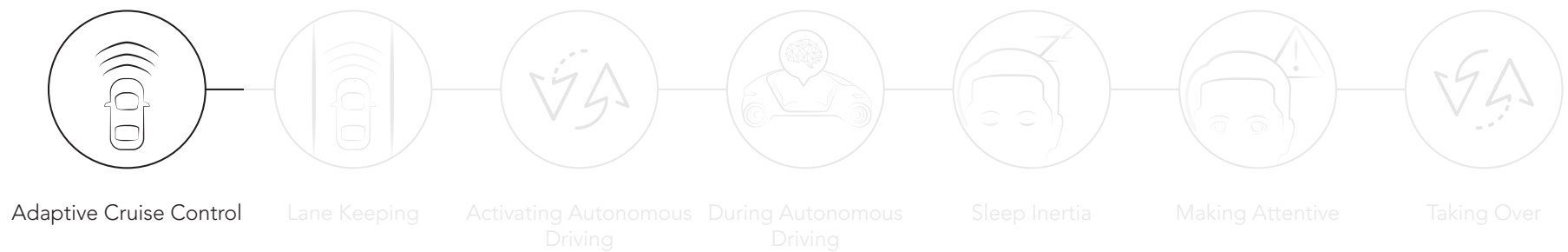


Figure 50. First section of the scenario: Adaptive Cruise Control (ACC)

Adaptive Cruise Control

What's important?

Adaptive Cruise Control senses the environment in front of the car and checks the speed limit signs and uses this information to adjust the speed of the car. It is important to show the user that it is still responsible and show the limitation.

ACC available

By applying the newly designed paradigm, the speedometer will have a white filling, indicating ACC is always available. Since the right lever is used to control ACC, the LED in the lever will be white.

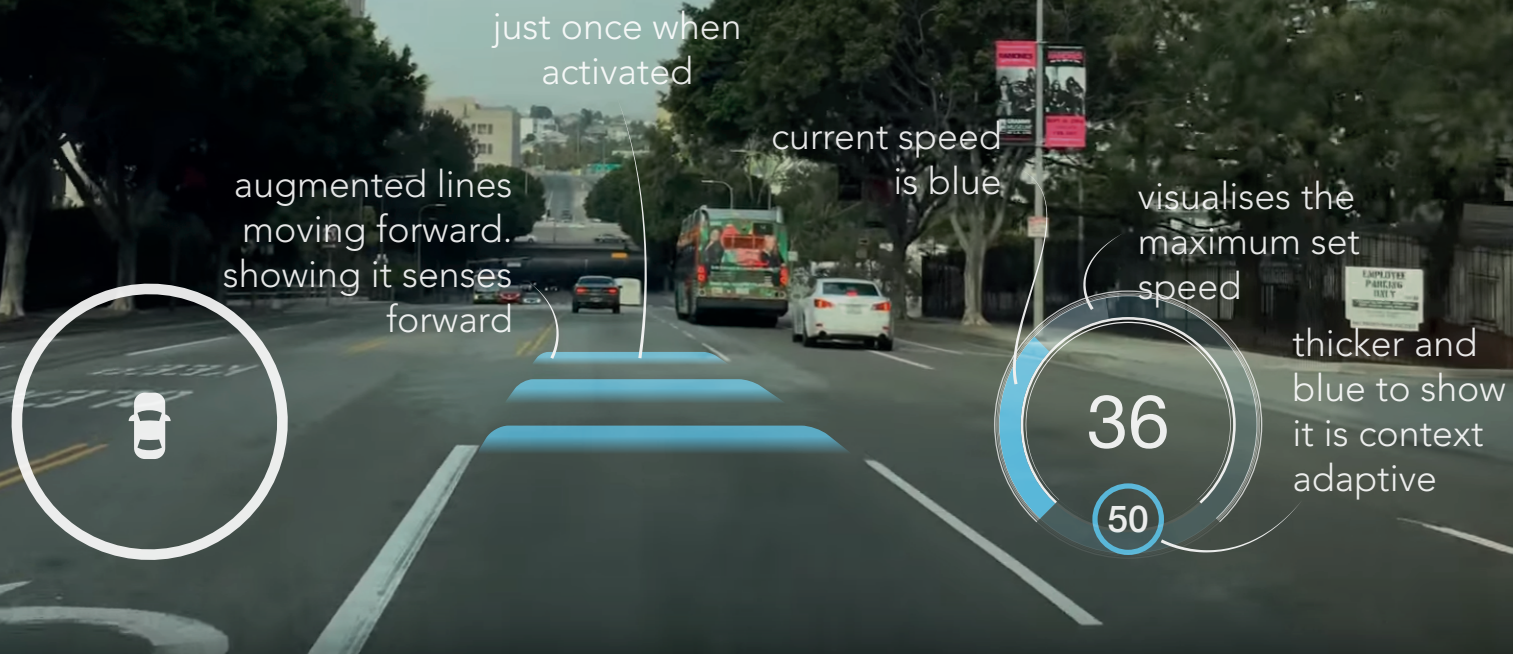
ACC active

When the right lever is pressed to activate ACC, the feedback of the lever being pressed is the first thing the user will notice. At the same time, the white filling indicating the current speed will turn blue giving the message the speed is controlled by the system. When ACC is context adaptive (sets max. speed automatically to the maximum speed limit) the max. speed limit indicator will also turn blue and increase in size to indicate it is related to the maximum allowed speed. The LED in the right lever will also turn blue. The HUD is visualised in Figure 51.

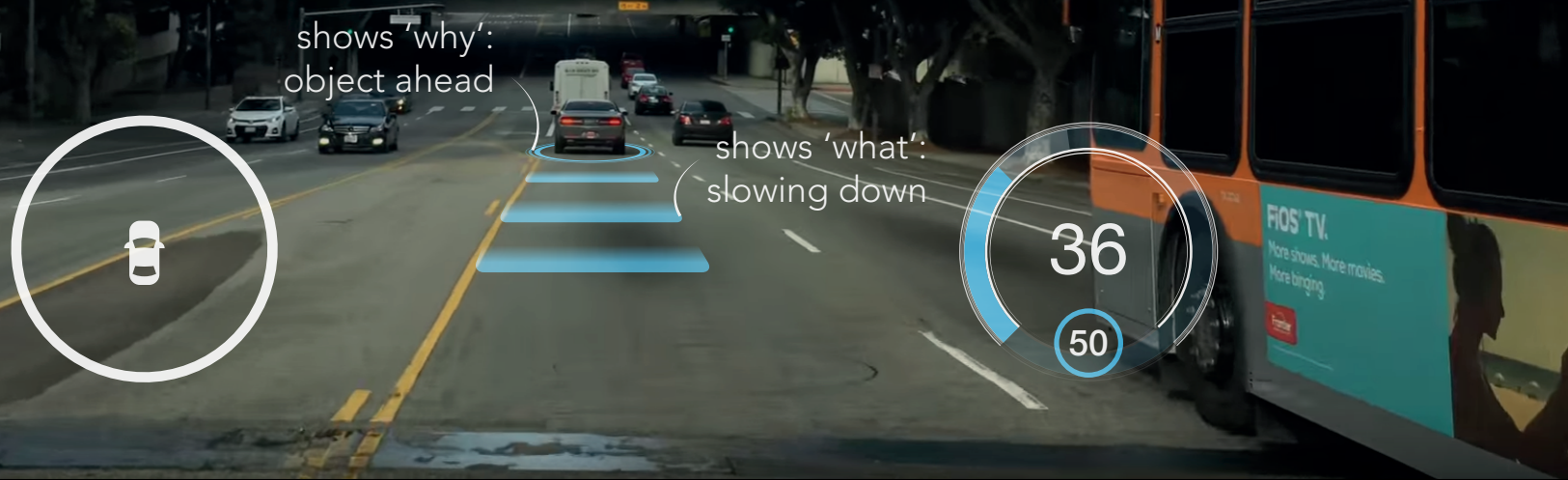
To build trust with the user, the moment ACC is activated on the augmented section of the HUD, a flowing motion forward of stripes appear on the road, indicating that the system will sense the environment in front of the car and thereby showing the limitations.

When the system will significantly change the longitudinal movement of the car as a result of ACC, it will be shown augmented on the HUD (Figure 52). This is done by applying the sixth design principle: providing the right information of automated actions. Since the user is still responsible, safety has priority and thus both the 'why' and 'what' will be shown to the user. On the augmented section of the HUD, it will show the object (the 'why') which is the cause of the change in speed and if the car will accelerate or decelerate (the 'what') with a moving animation.

ADAPTIVE CRUISE CONTROL activating



ADAPTIVE CRUISE CONTROL active



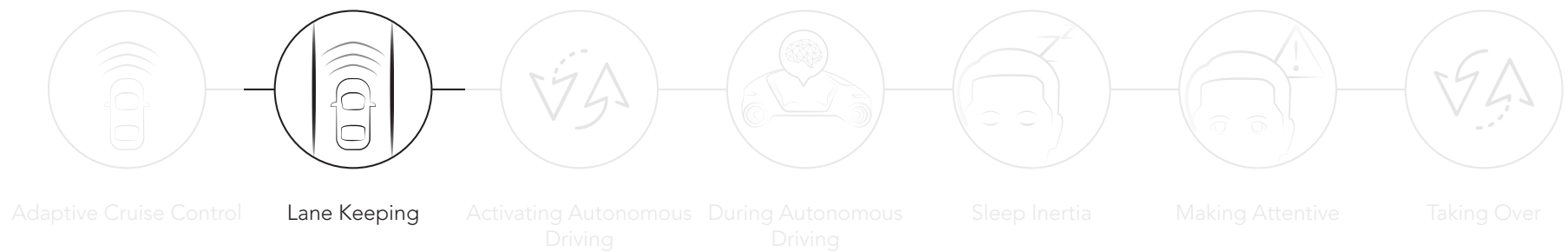


Figure 53. Second section of the scenario: Lane Keeping

Lane Keeping

What's important?

Lane Keeping keeps the car within the lines of the lane. In contrary to what the Tesla makes you believe with their feedback is that it does not take over the control of steering completely. These limitations must be clear to the user. A clear distinction with fully autonomous driving where the system is responsible needs to be designed.

Lane Keeping available

Since the system can also recognise the lines of the lane, these will be displayed too. The assumption is made that when this system can recognise the lane, lane keeping will also be available. The lanes will pop-up white utilising the new paradigm and indicating that lane keeping is available at this point.

