Designing Phased Transitioning of Control in Highly Automated Vehicles

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Designing Phased Transitioning of Control in Highly Automated Vehicles

Assisting Human Decision-Making through Human-Machine Interaction

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DFP006 Future Mobility (FBP)

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Table of Contents

List of Figures 6
List of Tables 6
Acknowledgment 7
Executive Summary 8
  Design Iterations 8
  Research 8
Prologue 10
  Final Bachelor Project 11
  PDP Goals 12
Introduction 13
  Design Objective 13
  Research Objective 13
  Research Question (RQ) 14
  Null Hypothesis (H_0: $p_1 = p_2$) 14
  Alternative Hypothesis (H_a: $p_1 < p_2$) 14
  Example of Application 14
  Planning 15
Process and Results 16
  Brainstorming 17
  Monitoring Phase 17
  First Iteration 18
  Second Iteration 18
  Third Iteration 21
  Fourth Iteration 22
  Iteration 4.5 24
User Research 25
  Study Setup 26
  Intermediate Step: UX Guerrilla Testing 31
  User Study Results 32
Conclusion 36
  Research Question (RQ) 36
  Usability 37

Take-away Messages 37
Design Recommendations 38
Discussion 39
Epilogue 41
PDP Goals Reflection 43
Reflection 44
References 47
Appendix A: Questions after each of the six tests 50
Appendix B: Ethical Review Form 51
Appendix C: Interview Questions Richard Schram 56

List of Figures

Figure 1: Expertise development during my internship in the previous semester 11
Figure 2: FBP planning grouped by areas of expertise 15
Figure 3: Visual representation of hybrid design research process 15
Figure 4: Tesla's Human-Machine Interaction...16
Figure 5: Control transition from computer to human 17
Figure 6: First iteration of HMI 18
Figure 7: Second iteration of HMI...19
Figure 8: The top bar displays the current mode 20
Figure 9: Dynamic information is displayed on the left..20
Figure 10: Non-driving related information is displayed on the right...................................20
Figure 11: Different explorations for a more dynamic top bar 21
Figure 12: Chosen top bar design featuring a pointer and directional transition animations 22
Figure 13: Lay-out for sidebar displaying dynamic content based on current phase 22
Figure 14: The HMI features large icons and typography 23
Figure 15: The HUD brings the interface closer to the environment 23
Figure 16: Four white LED's communicate the required action 24
Figure 17: Automation levels, defined by the SAE (SAE International, 2018) 26
Figure 18: Van der Laan-scale (Acceptance Scale)..27
Figure 19: Overview of simulations and scenarios 27
Figure 20: Overview of all scenarios 29
Figure 21: One of the six tests in which take-over is required 30
Figure 22: Five test users are sufficient to capture 80% of insights (NN/g, 2000) 31
Figure 23: Correct responses without (p_1) and with (p_2) monitoring phase 33
Figure 24: Icon ambiguity (with steering wheel) has been found relatively late 37
Figure 25: Expertise Area development during final Bachelor semester 45

List of Tables

Table 1: Take-over scenarios (Gold, Happee, & Bengler, 2018). 25
Table 2: Experiment simulations 31
Table 3: Responses from UX Guerrilla tests..32
Table 4: Correct responses for each simulation 33
Table 5: Mean delay in response for Simulation 1 and 3 33

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- Other project coaches and students who gave me valuable feedback
- All people who participated in the user tests and user study
- Richard Schram
- Caroline

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Executive Summary

The main objective of this report is to draw a picture of my design and research processes. Different perspectives and potential approaches to user evaluation, research, and the creative process are discussed. The goal for my Final Bachelor Project (FBP) is to design an interface to improve transitioning vehicle control from computer to human, by increasing system transparency. During this project the focus lies on increasing the driver's understanding and take-over performance by allowing the driver to prepare for a possible take-over.

An automated vehicle is able to drive itself and doesn't require a human to monitor the environment, but then when the situation changes, the user may be required to take over rapidly. This can be difficult. A possible solution is to add one step between the vehicle driving itself and the human driving the vehicle: a 'transition phase' in which the human monitors the vehicle and the environment, thus understands what is going on before a take-over is required.

Design Iterations

The first iteration is very basic. It only shows whether monitoring is required and for what reason. A shortcoming of the first iteration is the absence of relevant system metrics such as the likelihood of a take-over, and in which mode the vehicle operates. The second iteration addresses this shortcoming. However, it is not necessarily clear from which direction this 'take-over' is initiated, e.g. from computer to human or vice versa. The third iteration has animated features to clarify and streamline the take-over process.

The fourth iteration is based on feedback from a cross-coaching session and from five UX Guerrilla tests. Two important design decisions were made. The first is to simplify and optimize the UI for a head-up display, allowing for improved situational awareness. Secondly, by adding two new modalities, accessibility is drastically improved, as well as ease-of-use by offering redundant communication. A succeeding sub-iteration includes some minor adjustments to the fourth iteration, such as an improved integration in the car interior, and updated icons.

Research

Using a simulation of an automated vehicle in combination with the final iteration of the Human Machine Interaction, the percentage of correct responses, and the reaction time are measured (among other things). Half of the tests show no monitoring phase, and the other tests show the final design with a monitoring phase. The alternative hypothesis is that take-over performance increases when showing the final iteration, since an effort has been made to improve the HMI through a monitoring phase. To better understand what elements over the HMI result in increased take-over performance, the study also includes a qualitative part.

Insufficient quantitative evidence has been found to conclude that take-over performance is significantly higher with a monitoring phase, as proposed in the final design.

However, five design iterations, a UX test, and a qualitative user study indicate that a 'monitoring phase' can be helpful. For instance, the standardized 'usefulness' score for the interface is high: 1.44 (on a scale from -2 to 2; Van der Laan, Heino, & De Waard, 1997).

In general, I am pleased with the design and research outcomes. However, looking back at the results, some aspects, such as the number of participants, and an information asymmetry are less than optimal.

Prologue

Figure 1 demonstrates the effect of my internship during the previous semester on my competency development (quantitative estimation). I have added a horizontal line to indicate what I think would be considered a good level of competence for each expertise area at the end of my Bachelor.

With regard to my Professional Identity & Vision (PI&V), I now have a better picture of what type of designer I want to become, although I still consider my PI&V work in progress. I am not sure if I ever completely understand my PI&V, and I consider it one of my weakest points as a designer. When comparing myself with other students, some of whom have a specific passion, I would say I am not a typical design student.

My interests heavily lean towards entrepreneurship, and product development in relation to business viability. At the same time I care about customers, and can feel personally attacked when a customer doesn't like a product or idea, since a product is a reflection of who you are as a designer. However, it's inherent to the practice of designing that you have to collect feedback, which is good. Seeing critique as opportunities for your design is the right mindset. This can sometimes be hard for me. Simultaneously, the fact that people are willing to give you feedback can be considered a compliment, as it implies that they take you seriously and want to help.

Besides, feedback on your product is not equal to feedback on you. I have worked for clients that had much critique on my work, but at the end told me they were very pleased with the results and the way I handled their feedback. Additionally, a design should be evaluated from different angles, and 'one size fits none'. I.e. if you try to design something that everyone likes, no one will like it. Taste is personal and observations remain subjective.

All of these personal observations are difficult for me to put into one consistent PI&V, and also makes me wonder how much my identity as a designer coincides with my non-professional identity. Defining my PI&V therefore feels like a much broader, and more spiritual quest than what I initially believed. I cannot give a definitive description of my PI&V at this point, which I believe already is a step in the right direction, since I recognize my difficulties with this topic, and continue my development.

One thing that is consistent across my work, is my preference for application-driven design. I enjoy seeing a design come to life, from its earliest sketches, in-depth research, to its final touches and market introduction. This also means that a great design needs to be feasible, viable, and desirable; checking all boxes.

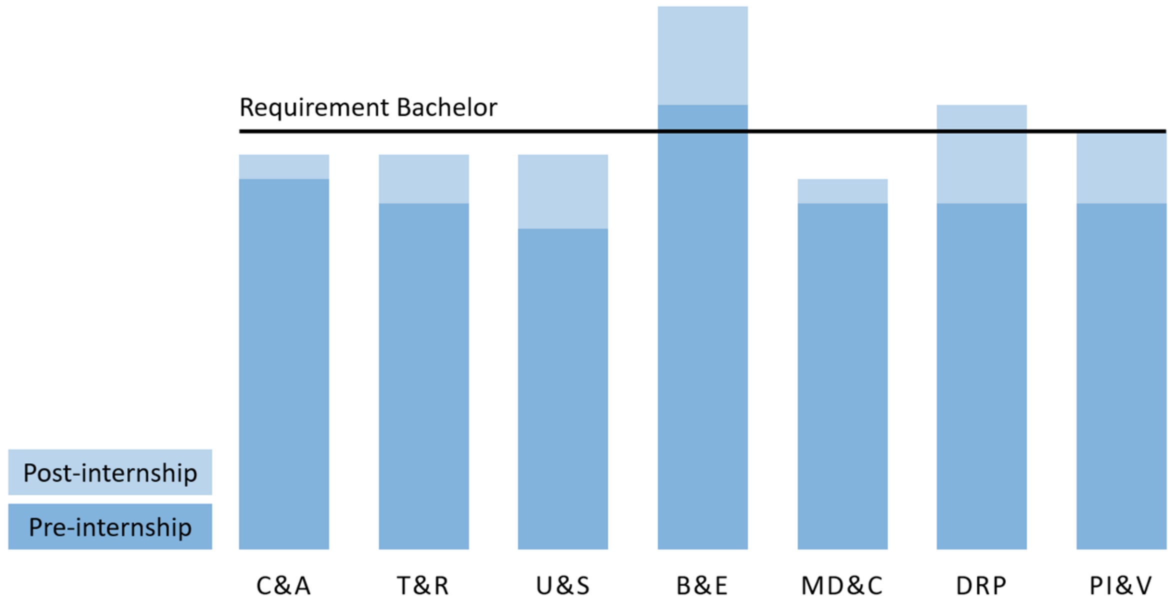

Figure 1: Expertise development during my internship in the previous semester

I will bridge the differences between the required level and my current level during this final semester. To make sure I will reach (and surpass) the required levels, I closely consider my personal estimations in Figure 1 during the selection of my Final Bachelor Project (FBP). I choose to focus on user research, which is out of my comfort zone, but therefore a valuable focus during this project from a personal development perspective.