Since the left lever is used for lane keeping, the lever will act in a similar matter as the right lever with ACC and the LED will turn white when it's available.

Lane Keeping active

Following the paradigm, when activated the lines will increase in thickness and turn blue (Figure 54). This is emphasised by emitting fading blue lines to the inside, showing that the feature will keep the

car within the lane. Whereas other cars (see Tesla research) use a steering wheel icon to indicate that lane keeping is on, this design only shows the lines of the lane. When using the steering wheel icon, it might send the wrong message that steering is taken over by the system completely, which is not the case. When an ambulance wants to pass, for example, it will not move to make space for it. By only using the lines of the lanes as an indicator for lane keeping, the message is that the feature will only keep the vehicle within these lines and nothing else. Monitoring the environment is thus still required by the user. In addition, the LED in the left lever turns blue.

To build trust, the moment lane keeping is activated, the lines of the current lane will be emphasised shortly on the augmented section of the HUD. Showing to the user that it can recognise the lanes.

Lane assist

By applying the sixth design principle in a similar matter with ACC, lane assist is designed (Figure 55). The lane line that will be crossed without interference is emphasised on the augmented sections of the HUD, showing 'why' the system performing an action. The emitting arrow is showing the car will steer towards that direction ('what').

LANE KEEPING activating

blue thicker lines that
emit lines to centre

augmented lane
lines emitting to
the centre

just once when
activated



Figure 54. Activating Lane Keeping

LANE ASSIST active

shows 'why':
crossing left lane line

shows 'what':
moving to the right



Figure 55. Lane Assist while active

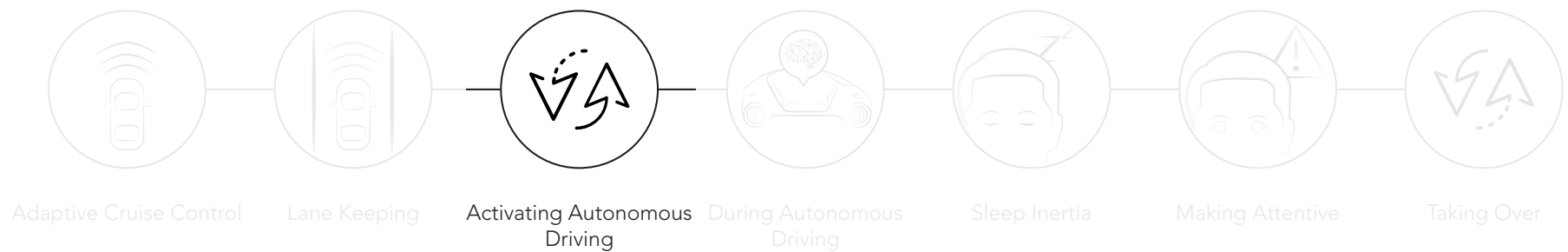


Figure 56. Third section of the scenario: Activating Autonomous Driving

Autonomous Driving

What's important?

During autonomous driving the system becomes responsible. This transition needs to be clear in the design. The interaction vision shows an effortless, fluent and guiding interaction is needed to facilitate the authority transition to autonomous driving. This needs to lead to a confident experience for the user.

Autonomous Driving available

As mentioned before, the steering wheel is used to indicate the status of autonomous driving. To indicate it is available, the LED strip is used according to the colour paradigm and turns white. This will be in combination with a pop-up icon of autonomous driving and the text: 'autonomous driving available'. This is in contrast with the trend of visualising rather than using text and numbers and design principle 8: 'dynamic interface'. Since autonomous driving is a new feature the icon is combined with the text explaining what it means. It is expected that in later versions or uses the icon will already be associated with autonomous driving and the text will then be unnecessary.

Activating Autonomous Driving

When activating autonomous driving by holding the

two levers, the first feedback for the user is the haptic feedback of pressing the buttons. When the levers are held, on the HUD a circle will appear which will fill up over time from two positions which are related to the position of the hands on a steering wheel. This will indicate that user needs to hold the levers until the circle is filled to activate autonomous driving.

Autonomous Driving activated

When the circle is filled and autonomous driving is activated, the steering wheel will vibrate shortly. The vibration is an indication that this is the point where autonomous driving is activated. It also acts as an usecue that the user can let go of the steering wheel. This is combined with a small pop motion on the HUD when the circle is filled. The steering wheel turns from white to blue and starts moving back into the dashboard. The movement of the steering wheel is a message the user is physically and mentally giving the steering wheel to the system and hereby the control and responsibility of driving. In addition, it creates more space and freedom for the user to do non-driving related stuff, which supports the small priority on 'Embracing the passenger'. To create a relation between the filling circle and autonomous driving, the circle visualises the steering wheel. It fills from the hand positions, turns blue like the steering

wheel and decreases in size as the steering wheel moves backwards. This process is visualised in a simple manner in Figure 57.

The simple circle on the HUD provides both feedback and feedforward for the authority transitions. It guides the user through them the process and creates a fluent interaction for the user by mimicking the actions of the steering wheel itself.

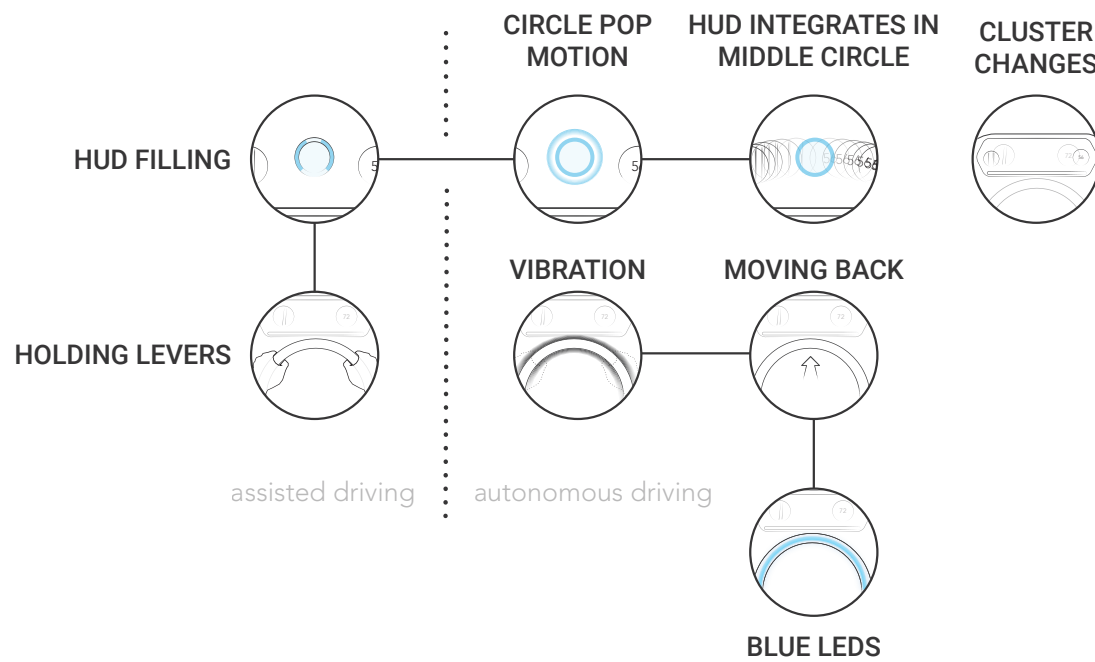


Figure 57. Framework of the transition to autonomous driving

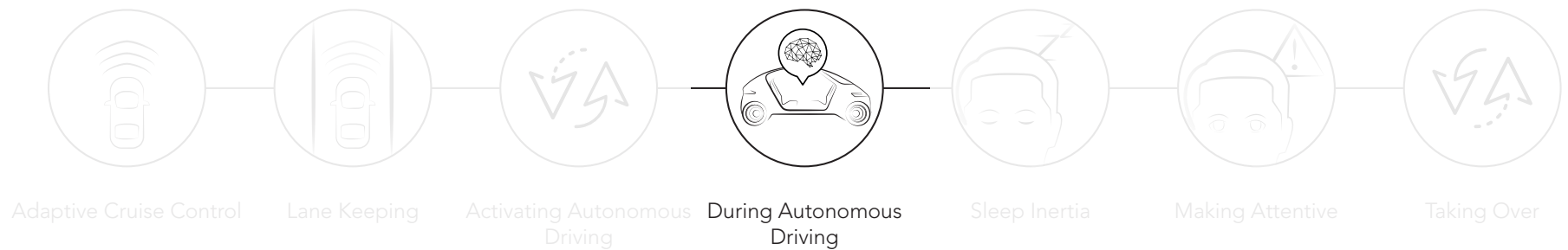


Figure 59. Fourth section of the scenario: During Autonomous Driving

During Autonomous driving

What's important?

This is a completely new and unproven experience for many users. Trust is the main factor during this section of the scenario. This section takes a case where a car in front of the vehicle is breaking suddenly and the system will deal with the situation by moving over one lane and overtaking the vehicle.

Visualising the actions of the vehicle

Applying the sixth design principle again during autonomous driving, a good relation with the car might have priority on safety as the system takes care of the car at this moment. However, as mentioned before, people still need to trust the system and since a take over can always be initiated by the user, safety might have priority in some cases.

The design principle is applied by using both the HUD (in a simple manner) and the instrument cluster display (Figure 60). The HUD will show just the 'why' section by the using the blue circle and point with orange to the object it is referring to. The instrument cluster allows for more detail and will not only show the 'why' by showing a bird-view overview of the situation with the corresponding object in red/

orange, but also the 'what' by showing the old and new trajectory of the car (video B).