Final Bachelor Project

Based on Figure 1 and my personal preferences I have listed my top three project squads:
1. Designing for Growing Systems in the home (DFP003)
2. Future Mobility (DFP006)
3. Seamless Interaction Design for Professionals (DFP005)

At the time of writing I am currently halfway through the final semester of my last bachelor year (B3.2). I have been allocated to the second squad; Future Mobility (DFP006). The squad's main expertise areas are U&S and T&R, which nicely align with my intended competency development.

PDP Goals

Personal Development Plan B3.2

User & Society
Conduct multiple user tests, both formally and through guerrilla UX tests. This helps with understanding the user in order to translate their needs into design solutions.

Analyze how not having to drive your car all the time may introduce new opportunities and challenges from both a technical and societal perspective. Technological advancements and societal changes go hand in hand. What does this mean for the proposed interface?

Technology & Realization
Implement multiple iterations to the proposed interface, based on the outcomes of the previous goals.

This helps me with my hands-on skills, as well as once again training an iterative mindset to designing new products.

Math, Data, & Computing
Student assistant job for the course Data Analytics for Engineers. Work on technical as well as tutoring skills.

Creativity & Aesthetics
Design two new websites: sentielwatches.com (E-commerce initiative) and nijsbouman.com (portfolio). This will help me with becoming more fluent in implementing technical knowledge I already have in a user-friendly and aesthetically pleasing way.

Business & Entrepreneurship
I haven't set a goal for Business & Entrepreneurship, because I believe focusing on other areas is more valuable. My intended level of competence has already been reached for this area.

Introduction

The main goal of this report is to draw a picture of my design and research processes this semester. Different perspectives and potential approaches to user evaluation, research, and the creative process are discussed.

This Final Bachelor Project (FBP) report also includes insight into my project goals, methods and results, and well as a personal reflection and an interview in the epilogue.

Design Objective

Automated Vehicles (AV's) are becoming more and more capable of driving without human input. In an increasing number of situations, AV's are able to take control on the road (Alessandrini et al., 2015). However, until the time that AV's reach full automation, car manufacturers need to consider instances in which a human needs to take back control.

My goal for my FBP is to design an interface to improve transitioning vehicle control from computer to human, by increasing system transparency. System transparency describes to what extend the user understands the current and future system processes (Yang et al., 2017). This is important to allow the human and computer to collaborate seamlessly in an automated vehicle, especially during those instances in which the computer needs help from a human to assess traffic and road conditions.

I am going to explore different interfaces, and study how the interaction between human and computer can be improved. The aesthetics should be modern and sleek, complementing the high-tech associations one might have with automated vehicles. In order to verify my design, I conduct a small user study with 19 participants. The insights of this study are used to improve the Human-Machine Interaction (HMI), in accordance with the principles of Research for Design (RfD).

The design process will be interdependent on the research process, which runs in parallel. Using different areas of expertise, the design undergoes different iterative design cycles.

Research Objective

In order to improve taking back control, the user first needs to broadly understand the AV's thought process (Carsten & Martens, 2019). Since most people cannot read complex computer code, an interface should address this. Increasing system transparency through an HMI could perhaps improve transitioning vehicle control from computer (AV) to human. System transparency can be improved through a myriad of ways. However, during this project I focus on increasing the driver's understanding and take-over performance by allowing the driver to prepare for a possible take-over.

Research Question (RQ)

Do driver take-over understanding and performance improve by adding a monitoring phase in-between full automation and a take-over request?

p_1 = % of correct responses **without** monitoring phase
p_2 = % of correct responses **with** monitoring phase

Null Hypothesis (H_0: $p_1 = p_2$)

No, driver take-over understanding and performance **do not** improve by adding a monitoring phase in-between full automation and a take-over request.

Alternative Hypothesis (H_a: $p_1 < p_2$)

Yes, driver take-over understanding and performance improve by adding a monitoring phase in-between full automation and a take-over request.

The hypothesis is to be validated with user tests, which contain both quantitative and qualitative elements (Creswell & Creswell, 2018). Different iterations show the progress during the course of the project.

This take-over is to be seamless and effortless to allow for increased safety and user comfort. The transition of control is crucial for adopting (partially) automated vehicles. As long as situations occur that cannot be handled by the computer, a human should be ready to take over.

System transparency can perhaps help to improve the mental model the user creates of the AV. In order to understand what the AV is doing, and what is expected from the user, the user needs to digest information from the road and from the vehicle. An interface can guide this process, thus improving situational awareness. This can help to more easily take back control from the computer if necessary. Key to this situational awareness is knowing what is expected by the AV at all times (Yang et al., 2017). When do I need to be monitoring the vehicle and road? When do I need to take over? Displaying different 'modes' in a continuum can help the user answer these questions.

Example of Application

Taking back control is much harder when you are not prepared to take back control (Radlmayr et al., 2014). The system clearly indicating that the user should be ready to take over, is an example of 'mode transparency'. The system should essentially aggregate all incoming sensor data to algorithmically determine what mode is appropriate. This mode is to be communicated to the user through an HMI.

What mode the vehicle currently operates in, is key information for the user to accurately respond to unforeseen scenarios (Boelhouwer et al., 2019). Mode confusion should be avoided at all times. Not all types of information contribute to better system transparency. Showing too much information may lead to confusion and actually disturb the take-over process (Carsten & Martens, 2019). However, showing key information, such as the current mode, can perhaps help the user to assess the situation more accurately, and take over control when necessary. The interface should be an aid rather than a standalone solution, is what is believed (Gold et al., 2016; Radlmayr et al., 2014).

Planning

In order to keep track of my progress, and make sure I align my effort with my project goals, I've created a rough outline of different steps within my project (Figure 2).

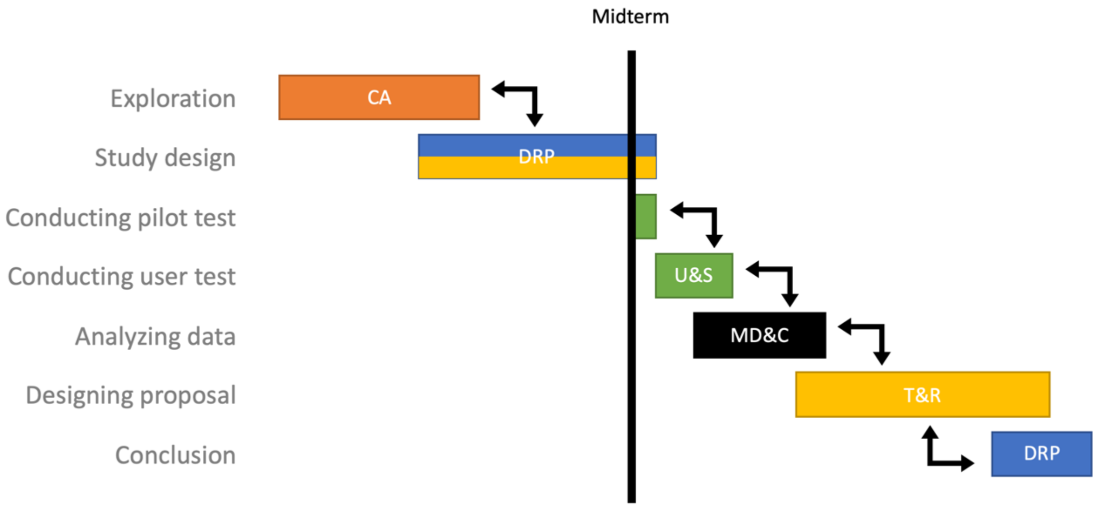

Figure 2: FBP planning grouped by areas of expertise

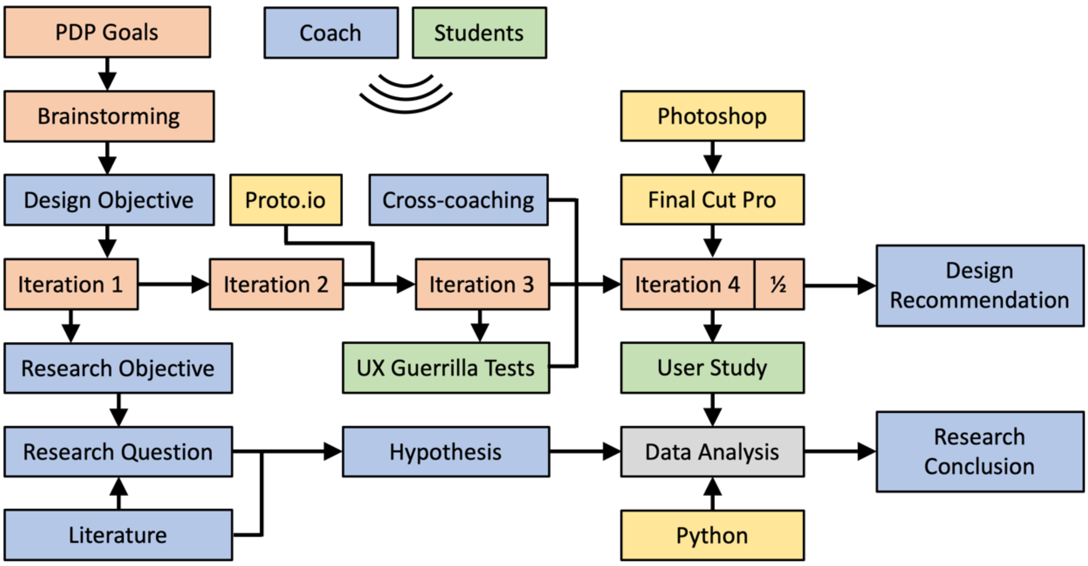

Figure 3: Visual representation of hybrid design research process

Figure 3 illustrates how different iterations relate to the user research and the conclusion, and what methods are used to improve various design iterations. All the activities are color-coded similarly to Figure 2. This report can be described as a hybrid between a design report and a research paper.

Process and Results

Tesla's Human-Machine Interaction (HMI) is one of the first car interfaces to feature system transparency visualizations (Small & Fairman, 2010). The 3D-graphics of other cars help the user to understand how the Automated Driving System operates (Figure 4). The underlying assumption is that by showing the user what the car sees, the user feels more at ease, and is able to better monitor and take-over control if required. However, a downside of this approach is that not all information is necessary all the time, and that some information may actually distract the user (Carsten & Martens, 2019). Additionally, the interface currently only operates with SAE Level 2 of Automation (SAE International, 2018). It is not clear how the interface functions with higher levels of automation.

Figure 4: Tesla's Human-Machine Interaction

This raises the question whether it is possible to improve this HMI, and what information is the most useful to show. I started considering all kinds of multi-sensory interactions, but eventually decided to focus on the visual and auditory aspects of an HMI, for the sake of keeping focus.

A plausible course of action is one in which the car is able to drive itself, and which doesn't require a human to monitor the environment, but then the situation changes and the user now is required to monitor. From this point, three things can happen. Option 1, the AV shifts back to a higher level of automation where the user is not required to monitor anymore. Option 2, the AV requests the user to take back control. Effectively, the user becomes the driver again. And option 3, the user decides to take over control. Option 3 doesn't make sense if the car operates with high certainty, and option 2 should be very clear as well, in order to avoid any misunderstanding between the human and the computer. Therefore, it is crucial for the user to understand in what mode the vehicle currently operates. Next to this, most cars have (additional) safety features, but these are not included in the HMI, because they engage regardless of the automated functionality (e.g. Collision Avoidance Systems).

Brainstorming

After the first brainstorming session, I concluded that the degree of (un)certainty the system faces during its traffic analysis, may be an interesting parameter to further explore. Additionally, I wondered how the different modes (SAE Levels of Automation; SAE International, 2018) can best be communicated to the user.

All in all, my focus is to further explore the user side of an HMI, and explore how the HMI can be implemented from a technical point of view.

When discussing the different levels of automation with my coach, I decided to look further into the scenario in which the user needs to take over control from the computer, or needs to start monitoring the environment. Most likely, this take-over will be an organically phased transition, in which the car will first request the user to monitor the traffic in case of uncertainty. In this 'monitoring' phase, the user may or may not need to take over.

This take-over is most certainly complex, as many factors play a role during this take-over. Human and computer need to collaborate, and thus share information (Carsten & Martens, 2019).

Figure 5 simplistically demonstrates the point at which the human needs to take back control (red).

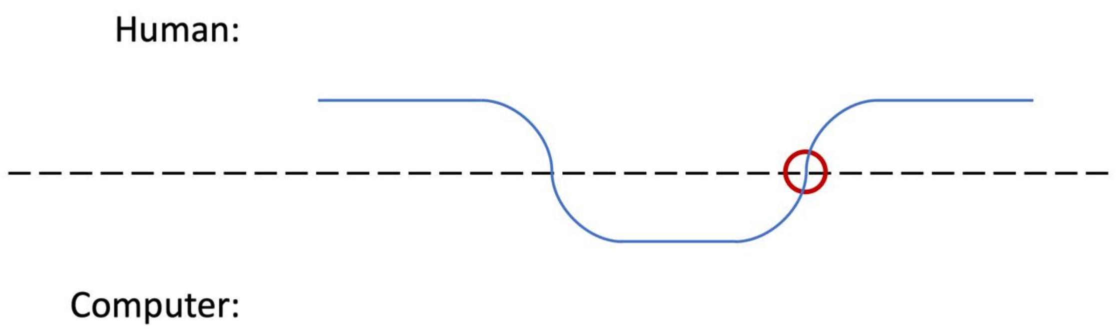

Figure 5: Control transition from computer to human

Monitoring Phase

After considering designing an interface for different levels of automation, I decided to look further specifically into the transitioning of control, by listing possible scenarios in which this transition may occur. It became clear that especially the transition from computer to human brings up a lot of questions. How much time should the user be given? What if there is an error with the system? How does the user know what is going on and what to do?

Then I realized that there should be one step between the vehicle driving itself and the human driving the vehicle: a transition phase in which the human monitors the vehicle and the environment, thus understands what is going on before a take-over is potentially required. The computer therefore needs to assess how likely a take-over is at any given moment, and communicate if monitoring by the user is required or not. The specifics of this intermediate phase are to be explored by means of different design cycles and user tests.

First Iteration

The first iteration as shown in Figure 6 is very basic. It only shows whether monitoring is required and for what reason. I purposely didn't put much effort in this iteration, since little information was yet at hand at the time. One design decision I've made entails that key information is immediately clear. Therefore, I've chosen a large font size and a bright red color. Additionally, all secondary information (e.g. climate, infotainment) is displayed within the white section at the bottom right. This is the corner which is naturally looked at the least (in most cultures), and which is the closest to the passenger (Brejcha, 2015).

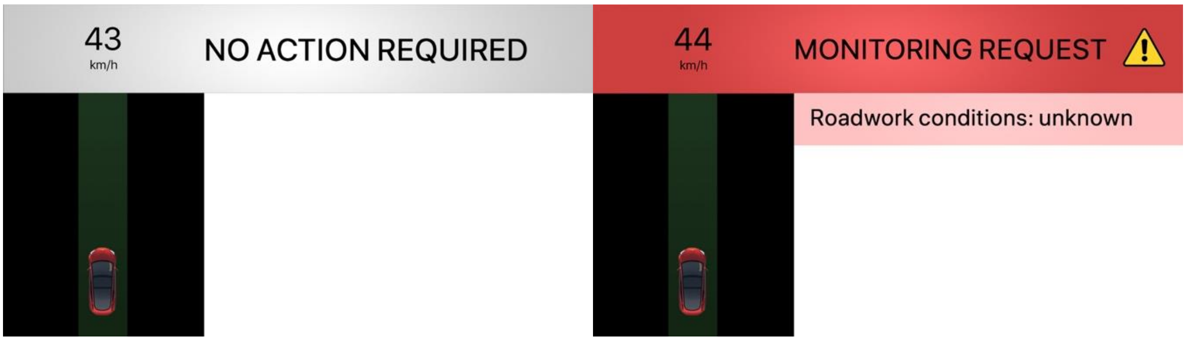

Figure 6: First iteration of HMI

This iteration was shown to other students during a midterm conference: video (Bouman, 2020a). Based on the collected feedback, the second iterative cycle was initiated.

Second Iteration

The second iteration as shown in Figure 7 is more sophisticated. A shortcoming of the first iteration (Figure 6) is the absence of relevant system metrics such as the likelihood of a take-over. Also, it is not clear what happens after for example a 'monitoring request' appears. What is expected from the user? No feedforward or a trace of action is provided (Wensveen et al., 2004), making it hard to understand or predict future events.

The second iteration shows in which 'mode' the vehicle currently operates. A mode defines to what extend the user is required to engage with operating the vehicle. Four modes can be distinguished. Each mode displays relevant information for that mode.