Figure 58. When the car is in autonomous driving mode and performs an action, it will provide the user with the information. In this scenario, the car in front is breaking suddenly and the system will act. ►

Figure 60. The system will provide the user with the information about the action. The instrument cluster shows 'what' the car will do and 'why' it's doing it by showing the old and new trajectory of the car and indicating the object it reacts to. The HUD shows only 'why' the car is doing it. ►



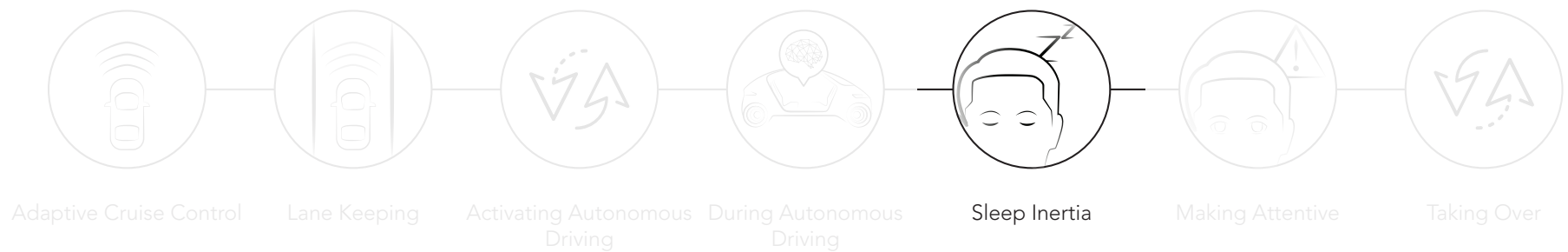


Figure 62. Fifth section of the scenario: Sleep Inertia

Sleep Inertia

What's important?

The user wants to be woken up slowly rather than suddenly as no action is required of the user yet. When woken up the user is not allowed to fall back asleep again, but can perform other activities.

Waking up

The seat emphasises which state the user is supposed to be in or allowed to be in. Therefore the back of the seat will start vibrating with increased intensity and frequency until the user wakes up. If the user wakes up, the seat will rotate from mode 'sleep' to 'relax' if the seat wasn't in it already. This will be combined with a rotating seat animation on the instrument cluster (Figure 63). The vibrating of the back of the seat also corresponds with the part of the chair that will be moving. After the rotating seat animation, the instrument cluster will show the message: 'x minutes to take over, stay awake' with x being the number of minutes until take over which depends on how long the user has been sleeping.

Waking up warning

If the user falls asleep again after this period (Figure 61) sound feedback is used (audio file A), which increases in tempo and volume when the user

does not acknowledge the warning. The warning is combined with a bright message on the instrument cluster with the text 'Wake up' that moves in bursts from left to right as shaking someone to wake up (Figure 64). This will also increase in speed. To acknowledge the warning the user has to open his or her eyes. A sound in combination with a visual confirms that the user has acknowledged the warning. The sound (audio file B) is a short 'ping' in combination with a pop motion on the cluster. The message disappears and the default screen fades in.

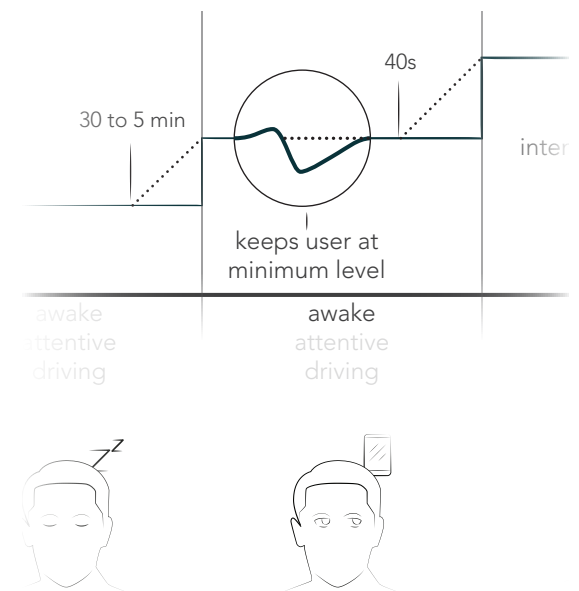


Figure 61. Excerpt of the framework of the take over to assisted driving.

Figure 63. Seat starts vibrating and afterwards rotating forwards. Meanwhile with a visual on screen shows what is happening.



Figure 64. When user falls back to sleep, a pop up message appears with the message 'wake up'. It is bright white so it stands out and draws the attention in combination with the shaking motion and sound warning. The warning increases in tempo and volume when the warning is not acknowledged. When acknowledged the white circle shows a burst motion in combination with a short sound. After which it disappears and the default screen reappears.



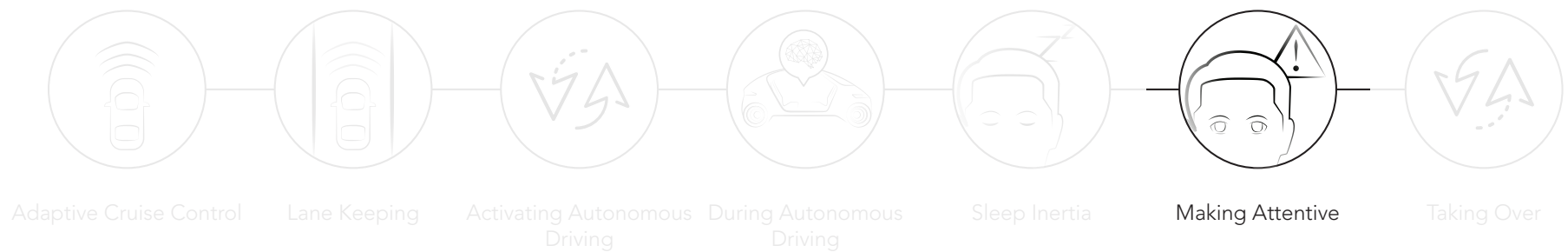


Figure 65. Sixth section of the scenario: Making Attentive

Making attentive

What's important?

The user needs time to stop their activities and prepare to watch the road. After which the user needs to watch the road to prepare for the take over.

Attention on the road

The 'two minute' notification is shown visually on the instrument cluster. The user has time to prepare for next stage. Forty seconds before the take over, the bottom seat starts vibrating in a similar manner as the back seat when waking the user up. The seat will then move forward to the 'drive' mode if the seat if it wasn't in it already. This will again be combined with a moving seat animation on the instrument cluster (Figure 66). After the animation, the message 'Attention on the road' is shown on the instrument cluster.

Since the user is paying attention to the road at this point and the seat is in 'drive' mode, the HUD becomes effective again and will, therefore, be used to show the take over time. The same blue circle is used as the one used to visualise the activation of autonomous driving. Whereas there was a filling motion to activate it, the opposite is happening here. The circle will empty as a countdown to the

proposed positions of the hands. The countdown itself in seconds will be shown inside the circle so the emptying of the circle is visually related to the countdown until take over. A message below the circle shows: 'standby for take over'.

Watching the road warning

If the user does not have their eyes on the road from this point, a warning will pop-up on the cluster with the message 'Watch the road' (Figure 67). This warning will have a jumping motion as a heads-up that the user should look up. This is in combination with auditive feedback (audio file C). These feedback aspects increase in urgency in a similar matter as the wake up warning if the warning is not acknowledged. When acknowledged by paying attention to the road the same confirmation motion and sound is used.

Figure 66. Seat starts vibrating and starts to move afterwards. This is combined with a visual on screen.



Figure 67. When the user becomes inattentive, an 'attention on the road' warning appears in combination with sound. The warning has a jumpy motion, grabbing the attention and telling the user to focus ahead of the road. The circle on the HUD empties slowly in relation to the countdown. The motion is towards the position of the hands.



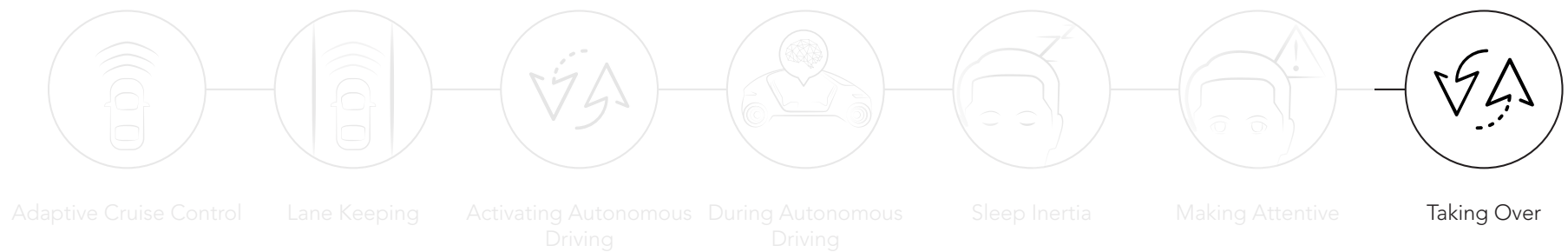


Figure 69. Sixth section of the scenario: Making Attentive

Taking over

What's important?

During assisted driving, the user takes over the control and becomes responsible. This transition needs to be clear in the design. A fluent and evident interaction is needed to convey this message. It should also have a similar interaction to the transition to autonomous driving to make it simple for the user.

Take over warning

Eight seconds before the take over the circle starts shaking in bursts (Figure 70). This shows that the area around where the hands are proposed to be will rotate quickly in bursts indicating that the user is should take the steering wheel. This is done in combination with sound feedback (audio file D). These warnings will also intensify in a similar manner to indicate a rising urgency. The message below the circle will also change into 'take over now'.

Take over to assisted driving

While holding both levers to take over, the circle on the HUD starts filling with a white colour (Figure 71). When filled after two seconds, the HUD sections from assisted driving pop out from the circle and move to their original positions. The steering wheel starts moving towards the user. When the steering wheel is

in position it will vibrate shortly and the colour blue will disappear indicating the actual point of take over. Holding both the levers will also mean that the user is forced to have both hands on the steering wheel and thereby making driving right after the take over more stable and safer. This process is visualised in a simple manner in Figure 68.