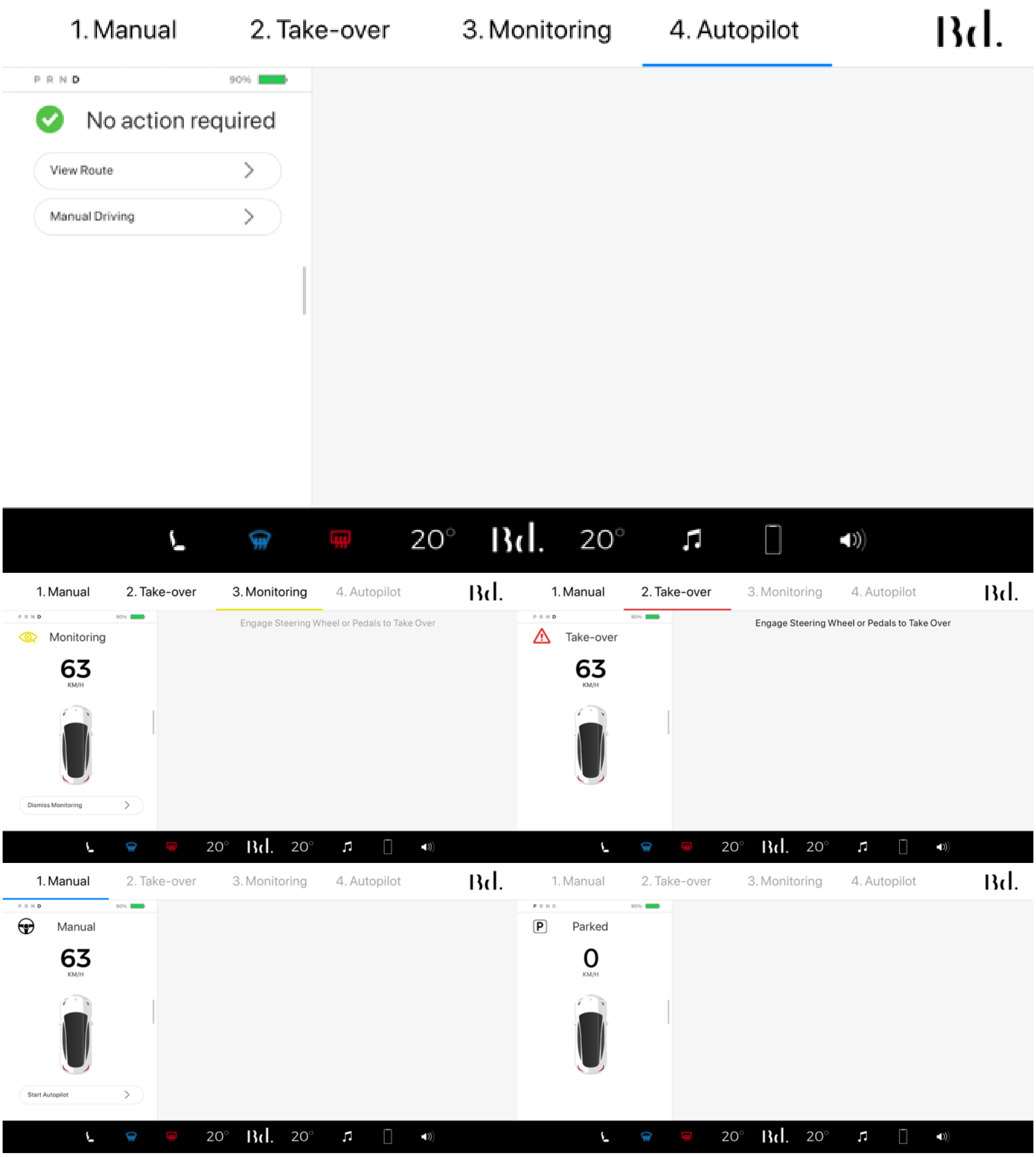

Figure 7: Second iteration of HMI

The top bar displays in which of the four modes the vehicle currently operates (excluding 'parked'). Central to this design is the way the current mode is displayed (Figure 8). The aim is to avoid mode confusion. The Tesla design language is used as a reference point. Mode changes are complemented by auditory feedback (bleeping). Note that each mode displays different information in the sidebar. Additionally, the gears and battery charge are shown.

Points of Improvement

From this visualization, it is not necessarily clear from which direction a 'take-over' is initiated, e.g. from computer to human or vice versa. For example, during informal talks with other students, many initially thought that you would start at '1. Manual' and finish at '4. Autopilot', which is not my intention. My intention is to show possible courses of action from any given mode, and clearly indicate what is expected from the user now, and in the near future. Another point of improvement: it isn't clear that the car visual represents your actual car, real-time.

In order to encourage the user to focus on the environment and the road, the infotainment is turned off when the car operates in level 2 of automation (3. Monitoring), as shown in Figure 7.

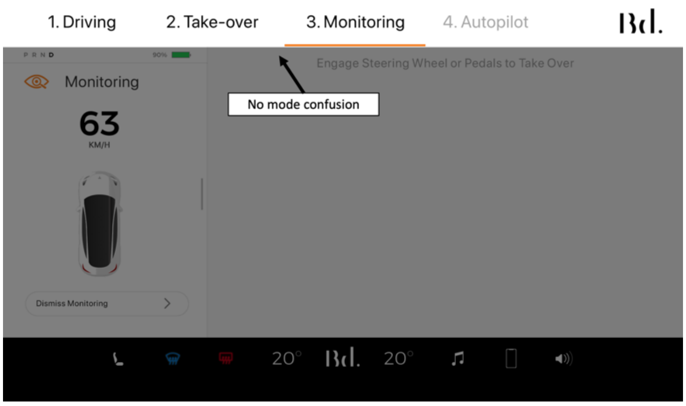

Figure 8: The top bar displays the current mode

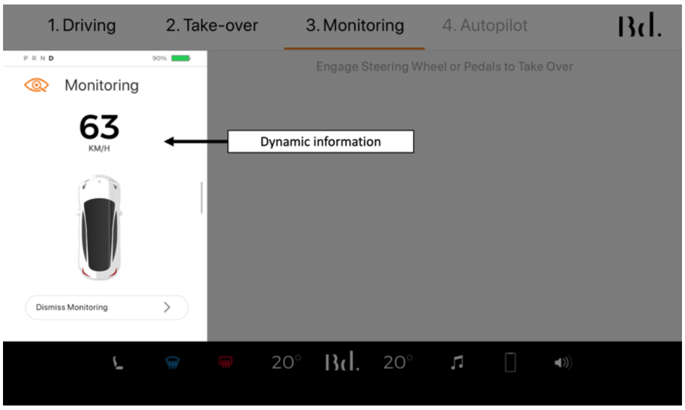

Figure 9: Dynamic information is displayed on the left

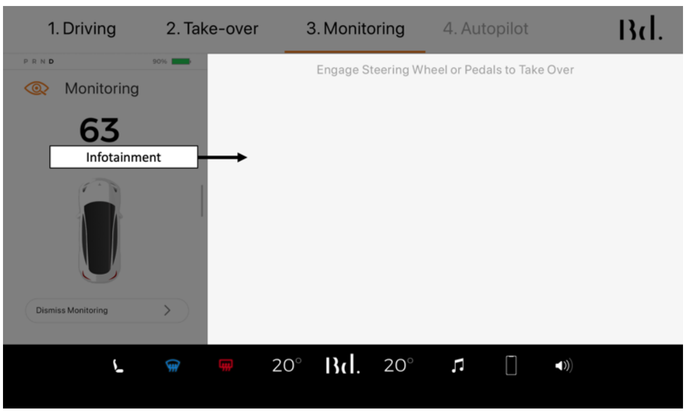

Figure 10: Non-driving related information is displayed on the right

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Each mode dynamically displays the most important information on the left (Figure 9). For example, the current speed, road conditions or distance to other traffic can be displayed to make clear why monitoring is required. Note: monitoring and take-over requests are two distinct things. They represent a different 'mode'. A take-over request is preceded by a monitoring request, except during an emergency.

Another point of improvement: how can the interface be the least distracting, and encourage the user to look around? Furthermore, is it possible to make the interface appear more fluent, seamless and dynamic, enhancing human-machine collaboration? Are color blindness and other accessibility-related topics considered? Last point of improvement: the numbers in front of the different driving modes are not in accordance with the levels as defined by the SAE International in 2018.

Third Iteration

With this iteration I hope to improve upon all the points mentioned previously. Considering different software solutions such as Ionic (Ionic, 2013), EB Guide (Elektrobit, 2014), Android API (Google, 2008), and Proto.io (PROTOIO Inc., 2011), I found the last tool to best fit my needs for designing the third iteration. It provides agile prototyping tools, and offers detailed customization tools as well.

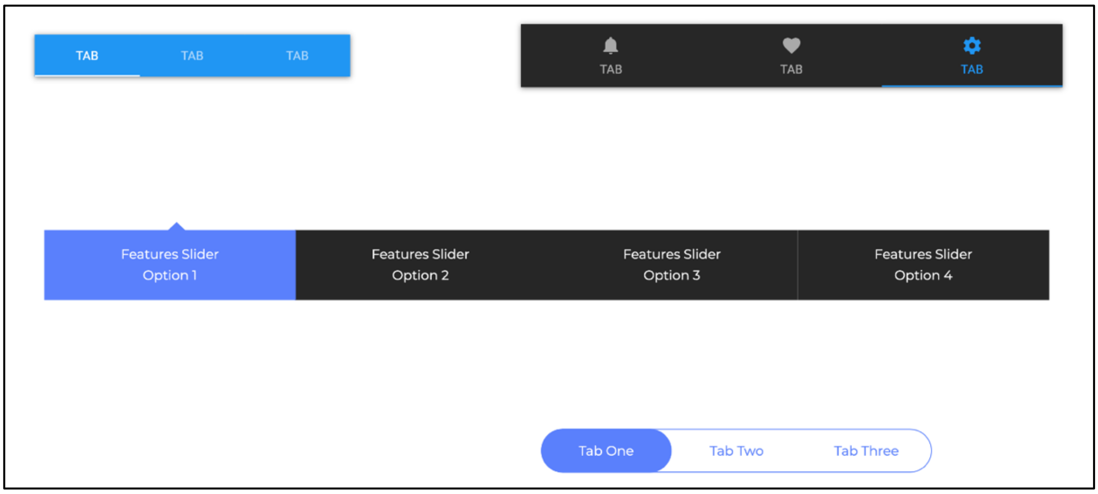

Figure 11: Different explorations for a more dynamic top bar

Figure 11 illustrates the exploration phase for designing the top bar. Eventually, I decided that the design of Figure 12 best fits the overall interface, since the pointer aligns well with the notion that the whole take-over is a graduate process, rather than different steps. However, I still decided to make clear that the process has four phases, with each a different human-computer relation. From this point I also decided to rename 'mode' to 'phase', since it better describes the relation with the user: a phase has a beginning and an end.

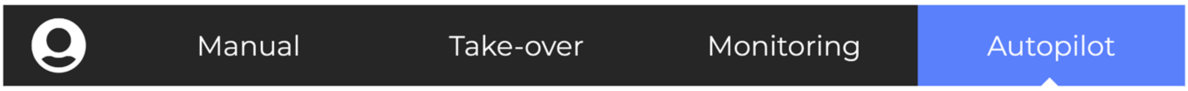

Figure 12: Chosen top bar design featuring a pointer and directional transition animations

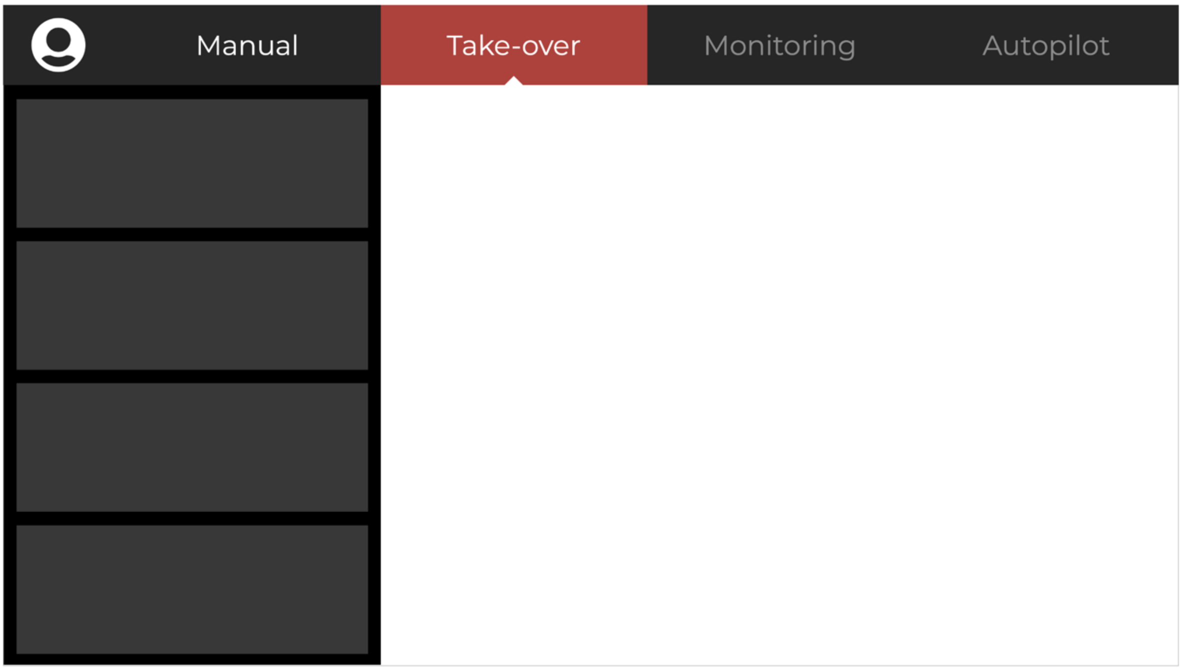

Figure 13: Lay-out for sidebar displaying dynamic content based on current phase

Figure 13 shows the finalized third iteration. The sidebar has cards, which can expand to show more details. This way, the interface displays only the most important information, while more information is easily at hand as well. This video (Bouman, 2020b) shows this in motion.

Fourth Iteration

The fourth iteration is based on feedback from a cross-coaching session and from five UX Guerrilla tests (page 31). Since this iteration heavily leans on animated interactions, a video with sound (Bouman, 2020c) is the best way to demonstrate this iteration. Two important design decisions were made. The first is to simplify and optimize the HMI for a head-up display (Figure 15), allowing for improved situational awareness. The HUD is positioned in order to minimize having to take your eyes off the road. Secondly, by adding two new modalities, accessibility is drastically improved, as well as ease-of-use by offering redundant communication. I.e. multiple modalities process the same information (Bourguet, 2003).

Figure 14 demonstrates the improved lay-out. By increasing the font size, removing touch-based elements, and adding icons, the HMI can now be projected onto the windscreen (HUD). This is important because it emphasizes what is expected from the user in three of the four phases: looking outside. Additionally, a battery indicator has been added, since this is a highly requested feature during the UX Guerrilla tests.

The three different modalities that communicate the current phase are conceptual, textual, and auditory (speech). The icons show in a conceptual way what phase the vehicle operates in. This helps low-literate users to safely control the vehicle. Additionally, it helps people with color blindness to understand the right emotion for a given phase. The text elements give more details to those who prefer reading, by explaining what is expected from the user. Third, a voice gives auditory feedback during a phase transition, alerting the user should he/she not pay attention, stating why a phase transition occurs, and helping low-literate people as well. Colors are chosen to match the desired state of mind, e.g. alertness or comfort.

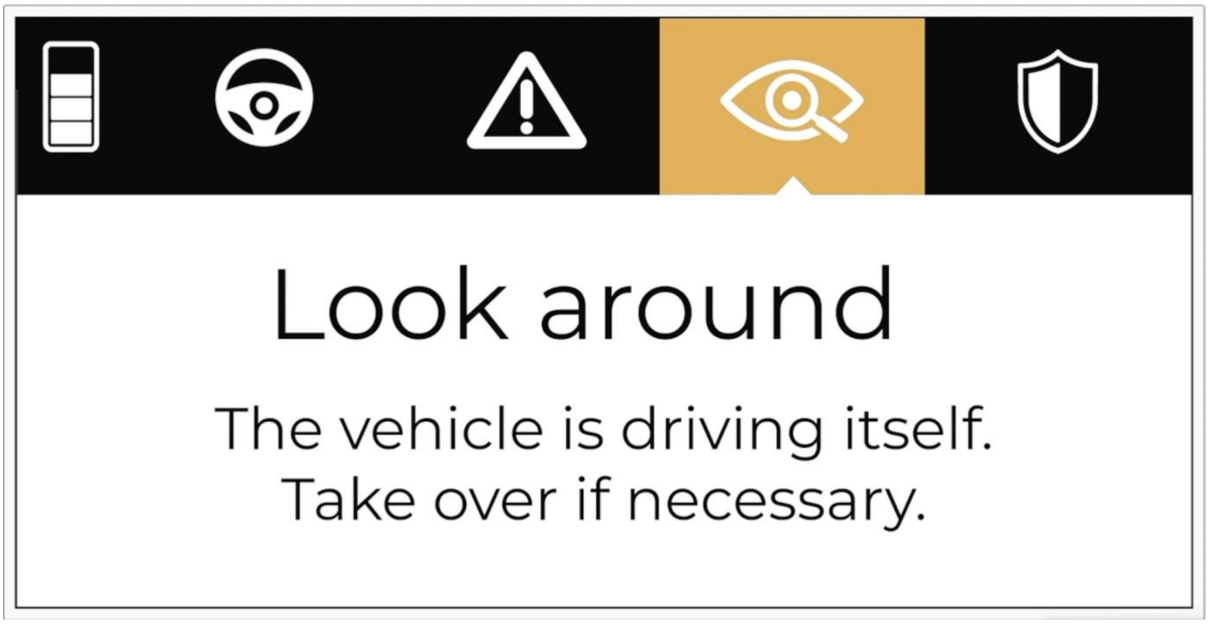

Figure 14: The HMI features large icons and typography

Figure 15: The HUD brings the interface closer to the environment

As can be seen in Figure 15, the HUD is projected in front of the steering wheel, not to bother the passenger with unnecessary information. The white text box can be disabled for those who have already familiarized with the different phases and what is expected at each phase. This makes the HUD even less intrusive. During manual driving, the HUD will fade away after some time as well, since the HMI is not relevant at this phase. Of course, other information can be displayed using the HUD at this phase, which is outside the scope of this report. When the user engages automated driving again, naturally the HUD will appear.

Iteration 4.5

This sub-iteration includes some minor adjustments to the fourth iteration, such as an improved integration in the car interior. This video (Bouman, 2020d) shows the improved design in action.

As can be seen in Figure 16, four white LED's on the steering wheel clarify what is expected from the user: taking the steering wheel and (gently) braking. Additionally, the infotainment screen fades away during the monitoring phase. This way the user is encouraged to look outside.

Figure 16: Four white LED's communicate the required action

User Research

The initial idea was to prepare different simulations and see what elements of an HMI contribute to a smooth control transition. The setup was to use a projector and a driver's seat to simulate a driving environment, and study, both quantitatively and qualitatively, different user responses. Since the campus is closed as of March 13th (Eindhoven University of Technology, 2020), I decided to conduct the user tests online instead.

Using a simulation of an interactive automated vehicle, I measure, amongst other things, the percentage of correct responses, and the reaction time. The interactive simulation is complemented with auditory feedback.

Considering the scenarios in Table 1, I focus on situation-related monitoring and take-over requests. This scenario is likely the most complex from a technical point of view, and therefore also interesting from a design point of view. For instance, the other categories ('End of automation zone' and 'Failure of sensors') are less ambiguous and easier to communicate to the user. It is the ambiguity of 'too complex' what interests me. What does it mean from a technical point of view, and how is this communicated to the user?