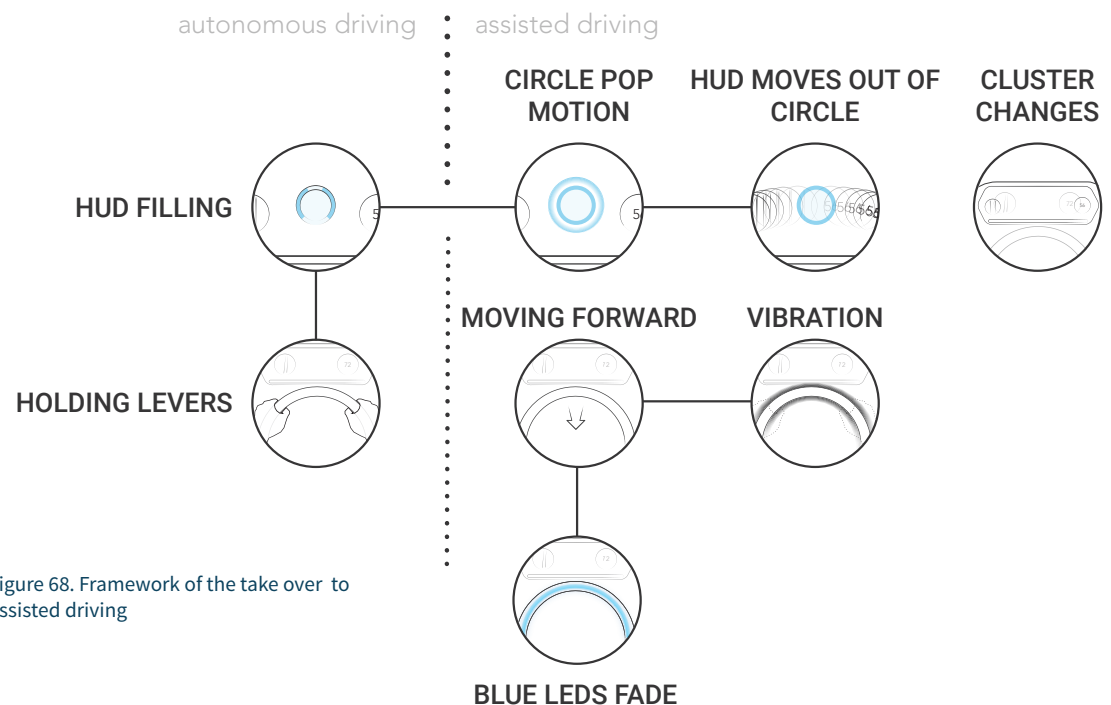


Figure 68. Framework of the take over to assisted driving

Figure 70. Message changes to 'Take over now'. Circle starts shaking to grab the attention of the user and indicate the user should grab the steering wheel. Cluster returns to default screen.



Figure 71. When the user holds both levers, the circle starts filling up white followed by a pop motion. The steering wheel starts moving towards the user while the blue leds fade out. When the default position of the steering wheel is reached, the steering wheel vibrates shortly and the HUD moves from the circle. The instrument then changes to the assisted driving mode.



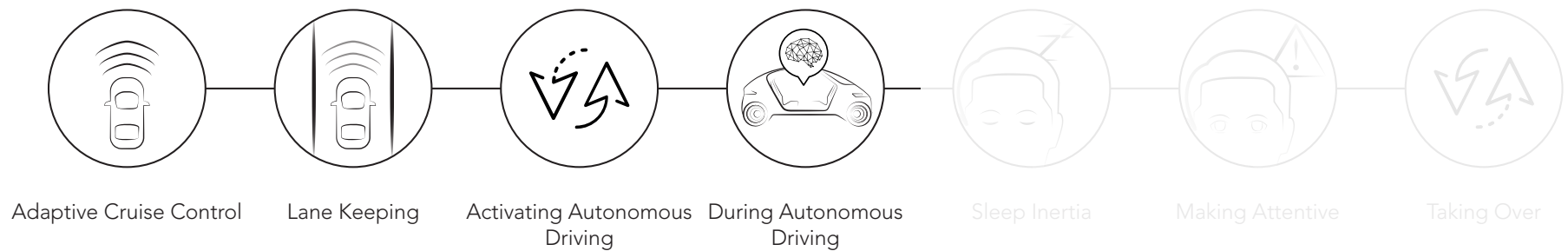


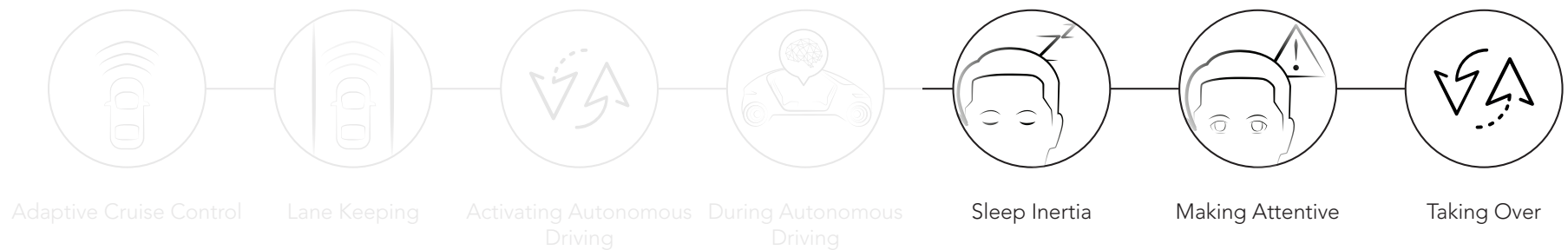
Figure 72. First four sections of the scenario. Transition to autonomous driving.

Transition to autonomous driving recap

Auditive and visual feedback modalities are used to facilitate the transitions within assisted driving and the transition to autonomous driving (Figure 75). The speedometer is used to show when ACC is active and that it controls the speed. The lane lines on the traffic aware section of the HUD are used to indicate that the function of lane keeping is to keep

the car within the lane (and not take over steering altogether). While activating and just after activating autonomous driving multiple things happen on multiple interfaces over a short period of time. To prevent confusion, a circle pop motion on the HUD and a short vibration in the steering wheel is used to indicate that the control is taken over by the system at that point. The movement of the steering wheel

can be a very strong interaction and send a clear message about the control and responsibility of the vehicle. The sixth design principle is used for both the automated features during assisted driving and during autonomous driving.



Transition to assisted driving recap

Three feedback modalities are used for the take over to assisted driving: visual, auditive and haptic(Figure 74). The haptic feedback in the seat emphasises and pushes the user in the desired user state. If the desired user state is not met afterwards, auditive feedback is used to warn the user until the user state is met. These modalities are always combined with visual feedback in the form of messages indicating

what is happening, how much time is left or what the user should do. In a similar matter as when activating autonomous driving, the vibration in the steering wheel will indicate that the car is in assisted driving mode.

Figure 73. Last three sections of the scenario. Transition to assisted driving.

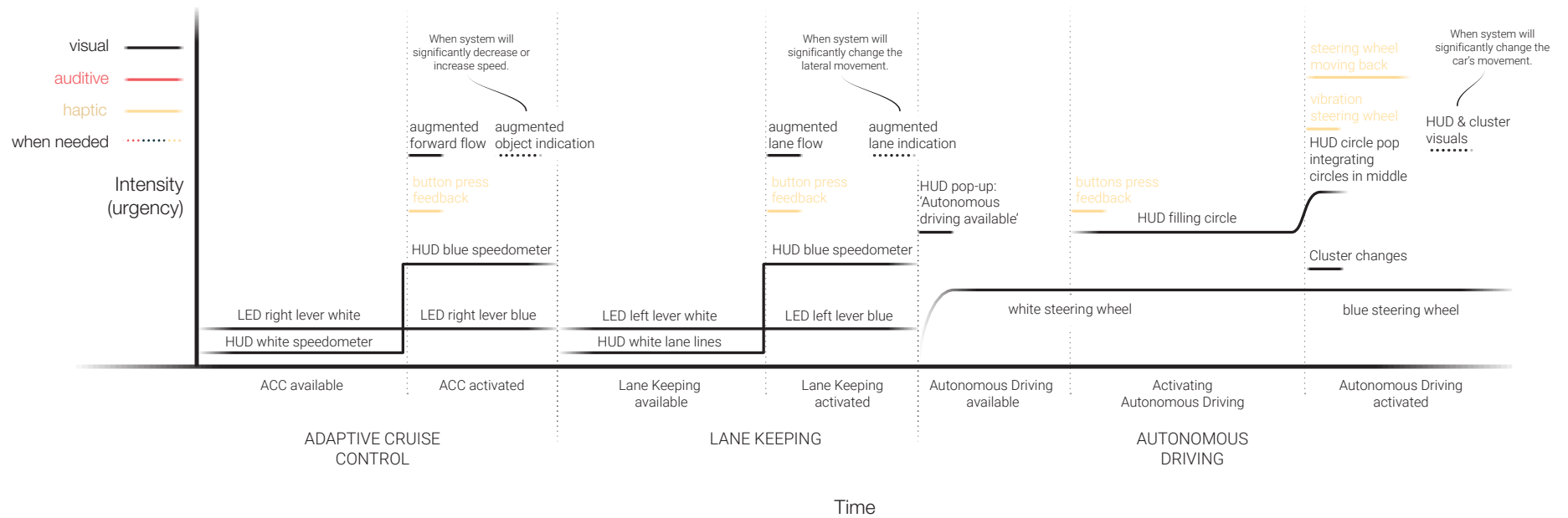


Figure 75. Intensity and type of feedback modality over time during assisted driving when activating the automated features.

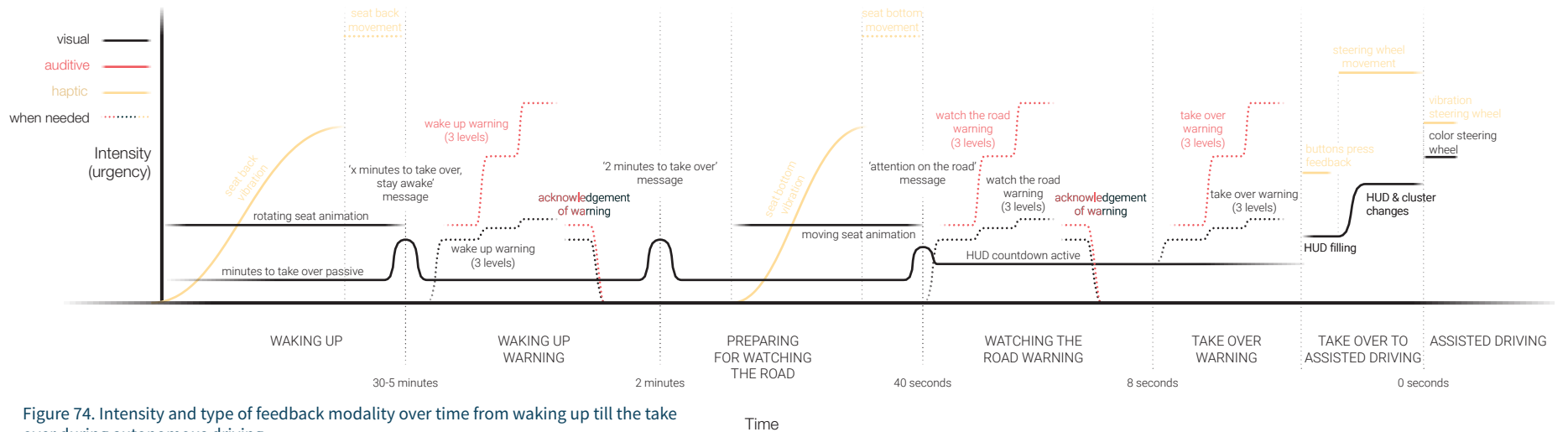


Figure 74. Intensity and type of feedback modality over time from waking up till the take over during autonomous driving.

6.8 CONCLUDING

A design is presented which tries to tackle the issues that arise with the transitions between different types of automation. For assisted driving the HUD is used as a primary display. It shows, in combination with augmented reality which of the automated features are activated and shows what their functionalities are. The levers on the steering wheel are used to activate these automated features. When autonomous driving is activated, the HUD shows a confirmation and becomes clean. The steering wheel itself vibrates shortly indicating the take over has taken place and moves backwards. The led strip on the steering wheel shows the status of autonomous driving as the steering wheel is taken as a symbol for autonomous driving. During autonomous driving the instrument cluster becomes the primary display, giving visual feedback to the user in combination with sound or haptic feedback. The haptic feedback comes from the seat which uses three modes to facilitate the allowed user states. When the user does not comply to the haptic and visual feedback, auditive feedback is used. Haptic feedback has a lower annoyance rate than auditive and is therefore a better modality to use for the first time. When activating assisted driving, the instrument cluster and HUD change back to the assisted driving modes and the steering wheel moves towards the user. A short vibration in the end indicates the actual point of take over.

Most of the design aspects are based on the literature research and field research. The design (with a focus on the transitions) needs to be tested on usability with a qualitative study to improve the design. This user test is shown in the next chapter.

CHAPTER 7

EVALUATING & OPTIMISING THE DESIGN

7.1 User Test Setup

What will be tested and how?

7.2 Optimisation

How is the design optimised?

7.1 DESIGN EVALUATION

To further improve the design a prototype is made and tested with 7 participants (potential users and experts). Most aspects of the interfaces were clear and the design was well rated with the SUS (76.1). The feedback for ACC was insufficient. Activating autonomous driving was experienced as positive and as a strong interaction. The participants wished and expected that the steering wheel would come back sooner automatically however. The augmented aspects of the HUD were not tested which might have had a negative impact on the feedback of the automated features. Some incremental changes can solve most issues that were found. The steering wheel needs to be presented sooner without giving the indication that assisted driving is activated.

A product usability evaluation (Delft Design Guide, 2014) is done to evaluate the use of the product through a prototype. The method aims for finding outcomes to ‘generate requirements for efficiency, effectiveness and satisfaction. Additionally to discover useful issues, such as errors and misunderstandings, possible improvements to resolve those issues and misunderstandings and opportunities to improve the safety and the user experience...’ (Delft Design Guide, 2014).

Goal

The goal of the user test is to gather information to further improve the design. It will be focussed on finding issues with the interaction with of the design and experience of it. The design will be tested with a focus on the transitions between modes of automation.

Research questions

How do participants interact with and experience the design and what are the causes for this?

What elements of the design can be expected to contribute to safe and comfortable transitions between the different driving modes and which elements influence these transitions negatively?

What usability issues do participants encounter and what are the strengths of the design? What are the causes?

Method

The user test will evaluate the proposed design in a qualitative manner, in order to gain insights on how the user uses the product and the underlying reasons, opinions and motivations behind it.

Moderating techniques

Three techniques for moderating are used: Concurrent Think Aloud (CTA), Retrospective Probing (RTA) (usability.gov, 2016) and Role-playing (Delft Design Guide, 2014).

With the CTA technique, the participants are asked to ‘think out loud’ while doing the test. This can allow for a better understanding of the participant’s thoughts as they occur and evoke real-time feedback.

With the RTA technique, the moderator asks follow-up questions about the participants thoughts and actions after the session. This will not interfere with the participant’s natural thought process and allows for more in-depth information.

Role-playing is used to reach a better understanding of the complexity of the design and the environment.

System Usability Scale (SUS)

The SUS is used to measure global assessments of the system’s usability (usability.gov, 2016).

Participants

In total 7 participants were used. 3 participants are specifically considered to be potential users and have experienced semi-automated driving before (E.g. Tesla model S). The other 4 participants are considered experts on the subject of autonomous driving. These can help to give insights on overlooked situations or other overlooked aspects in the design and provide extra knowledge of the realistic development of such a proposed system.

Location

The user test was conducted at the experience lab of VanBerlo in Ypenburg. In the room are two cameras to record video and audio during the test, which can be used for later evaluation. One is aimed at the participant to see his/her actions and reactions. The other is aimed at the prototype to link those actions and reactions to the design.

Procedure

One session will take approximately 50 minutes. There are at least 20 minutes between each session. The protocol of instructions and questions can be found in Appendix P. The schedule is as follows:

10 min: welcome and introduction

The participant is brought to the experience lab and is made comfortable. The context of the project and the procedure of the user test is explained. It is emphasised that the user is encouraged to 'think out loud'. The capabilities of the car will also be explained.

Since the focus is not on the first time use, some aspects of the design are already shown in a movie. The user will be told how to activate or deactivate the automated features, the feedback and other feedforward, however needs to be discovered by the participant.

5 min: getting familiar with the prototype

The participant is allowed to sit in the simulator and get familiar with the design, adjust the seat etc.

10 min: Scenario #1 - Driving manual

The participant is told that he/she just arrived on the

highway after a few minutes of driving and is asked to activate ACC. A few moments later the participant is asked in a similar way to activate lane keeping when the participant thinks it is available. Then the participant is asked to activate the autonomous driving mode when the participant thinks it is available. This is repeated at least three times.

5 min: Evaluation scenario #1

Scenario #1 is evaluated by the participant and moderator with an open discussion.

10 min: Scenario #2 - Driving autonomous

The participant is told that autonomous driving mode has been activated for a while and is shown a movie with a scenario visualising the take over to assisted driving.

Afterwards, the user is asked to relax and pretend to be sleeping and re-enact (role-playing) the scenario shown in the movie.

5 min: Evaluation scenario #2

Scenario #1 is evaluated by the participant and moderator with an open discussion.

5 min: Scenario #3 - During autonomous driving

The user is shown a movie (movie x) where the car is performing multiple actions during autonomous driving. The participant is asked what (s)he sees and what it means. The participant is also asked what the experience would be seeing this during autonomous driving.

5 min: Open discussion, SUS and wrap-up

The whole session is evaluated with the participant after the SUS is filled in. The session is wrapped up.

Prototype

The prototype is integrated into a car demonstrator (see Figure 76). A beamer projects dash-cam video in front of the car to simulate a driving environment. This does not only include the video but also the audio, since the auditive feedback is also tested. A screen is placed under the dashboard and is reflected in the windshield to simulate a HUD. A secondary screen is used to visualise the instrument cluster. Speakers in the car are used for the sound feedback of the design.

The physical interactive aspects of the design are the steering wheel (rotatable, retractable and vibrating) and the two levers behind them. The interaction with the levers and the retracting of the steering wheel

will have impact on the HUD, instrument cluster and the LEDs on the steering wheel and levers. The pedals can be used but have no actual effect, they are there to simulate the effect of driving.

The seat modes are not made in the prototype. The participants will be told about the status of the seat and asked to imagine the interactions with the seat.

How it works

Behind each lever is a button, these buttons provide the input for the connected Arduino. The output of the Arduino controls the LEDs, the vibrating motors on the steering wheel and the stepper motor which controls the movement of the steering wheel making it retractable. To make the HUD and the instrument cluster reactive to the input of the Arduino, the Arduino will print certain messages. These messages communicate to another program (which is coded to play certain movie files on the HUD and instrument cluster on these certain messages) which movie should be played. Appendix O shows the hardware connections to the arduino. Appendix N shows a solidworks model of the prototype.

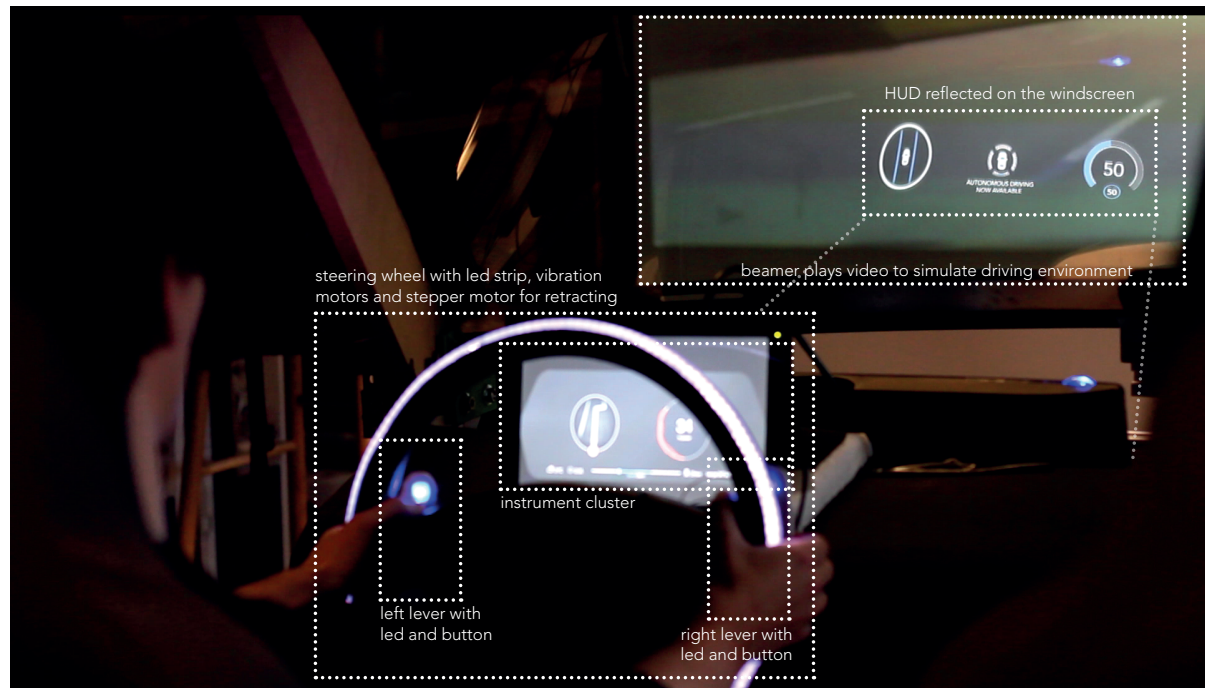


Figure 76. Set-up of the prototype.