Scenario	Temporal criticality	Implication
End of automation scenario:		
Exiting highway	Low	take-over
Construction zone (map based)	Low	take-over
End of automation scenario (conditions)	Medium	take-over/monitor
Failure of sensors:		
Temporary loss of single sensor	Medium	monitor/non
Failure of single sensors	Medium	take-over/monitor
Failure of multiple sensors	High	take-over
Situation-related take-over:		
Map or V2X-based detection of limit	Low	take-over/monitor
On-board detection of system limit	High	take-over
Situation classified as too complex	High	take-over/monitor
Situation/object cannot be classified	High	take-over/monitor

Table 1: Take-over scenarios (Gold, Happee, & Bengler, 2018).

Considering cars with level 3 capabilities activated (SAE International, 2018), the driver can safely shift their attention away from driving tasks, and start doing something else. This is called the 'operational design domain'. The vehicle will handle situations that require an immediate response, like emergency braking (Gold, 2018). The driver, however, must still be prepared to intervene within some limited amount of time, when requested to monitor the vehicle or take over control. In this scenario, the user will be prompted to monitor first, and take over if necessary. In summary, the level of automation will decrease from 3 to 2, and the user decides whether a full take-over (back to level 1 or 0) is required. The scenario where a take-over request appears without an intermediate monitoring phase, will not be considered during the user tests.

SAE level	SAE name	SAE narrative definition	Execution of steering and acceleration/ deceleration	Monitoring of driving environment	Fallback performance of *dynamic driving task*	System capability (*driving modes*)	BASt level	NHTSA level
***Human driver* monitors the driving environment**								
0	No Automation	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a	Driver only	0
1	Driver Assistance	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes	Assisted	1
2	Partial Automation	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes	Partially automated	2
***Automated driving system* ("system") monitors the driving environment**								
3	Conditional Automation	the *driving mode*-specific performance by an *automated driving system* of all aspects of the *dynamic driving task* with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes	Highly automated	3
4	High Automation	the *driving mode*-specific performance by an *automated driving system* of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes	Fully automated	3/4
5	Full Automation	the full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**		

Figure 17: Automation levels, defined by the SAE (SAE International, 2018)

This course of action can be expressed by measurements of time.

$$t_{\text{take-over}} = t_{\text{first maneuver}} - t_{\text{take-over request}}$$
$$t_{\text{monitoring}} = t_{\text{eyes on route}} - t_{\text{monitoring request}}$$

However, a take-over may not be necessary. Therefore, both the scenario in which action is required and the scenario in which action isn't required should be considered.

Study Setup

Let's have a look at all simulations and scenarios that are required to successfully test the independent variables, i.e. response time, and percentage of correct responses. A correct response is defined as the same response a driving instructor would have had for a given scenario (take over control or not) within a certain time limit. All other responses are incorrect. These correct responses are verified with pilot participants.

All scenarios start with a monitoring request at some point, and may or may not require a take-over. This 'habituation' phase is to make sure that the participants cannot predict whether and when a take-over is required, and to create a realistic course of action. To account for random noise, a within-subjects study design is chosen (NN/g, 2018). This means that it is less likely that differences are significant between different simulations, since all the simulation conditions remain the same for a given participant. Additionally, the order of simulations is randomized, reducing a possible learning effect. To check whether participants pay attention, a sanity check will be conducted as well. This check tracks down false responses or ‘guesses’.

The user study also asks for the demographic background of the participants, as well as driving experience and possible accessibility issues. Lastly, a qualitative part at the end is included to give insights into the HMI in terms of usability, User Experience, and the overall impression. To this end, a standardized ‘Van der Laan-scale’ will be used (Van der Laan, Heino, & De Waard, 1997).

1 Useful I__I__I__I__I__I Useless
2 Pleasant I__I__I__I__I__I Unpleasent
3 Bad I__I__I__I__I__I Good
4 Nice I__I__I__I__I__I Annoying
5 Effective I__I__I__I__I__I Superfluous
6 Irritating I__I__I__I__I__I Likeable
7 Assisting I__I__I__I__I__I Worthless
8 Undesirable I__I__I__I__I__I Desirable
9 Raising Alertness I__I__I__I__I__I Sleep-inducing

Figure 18: Van der Laan-scale (Acceptance Scale)

To get as many responses as possible, the user test is promoted as a ‘game’ that tests your ability to operate automated vehicles. The results of the game will be shown only at the end, to reduce a possible learning effect.

The right answers are verified with two pilot participants who have a driver’s license and more than 20 years of experience. To make sure they honestly believe that the predefined answers are indeed the right answers, I told them that these answers are subject to discussion, and asked them whether they want to think along, avoiding pleasing behavior. Figure 19 shows which simulations have been prepared.

Simulations		Take-over required?	
	Independent:	True	False
Monitoring request:	with explanation	TW	FW
	no information	TN	FN

Times before monitoring request:
a) 12 seconds
b) 8 seconds
c) 4 seconds

Scenarios		Take-over required?	
	Dependent:	True	False
Took over?	True	I	III
	False	II	IV

Times until take-over required:
a) 12 seconds
b) 8 seconds
c) 4 seconds

Figure 19: Overview of simulations and scenarios

The independent variable in this setup is the presence of phase transition communication ('explanation') during a monitoring request, i.e. whether the improved HMI is shown or not. The first matrix shows that the independent variable is tested with the help of four kinds of tests. For each simulation, the time before the monitoring request and the time until take-over (as defined beforehand) are semi-randomized. Participants will watch a video and are asked to choose action **a) take over**, or **b) not take over**. Some scenarios require a take-over and others don't.

Let’s have a look at the scenarios (kinds of responses) one by one.

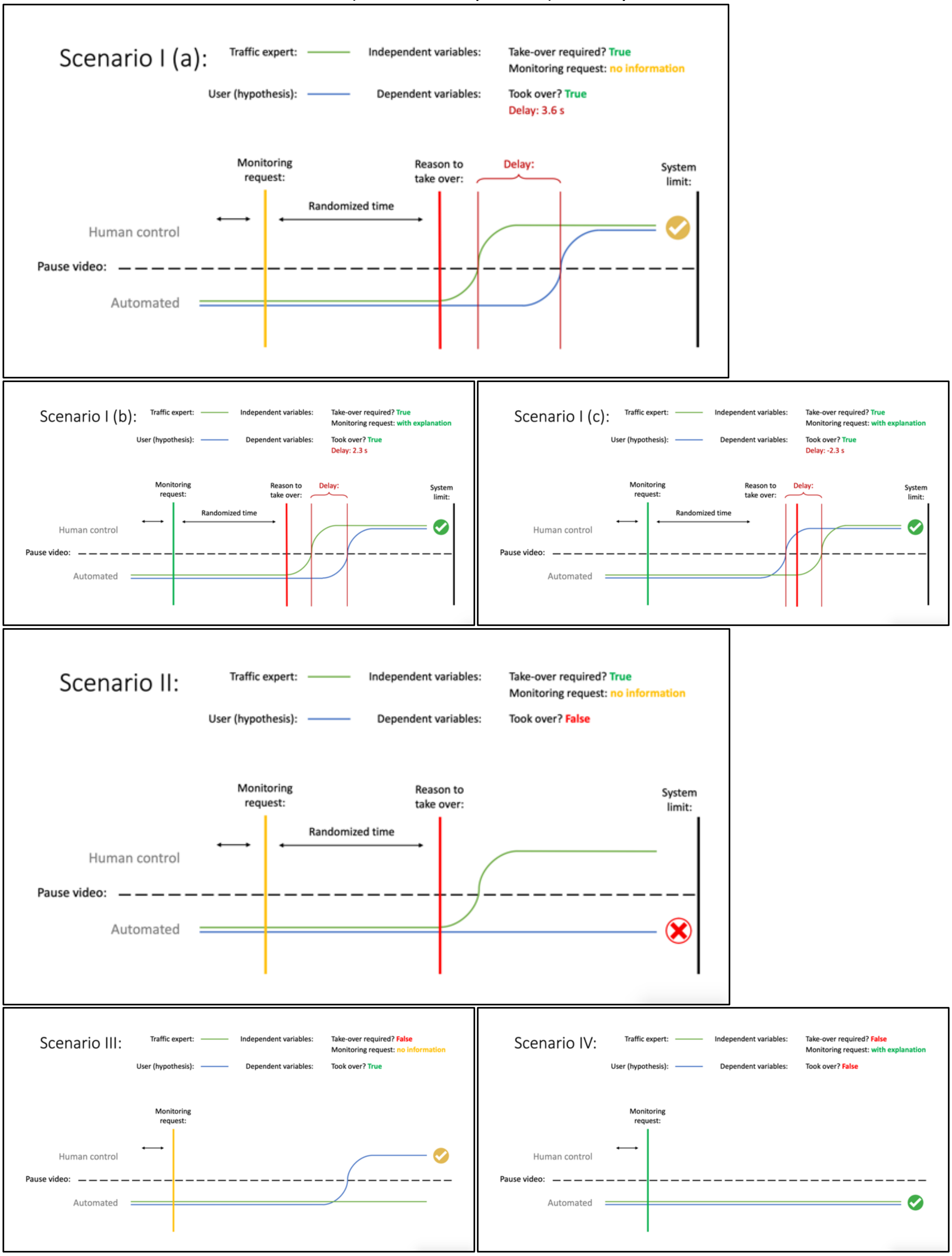

Figure 20: Overview of all scenarios

For each scenario the following is determined: a course of action by the user, and the ideal course of action by me (in collaboration with experienced drivers), whether take-over is required, whether 'phase transparency' is provided during the monitoring request, and how the delay is measured.