Results

A matrix of the results per category and participant is presented in Appendix G. The results are presented on the ACC, the Lane Keeping, activating autonomous driving, taking over to assisted driving and what the car shows during autonomous driving. 'Q' is a quote from one of the participants. 'P' stands for participant.

Instrument Cluster

On the instrument cluster most elements were clear and understood (Figure 77). One participant thought the power sections meant the battery level. Five participants knew how many km was left for the route, but were not sure what the number in blue (amount of km possible in autonomous driving) meant. Some of them indicated it would probably be related how much km have been driven already on the route. None of the participants understood why the other lane on the navigation during assisted driving was highlighted. No link could be made to visual semantics. The warnings displayed during autonomous driving were experienced by most participants as something that grabs the attention because of the bright light and motions.

Head-up Display

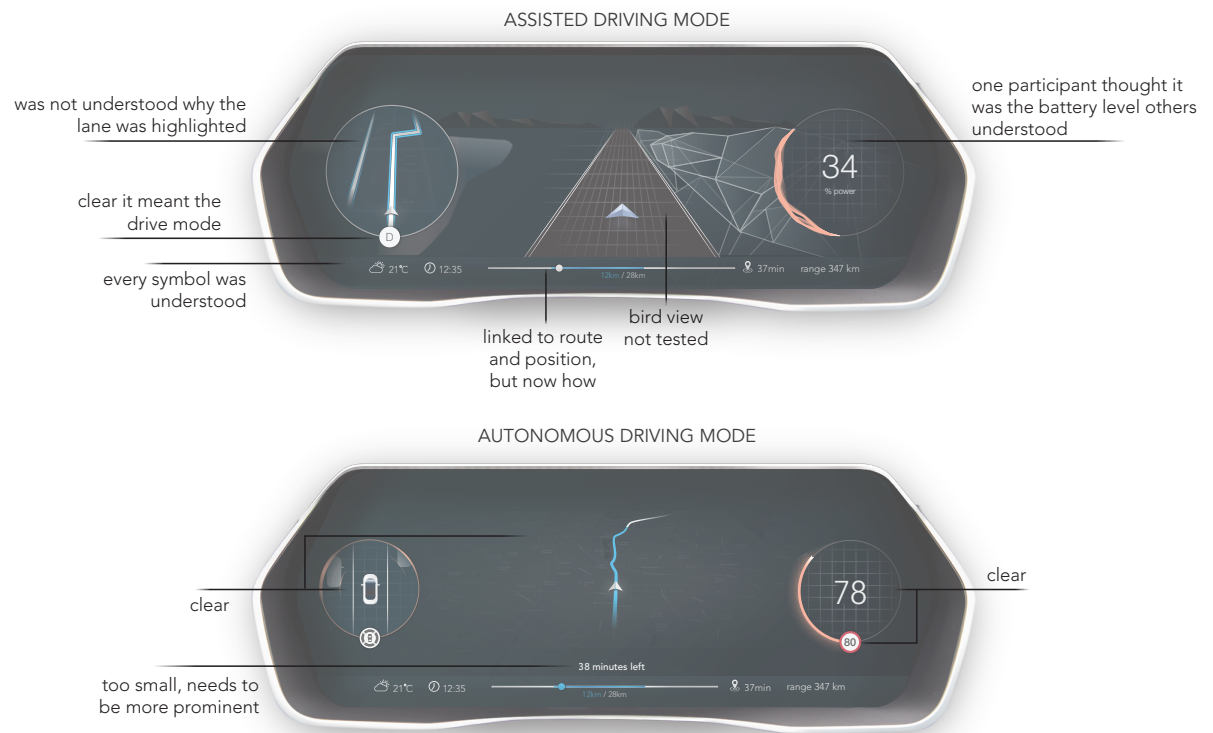


Figure 77. Results on the instrument cluster.

The main features of the HUD itself were completely understood. Some participants even mentioned that the traffic aware section is something they desired to have in their own car.

Adaptive Cruise Control

When activating adaptive cruise control for the first time, the participants were still unsure if it was actually active or not. The participants had to activate and deactivate it multiple times before they could say with confidence that the blue speedometer indicates that the speed is controlled by the system. Mostly the group with expert knowledge mentioned that only a change of colour on the speedometer is not sufficient. That participants did notice however that the speed limit was 50 km/h and when ACC was turned on it would limit it itself the this speed limit.

Q1: 'I can only notice if it's [ACC] is on when the car in front of me will break' - P expert knowledge

Q2: 'It gets another colour, so it's probably activated' - P semi-automated driving

Lane Keeping

Almost every participant understood when the

feature was on, available or off after activating it. These participant had a similar reaction as Q3, saying that they now understand how it works.

Q3 after activating lane keeping: 'Ah, so white means it is available and blue that is activated' - P expert knowledge

Levers

Four of the participants noticed the lights on the lever and all of them indicated it described the status of the of the related automated features. Two of the participant also said they linked the right lever to the right side of the HUD and the left lever to the left

side of the HUD. The LEDs on levers did not affect the usability negatively. For the participants who did notice it and its meaning, it made sense.

Activating Autonomous Driving

It was clear to all participants when autonomous driving was available. One participant mentioned that if he applied the same analogy as with lane keeping, autonomous driving would be available when the LEDs on the steering wheel turned white. Although one participant did not notice the HUD message as he was distracted by the steering wheel the first time.

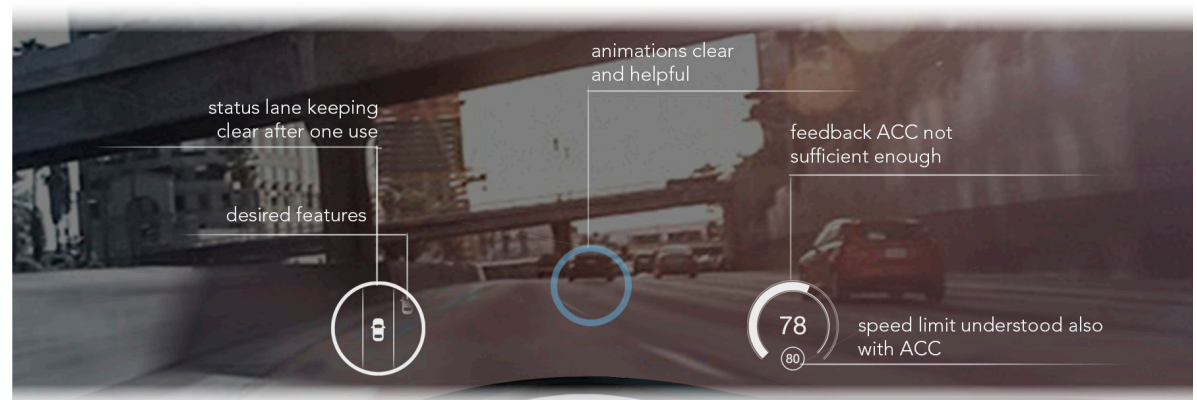


Figure 78. Results on the Head-up Display.

Activating autonomous driving was overall a positive experience for the participants. Q4 and Q5 show some enthusiastic results during or right after the transition.

Q4 after activating autonomous driving: 'Yes... Yes this is nice' - P expert knowledge

Q5 after activating autonomous driving: 'Wow this is great!' - P expert knowledge

The participants understood that the filling of the circle on the HUD was related to holding the levers. After activating it for the first time, some people

were doubting about at what point the control was given to the system. These same participants said after trying it a second time that autonomous driving was activated when the circle on the HUD was filled. Some participants mentioned that they especially liked that the circles on the HUD merge into the middle one (Q6). One participant mentioned that his focus shifted from the HUD to the instrument cluster because of the timing of the animations.

Q6: 'That is nice, that animation that those two things come together.' P semi-automated driving

When the participants noticed the vibrations in

the steering wheel, they felt that it was meant as a warning to let go of the steering wheel or that is was going to move. Some participants also mentioned that it felt nice that the steering wheel moved back out of their hands. It felt as a strong confirmation that the system takes control of the vehicle (Q7 & Q8). The participants felt confident letting go of the steering wheel.

Q7: 'It felt like it [the steering wheel] got pulled out of my hands. I think that was quite confirmative. It was not like 'now just let go and hope it will go alright'. ' P semi-automated driving

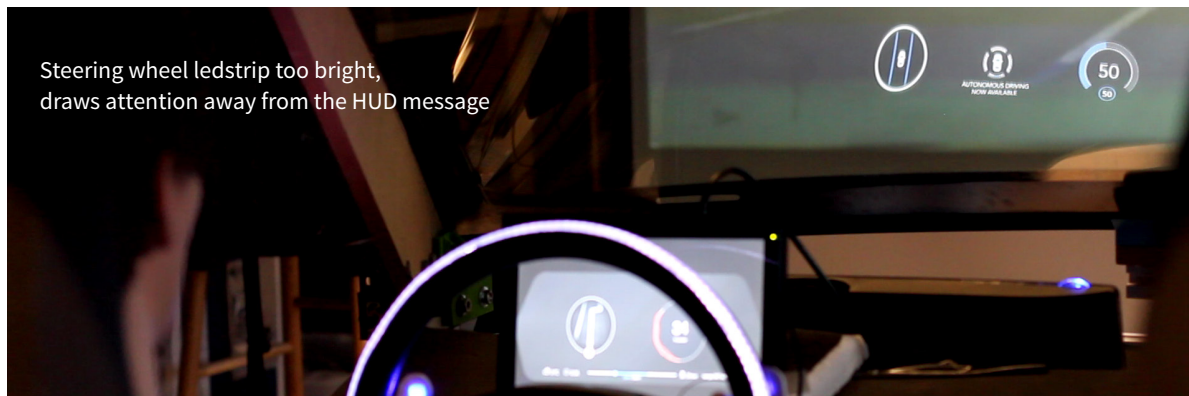
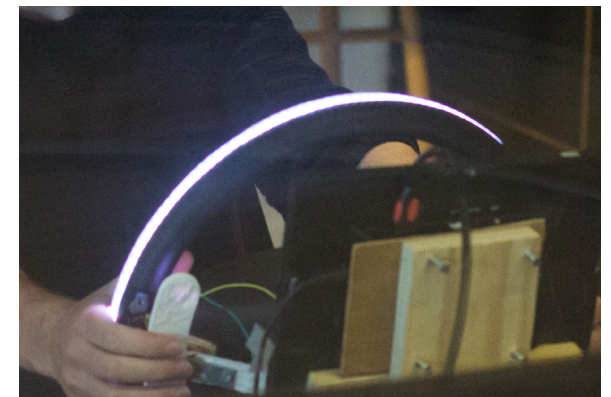


Figure 79. Prototype from different angles.