The desirability of a given scenario is expressed by either a check mark or a cross. As can be seen in Figure 20, Scenario II should be avoided, since in this scenario the user doesn't take-over, although a take-over is required. Scenario III illustrates a 'false' take-over; one that is not necessary. Scenario IV shows the case in which the user justly decides not to take over.

Considering Scenario I, courses of action (a), (b), and, (c) are depicted, showing the hypothesized effect of a monitoring request with either phase transparency or not. The delay marked in red is merely exemplary. Adding phase transparency should decrease the response time (b). This is to be verified. Scenario I (c) displays the case in which the user takes over before expected, effectively resulting in a negative delay.

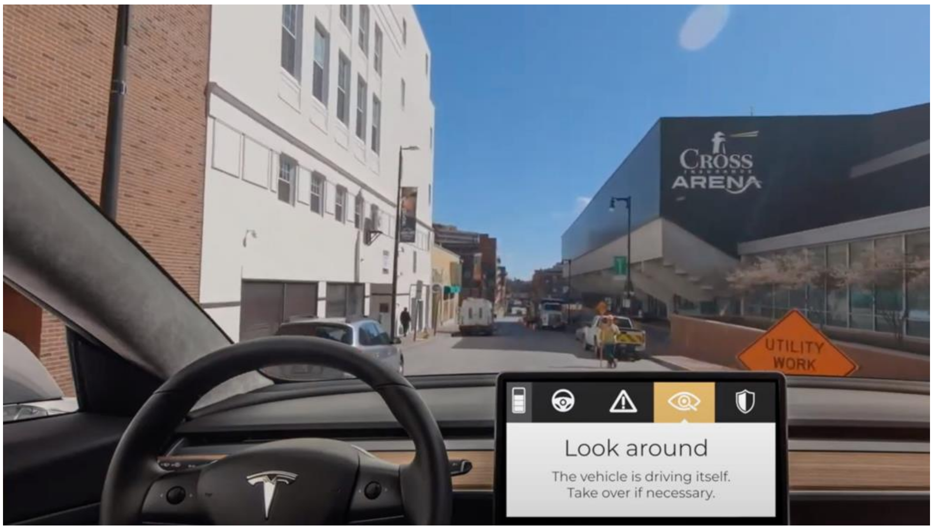

Figure 21: One of the six tests in which take-over is required

Experiment

The experiment includes 6 tests. Each test displays one of three simulations (Table 2) and one of two interfaces. One interface (first design iteration) aims to measure p_1, and another interface (final design iteration) aims to measure p_2; percentage of correct responses. The tests are displayed in a randomized order. This way, the learning effect when seeing a simulation for a second time, cancels out. Figure 21 shows one of the tests, in which take-over is required (simulation), and p_2 is tested. Each test evokes one of four scenario's (Figure 20), from which conclusions can be drawn. The main question is whether the improved interface increases take-over performance. A few questions after each test establishes the user's response time, confidence, and reasoning (Appendix A).

ID	Simulation name	Take-over required?	Reasoning
1	Construction work	Yes	In this scenario take-over is required, since the speed is too high considering the road works.
2	Truck middle of road	No	In this scenario take-over is not required, because the speed is fitting considering the space in front of, and next to the vehicle.
3	Stop sign	Yes	You are required to take over, because the stop sign is about to be ignored.

Table 2: Experiment simulations

Intermediate Step: UX Guerrilla Testing

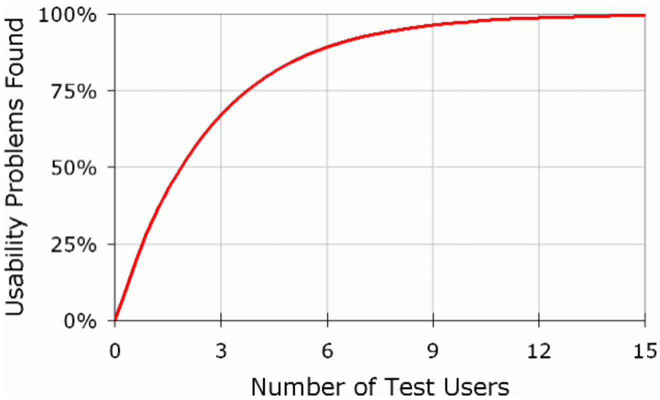

Figure 22: Five test users are sufficient to capture 80% of insights (NN/g, 2000)

As can be seen in Figure 22, testing with five participants already results in 80% of all qualitative insights. Therefore, I've chosen to test the HMI with this number of participants.

A UX Guerrilla test has been conducted with the third iteration (page 21). As can be seen in Table 3, the observations are not organized or statistically justified. Participants are all people who I can easily question, because they are friends and family. This limits the time needed to conduct the tests (Nielsen, 1994). All of these shortcuts are purposely taken, because the goal of this UX test is not to be very precise. It's a low effort and relatively simple testing method. A more precise study will follow.

I've shown the HMI to the users first, and then asked them to play around with it as well. Meanwhile, we informally talked about it. I collected interesting observations in Table 3. I haven't found critical usability issues during the testing, which allowed me to move on to the next iterative cycle rather quickly. I addressed interesting observations while designing the fourth iteration (page 22). The choice whether to do something with the feedback I collected, is based on personal preferences and experience.

User	Age	Positive observations	Possible improvements
1	21	"The information is clear and well-organized.", "The design looks very modern.", "The choice of colors is good."	"Perhaps the battery is important information as well.", "What happens when you don't take over?", "Maybe add some explanation the first time someone uses the system."
2	44	"I want this in my car now as well."	"I would prefer the screen directly above my steering wheel."
3	18	"The animations look cool."	"I would like to see the speed and battery percentage as well."
4	25	"This makes sense, because the speed is not needed when the car is driving itself."	"I have to turn my head though, if I want to see what mode I'm in.", "There is quite a lot of empty space."
5	59	"The colors are clear.", "The screen looks clear and uncluttered."	"It's not clear what buttons I can and cannot touch.", "What is the difference between monitoring and take-over?", "Do the modes change automatically?"

Table 3: Responses from UX Guerrilla tests

User Study Results

Participants

19 participants fully completed the tests, of whom 7 male, and 12 female. Most participants are between 18 and 25 years old (52.6%). Other age groups are represented as well, e.g. 56-65 years old (21.1%). One participant suffers from color blindness, but was not excluded from the experiment. No participants have other visual disabilities. All participants possess a driver's license. Both inexperienced (less than 5 years of experience) and experienced drivers (more than 10 years of experience) are included. Each group represents around 45% of participants. However, self-reporting suggests that 84.2% of participants are experienced drivers. Car ownership is around 58 percent. The average level of education is high, with 47,4% of participants holding a bachelor's degree or higher, and 100% holding a high school degree or higher. None of the participants had experience with automated vehicles, and two participants were familiar with SAE's levels of automation (SAE International, 2018). 47.4% of participants consider themselves technology-savvy.

Test results

The median amount of correct responses is 4 and the mean is 3.41 (max. 6). Around 26 percent of participants have no incorrect responses at all. 63.2 percent of participants have 4 or more correct responses. Only one test (sim 3; p_1) has more incorrect than correct responses (52.6% incorrect). Test II (sim 2; p_1) has the most correct responses (94,7%).

N = 19	p_1 (correct responses)	p_2 (correct responses)
Sim 1: Construction work (Take-over)	11 (≈58%)	12 (≈63%)
Sim 2: Truck middle of road	18 (≈95%)	15 (≈79%)
Sim 3: Stop sign (Take-over)	9 (≈47%)	10 (≈53%)

Table 4: Correct responses for each simulation

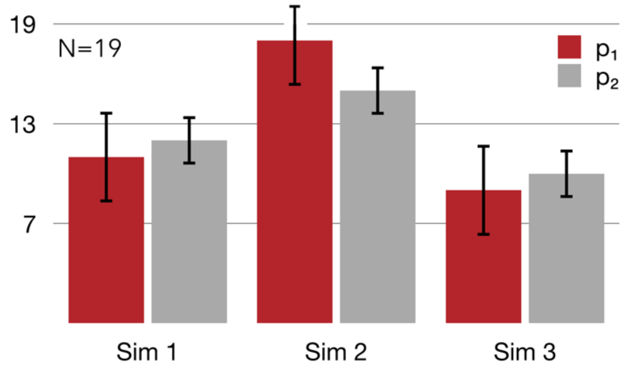

Figure 23: Correct responses without (p_1) and with (p_2) monitoring phase

The tests measuring p_2 perform marginally better (less mistakes) for two of the three simulations, which happen to be the simulations where a take-over is required (Table 4). This suggests that the HMI measuring p_2 stimulates take-overs (final design iteration).

As can be seen in Figure 23, p_2 is lower than p_1 for simulation 2, indicating that the null-hypothesis cannot be rejected. Additionally, margins of error are overlapping. This means that no significant difference is apparent based on Figure 23.

N = 19	μ_1 mean delay	μ_2 mean delay
Sim 1: Construction work (Take-over)	4.82 s	2.45 s
Sim 3: Stop sign (Take-over)	2.88 s	1.33 s

Table 5: Mean delay in response for Simulation 1 and 3

In Table 5 the mean delay (or 'response time') is calculated for each simulation in which take-over is required, using the data from the participants who correctly responded. The response time is calculated by subtracting the first time the reason to take over appears from the take-over times. As can be seen in Table 5, the take-over delays for tests measuring p_2 are lower.