Q8: 'Retracting the steering wheel is of course very clear, but it also not that far that I can't reach it anymore. So in that respect it is of course more a symbolic gesture.' - P expert knowledge

During Autonomous Driving

The animations during autonomous driving when an action is performed by the vehicle were mainly received positively and were understood (Q10). They would like to have this kind of information especially while using the system the first few times.

Q9: 'The circle is a feedback to show that the car has everything under control.' - P Semi automated driving

One participant, however, mentioned that even though he liked it, the circle represents the steering wheel at some moments and a radar at other times which seems inconsistent (Q11).

Q10: 'Sometimes it is a steering wheel and sometimes it is a radar thing, but it is not bad either...' - P expert knowledge.

Take over to Assisted Driving

Most of the participants mentioned that the sound

for the wake up warning was not loud enough and probably too mild. Overall the sounds were experienced good (especially the sound for the watch the road warning), because it felt like alarms of a mobile phone which grab the attention (Q12).

Q11: 'It sounds like an alarm of a mobile phone so that's nice' - P Semi automated driving

The messages on the screens were understood and the participants knew what to do. Some participants however mentioned that they will probably take over sooner and also pay attention on the road sooner.

Q12: 'I would adjust my seat already. [seat animation] oh wait it happens automatically [lauging], that's convenient.' - P expert knowledge

Also, the time until take over would ideally be more prominent on the screen even though it was noticed and increases in size during the messages.

Some of the participants also expected the steering wheel to come back automatically before the take over. They mentioned that they think that would be better, because it would make the transition easier

and they would feel better prepared (Q15). They do find it convenient that the message and countdown for the take over shows up on the HUD.

Q13: 'Maybe for the take over, that the steering wheel comes back sooner. That it will be presented sooner, so that the steering wheel is already back before the time is over.' - P semi-automated driving

Q14: 'I would expect it to come back automatically...' - P expert knowledge

System Usability Scale

The average score of the SUS given by the participants is 76.1. This means (Bangor, 2008) the score based on usability lies between 'good' (71.4) and 'excellent' (85.5). Noticeable is that the SUS score for the participants with semi-automated driving experience gave a significantly lower score (69.2) than the participants with expert knowledge (81.3). Figure 80 shows the ratings per statement per group of participants. It shows no significant difference between the groups per statement. With most statements the participants with expert knowledge rate the statements better.

When calculating the scores per statement to ratings from 1 (worst) to 4 (best), the statements that scored best were:

- 'I would need the support of a technical person to be able to use the system' (3.9)
- 'I would imagine that most people would learn to use this system very quickly' (3.6)
- 'I found the system unnecessarily complex' (3.3).

The relative worst scores were related to the statements:

- 'I felt very confident using the system' (2.4)
- 'I found the various functions in this system were well integrated' (2.6).

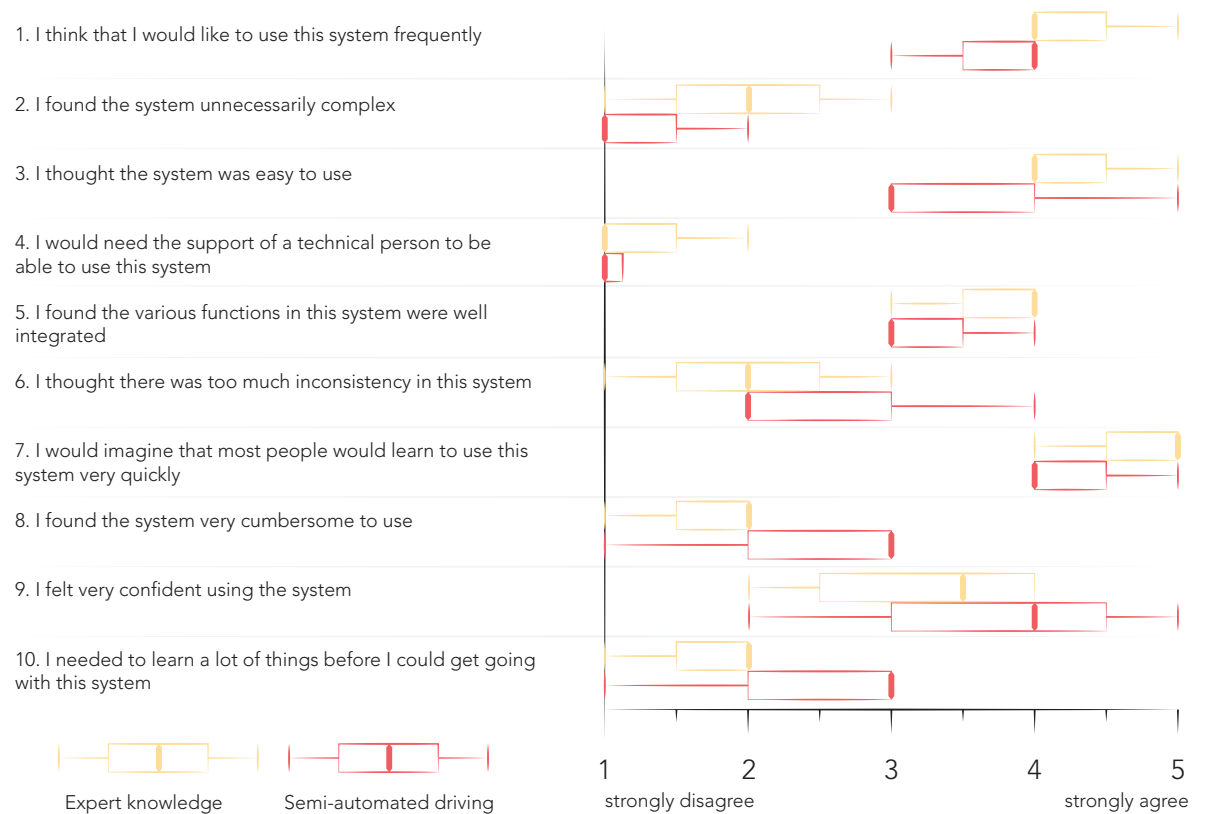


Figure 80. Box-plots of the SUS based on the ratings given by the groups of participants of each statement.

Discussion

The augmented reality aspects on the HUD were not tested in the design. This affected the user test more than was anticipated beforehand. Especially concerning the activation of adaptive cruise control as this probably includes the message that was missing in the prototype. Also, the dash-cam movie on the beamer did not respond on using the steering wheel or the pedals. Therefore a lot of physical feedback is missing. For example, the car did not decelerate when the user does not use the pedals. This especially affects the feedback for adaptive cruise control and autonomous driving.

The reason that the message on the HUD showing that autonomous driving is available was not seen, could have been due to the distraction as the steering wheel lighted up quite bright (which is not the case in the real design). It could also mean that the message is not long enough on screen. The message was seen by everyone the second time, probably indicating that the led strip is a new experience for people and distracts them the first time. The vibrations in the steering wheel were not always noticed in the prototype due to restrictions of the material.

Although the messages on the instrument cluster

during autonomous driving were clear, people will still take over or watch the road earlier than needed to. This might be because they wanted to show good behaviour during the test or that it has to do with the fact that none of the participants have actually driven in an autonomous car before and hereby want to feel confident going through the take over.

System Usability Scale

It was expected that the participants would not give a high score for feeling confident while using the system, as new features as autonomous driving and for some participants lane keeping were used. Also new forms of feedback were used. It is expected that it will take some time before users will get used to the system.

Conclusion

The overall experience with the design was quite good, which is also backed by the SUS-score. The instrument cluster and HUD (the aspects not related to the automated features) were mostly clear. Some small incremental changes can be made to make it easier to understand for users. Although, when the interfaces are used in a dynamic environment, the user might be able to link the elements in the design to their functions. There are some aspects in the

design that were not clear however. The feedback for the ACC was not sufficient although this could be solved with the augmented reality feature or adding an icon which is still linked to ACC by many people. It remains unknown how the augmented aspects would affect the design. Even though the message that autonomous driving is available was clear after the second time, keeping the autonomous driving logo on the screen might help to understand the LED strip on the steering wheel. The process of activating autonomous driving was a nice and clear experience. The participants felt more confident in letting go of the steering wheel. The steering wheel should present itself back sooner though, as a sign that a take over is soon and to make the transition smoother. The challenge is then, however, to make clear that assisted driving is not active yet when the steering wheel is presented. Even though the messages shown during autonomous driving when the system is performing an action are clear and desired, the visualisation of the circle itself can have a confusing meaning when also used to represent the steering wheel.

Some incremental changes can be made to the instrument cluster to make the navigation clearer during assisted driving. The time until take over can be more prominent and the route visualisation on the bottom can be more clear.

The shape of the levers are comfortable, but have the wrong semantic. People might link them to gear switches from racing cars.



7.2 OPTIMISATION

Assisted Driving

Visual redesign HUD

The HUD lacked some visual consistency. A visual redesign is made of the HUD together with the adjustments concluded from the user test. The vehicles on the traffic aware section got a more mature and modernised visual feeling. The lines for lane keeping are made thicker so they are also 'glance-able'. The visual style of the speedometer is adjusted to the traffic aware section, using the same stroke widths and sizes.

Adaptive Cruise Control feedback

The feedback for the adaptive cruise control was lacking. If the addition of the augmentations wouldn't be sufficient an icon should be added at the position of the maximum speed. This should be tested in a follow-up study.

Autonomous driving available icon

To clarify that the white steering wheel is related to 'autonomous driving available' the white icon of autonomous driving which pops-up moves to the left bottom of the HUD and decreases in size.

Visual redesign navigation instrument cluster

The navigation is visually redesigned to make routes

more clear and distinctive from the environment.

LED strip steering wheel fades in slowly

When autonomous driving becomes available, the white led strip will fade in slowly to prevent distraction.

Autonomous Driving

Time until take over message

The time until take over is from 5 minutes until take over more prominent on the screen and more 'glance-able' (Figure 83). This gives the user more confidence, knowing that the time until take over can be seen easily.

Take over sequence to assisted driving

Ten seconds before the take over to assisted driving the steering wheel will already move forward



Figure 81. Redesign of the head-up display in assisted driving and navigation in the instrument cluster

towards the user (Figure 82). When the movement ends, the text on the HUD changes from 'standby for take over' to 'take over now' which is eight seconds before the take over. Hereby the steering wheel presents itself to the user as an indication that the take is needed. The HUD, the instrument cluster and the LED strip on the steering wheel still remain in the autonomous driving status to prevent that the user thinks that assisted driving is suddenly activated. While holding the levers the HUD circle starts filling with a white colour until the 'pop' motion which is combined with the vibration in the steering wheel, indicating that assisted driving is now active. The blue lights on the steering wheel will fade away right after the vibration. After the pop-motion the changes on the instrument cluster take place after which the HUD fragments move from to circle to their original places. This switches the visual focus of the user the last place of changes which is the HUD and thus the road ahead.

LEDs on the levers

The LEDs on the levers, indicating the status of the automated features, did not have a clear negative or positive impact on the design. It can be argued, however, that it could clarify the use of LEDs in the steering wheel. It is also a question of how visible the

levers will be to the user as these needs to be visually different.

Text below the route in the information bar

Text is added to clarify what the numbers below the route on the information bar mean. Based on this information new route can be chosen if users prefer to drive as much autonomous as possible.

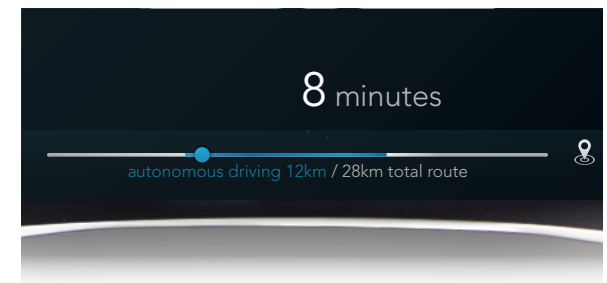


Figure 83. Time till take over during autonomous driving is larger and text is added below the route on the information bar.

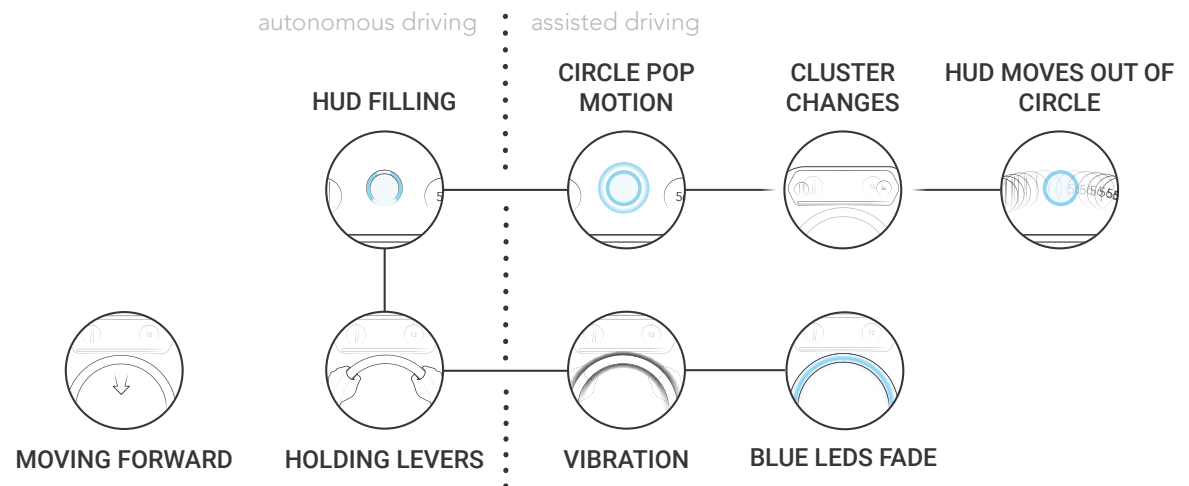


Figure 82. Framework of the redesign of the take over to assisted driving

7.3 CONCLUDING

The design was evaluated by 7 participants with an interactive prototype and a movie. Most elements of the design were well understood. Especially the retracting steering wheel was a nice and clear experience for the participants. Also, the animation during autonomous driving and the circle of the HUD provided helpful information. The design was optimised on a visual level for the HUD and the part of the instrument cluster. An icon of autonomous driving was added for a better understanding of when autonomous driving is available. The main improvement is that the steering wheel presents itself sooner as an indication that the user needs to take over.

The next chapter will conclude the whole project and provide recommendations for further development. Also, an evaluation is done on the project.

CHAPTER 8

CONCLUSION

8.1 Conclusion

What will be tested and how?

8.2 Recommendation

What are the conclusions of the analysis?

8.3 Evaluation

What are the conclusions of the analysis?

8.1 CONCLUSION

This project's goal was to design a system where the transitions to and from autonomous driving in a highly automated car are comfortable and safe. Literature and field research indicate human-factors issues like the loss of situational awareness and vigilance decrements that affect these transitions. Three user states (sleeping, inattentive and attentive) were defined to facilitate the transition to assisted driving. This led to a basic time framework for the conceptualisation. Four design elements are integrated into one system: head-up display, instrument cluster, steering wheel and seat. The design was evaluated with potential users and experts on autonomous driving in order to optimise the design. Retracting the steering wheel was experienced as a clear and confident experience. To improve the design, the steering wheel will present itself to the user when a take over is needed shortly after. Not all the design features were tested. For further development, the augmented reality aspects need to be tested to verify if the automated features are clear.

Figure 84. Visual overview of the final design. Letting go or grabbing the steering wheel are strong interactions to confirm authority transitions. The seat embraces the user by acknowledging the user as a passenger.



8.2 RECOMMENDATIONS

Communication with other road users

The research with the driving students concluded that communication with others while driving is important. When the driver is not in control when driving autonomous for example, the communication becomes even more relevant as the other road users can't find eye-contact or interact with other physical gestures mostly used to show that the other road user is acknowledged or granted priority. The system should, therefore, show some form of feedback to other road users replacing the feedback from the driver. The BMW vision and Mercedes-Benz F015 concept cars (Figure 85) are already showing design elements which make the car predictable to other road users. This could be a next step in the design process for the development of a level 4 car as presented in this project.

Steering wheel retraction

The retracting of the steering wheel can have a better interaction with the physical dashboard. As an example, the dashboard can be designed in such a way that the steering wheel will 'fit' in the dashboard making it visually attractive and functional. This is also done in the concept car of Volkswagen (2016) as can be seen in Figure 86.

Circle of the HUD

The circle of the HUD was used at multiple stages of the scenario. At all stages, the circle provided a helpful interaction, but represents a steering wheel at some points and autonomous driving at a different stage. To be very concise a new visualisation should be made for one of the stages or a new design in its whole.

Removal of Lane Keeping

If autonomous driving is more available than anticipated in this project it is recommended to remove Lane Keeping as automated feature to prevent confusion on responsibility. Lane Keeping would offer few opportunities to be helpful if autonomous driving would be available during most of these opportunities. Lane Assist can still be a beneficial feature.

Embracing the passenger further

The Mercedes concept car in Figure 87 shows a next level way of 'embracing the passenger' by making the two front seat rotatable and hereby creating one environment for the passengers.

Preventing motion sickness and creating situation awareness

Motion sickness was one of the other human-factors issues that are relevant to automation in a vehicle. Some interactive elements can be designed in the interior of the car for example which react on the environment outside of the vehicle. This could not only help to prevent motion sickness, but also create situational awareness at the same time. A similar interaction is designed in the dashboard of the BMW Vision (Figure 88), but for assisted driving.



Figure 85. Outside HMI that communicates with other road users. On the left the Mercedes-Benz F015 concept and on the right the BMW Vision concept.

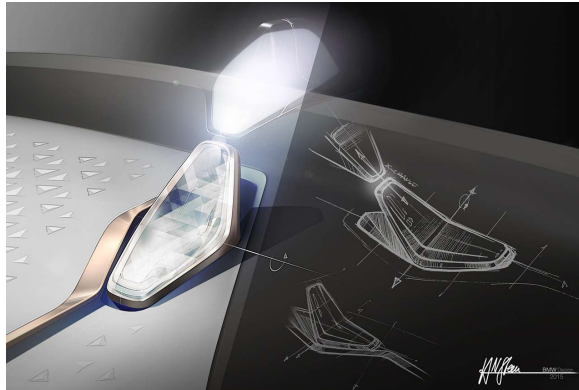


Figure 87. Interior of the Mercedes-Benz F015 concept, showing rotatable front seats.



Figure 86. Steering wheel interaction of the concept car of Volkswagen (2016).



Figure 88. Dashboard of the BMW Vision that interacts with the environment and visualises dangerous situations.

8.3 EVALUATION

New development

A level 4 high automated vehicle does not exist yet. This means that some of the scenarios are based on assumptions. When the first set of highly automated vehicles reach the market, the capabilities and limitations of the system will become clearer and with this new development, other uncertainties will disappear. This (or by user testing) could also indicate which automated features should be on after the take over to assisted driving. This should be experienced in a more realistic setting with working adaptive cruise control and lane keeping to get reliable results.

Implementation of the design

The system proposed in this project can be implemented by other (car) companies. Some adjustment (mostly visually and auditive) need be made beforehand to fit the companies character as this design is not aimed at such a specific target group like BMW or Volkswagen does.

Evaluation on the interaction vision

A confident experience was tried to achieve during the transitions of authority. The user test indicated that 'confident' was one of the qualities mentioned during this part of the design scenario.

Unsolved Human-Factor issues

As mentioned in the recommendations, the human-factor issues of motion sickness and predictability of the vehicle to other road users are not solved in this design and can be developed in a follow up project.

Take over initiated by the user

Since the system allows the user to take over at all times, a take over can be initiated by the user before the message 'take over now' appears. This means there is a chance that the driving performance has not regained its standard level yet. This issue might not be solved directly if one of the criteria of the design is that the system allows a take over by the user at all times. It could be indirectly solved by designing active safety features as is done in this project. How much they contribute to safe driving is still unsure, but can be tested in simulations.

What is the take over is not met?

When the user does not take over control when supposed to, the car will automatically drive to a safe location to stop. What happens in terms of feedback during this moment is not defined in this project and can be done in a with further development of the design.

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