A paired T-Test is conducted to compare μ_1 and μ_2 (Table 5) using delay as a performance measurement. The alternative hypothesis is a directional hypothesis: the delay is expected to be lower for μ_2. The resulting p-values for simulation 1 and 3 are 0.014 and 0.135 respectively. Using $\alpha = 0.05$ (publication confidence level) as a threshold, simulation 1 suggests a significant difference in delay. The alternative hypothesis is likely to be true considering simulation 1, but considering both simulations, the p-value equals 0.07.

There's no significant difference in take-over confidence (how certain are you that you've made the right decision?) with simulations measuring p_1 vs. p_2. The p-value equals 0.140 for a one-tailed homoscedastic T-Test, using the results of a five-point Likert scale.

Qualitative observations

Most participants indicated that they had difficulties with interpreting the traffic situation, because they do not know what situations the car is able to handle, and to what extent.

A common way of reasoning is (not) to take over based on the assumption that the car can or cannot handle an approaching situation:

> "I was not sure the car detected the stop sign."
> "I assumed the car saw 'slow' and is going to take care of it."
> "I think the car recognizes the sign."
> "Because the car went slow, so that felt for me like the car anticipated traffic at the place where you did not have a good view."
> "I expect the car not to recognize signs that are shown by road workers."
> "There was a traffic guard and an unusual situation upcoming, something that might not be interpret well by the self-driving car."
> "Because when I was at the intersection I could not see if there was traffic coming so I assumed the car did not either so I intervened to slow down the car."

Another category of reasoning regards apparent mistakes only when they happen:

> "The car missed a stop sign, I would take over to stop for this; otherwise I'd get a fine."
> "Crossing with difficult traffic situation and stop sign which was ignored by the car."
> "The car went to fast for the pedestrians that walked on the side of the road and the upcoming intersection."
> "I didn't see anything dangerous and I would have done everything the same as the car in the video."
> "Because there was an exit and the car went too fast to be sure if another car was coming."
> "I should have taken over, because the car did not come to a complete stop at the stop sign."

Others also indicate how they are influenced by the system (in line with the alternative hypothesis):

> "The car told me to pay extra attention and I did not know for sure what the bus would do."
> "Road works ahead. I was warned."
> "Warning from car system."
> "The car indicated it was aware of the road work ahead."
> "I would take over because the car mentioned that the 'situation cannot be classified', that sounds risky."
> "Because of the comment: situation cannot be classified."

A Van der Laan-scale (Acceptance Scale) has been included in the questionnaire to identify the stronger and weaker points of the HMI. Participants find the HMI ‘assisting’, with only one participant ranking it ‘neither worthless nor assisting’. All others give higher scores. The HMI is also to a large extend ‘raising alertness’ (15/19 participants agree), and is seen as ‘useful’ (18/19 participants agree). However, the interface is not very ‘likeable’, with only five participants qualifying it as ‘likeable’ or ‘very likeable’. All of this results in a ‘usefulness’ score of 1.44 on a scale from -2 to 2. This is equal to the average of all average scores for 1, 3, 5, 7, 9 (Figure 18). The satisfaction score is lower: 0.57. This is the average score of the remaining Likert scale questions (Van der Laan, Heino, & De Waard, 1997).

Conclusion

Research Question (RQ)

> Do driver take-over understanding and performance improve by adding a monitoring phase in-between full automation and a take-over request?

Insufficient quantitative evidence has been found to conclude that take-over understanding and performance are significantly higher when a monitoring phase is added (H_a: $p_1 < p_2$). The null-hypothesis (H_0) can therefore not be rejected based on these findings.

Only two of the three scenario's demonstrate better results with a monitoring phase, and for these scenarios, the percentages of correct responses have overlapping margins of error for p_1 and p_2. Response times show a slightly different picture. For all three scenarios the response times are lower with a monitoring phase included. However, the p-value of 0.07 is just above $\alpha = 0.05$ (publication confidence level).

There's no significant difference in take-over confidence (how certain are you that you've made the right decision?) with simulations measuring p_1 vs. p_2. The p-value equals 0.140 for a one-tailed homoscedastic T-Test, using the results of a five-point Likert scale.

However, the five design iterations, the UX test, and the qualitative user study indicate that a 'monitoring phase' is the right method from a design perspective. For instance, the standardized 'usefulness' score for the interface is high: 1.44 (on a scale from -2 to 2), and many participants indicate that decision-making is positively influenced by the HMI (Van der Laan, Heino, & De Waard, 1997; page 32).

In general, three types of user strategies can be identified with regard to the monitoring and take-over process:

1. based on the assumption that the car can or cannot handle a given approaching situation
2. based on apparent mistakes only when they happen
3. mainly reactive upon phase changes and system communication

These strategies are about equally common, based on the self-reporting of the 19 participants.

All in all, I recommend to further investigate the effect of adding a monitoring phase in-between full automation and a take-over request.

Usability

Although the study focused on a broader research question, some interesting usability points of improvement can be identified as well. For instance, one participant indicated that the battery icon looked like one of the phases at first, which caused confusion. This participant also indicated that he/she rarely looked at the interface, only during a transition. The traffic required all his/her attention. Thirdly, he/she had difficulties with understanding the icons, and suggested to add two 'hands' to the manual driving phase icon, to emphasize that you need to put your hands on the wheel during this phase. Overall, I was pleasantly surprised by the amount of valuable written feedback I received.

Another participant argued that the 'shield' icon implies that other phases are less safe, which is not necessarily true. But since only one participant indicated this, I didn't alter the icon.

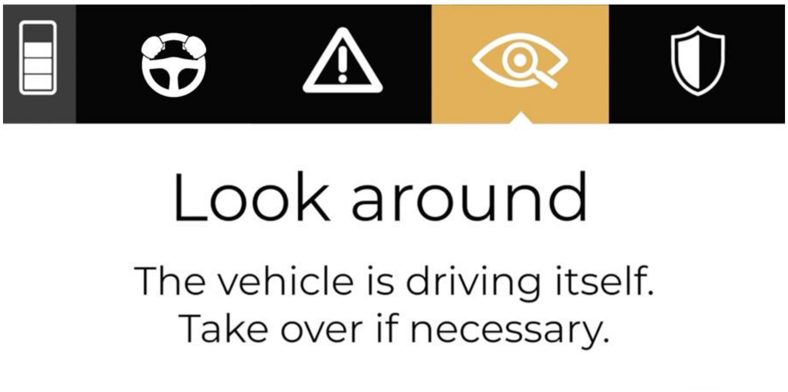

Figure 24: Icon ambiguity (with steering wheel) has been found relatively late

Take-away Messages

Small details can have a big impact on your design. Engaging with users early in the design phase helps to identify ambiguities early on. For example,
Figure 24 shows an icon redesign of the steering wheel, now including hands. A seemingly small design change actually makes the icon much clearer, especially next the other icons. It is now clear that the icon represents the user driving the car, whereas it previously could also have been interpreted as the computer driving the vehicle.

Many participants of the user test indicated that they had difficulties with understanding what de car is and isn't capable of. This is problematic, since this understanding is important for the decision-making process. It is uncertain if the difficulties with understanding are due to the study setup, or due to it being inherently difficult to make the right decisions within level 3 of automation (SAE International, 2018). It seems like level 3 is the trickiest from a design perspective, because you cannot fully divergent your attention away from driving, but at the same time you may get the impression you can. This is known as 'overtrust', and this certainly occurred during the experiment as well (Walker et al., 2018): "I assumed the car saw 'slow' and is going to take care of it," as indicated by one of the participants.

However, the slow sign was not an official sign, but just a flag with 'slow' printed on it. It is very likely the car did not recognize the sign. Thus, keeping the driver engaged is the key to safety.

Overtrust can also result in an 'automation surprise' (Carsten & Martens, 2018): "I should have taken over, because the car did not come to a complete stop at the stop sign." In this situation the automation of the vehicle makes the situation worse. Rather than improving the driving experience and safety, the vehicle fails to perform a task (stopping for stop sign), which is rather easy for a human to perform.

Design Recommendations

Isn't it wiser to not let the user give away control in the first place when giving back control to the user remains very difficult? Think about the pros and cons of implementing a self-driving (automated) system, compared to an assisting driving system. Is the user really better off with the option to give away control? Only if the answer is confidently 'yes', should the phase transitions as proposed in this report be implemented. There is also an ethical aspect involved: why would you give the user difficult monitoring and take-over tasks, if the benefits are not that obvious?

Can big data improve the HMI? During the experiment it became clear that mistakes were made at very similar locations. This suggests that specific parts of a road can be difficult to understand for the computer, and/or are difficult for the human to - jointly with the machine - handle. If for instance at a certain location many take-overs are executed, then this can be an interesting metric for further research and safety measures. Perhaps self-driving features should be disabled at this location using geofencing, and only be enabled again if the car manufactures have been able to solve the problem. An additional benefit of this approach is that the likelihood that self-driving features work, increases when this is supported by big data. For example, if a certain road is known to have very little take-overs, monitoring may at a certain point not be required anymore. This way, all vehicles on the road learn from each other.

Discussion

In general, I am pleased with the design and research outcomes. However, looking back at the results, some aspects are less than optimal.

Number of participants
19 participants participated in the user study, which results in an overall confidence interval of around 0.229 (1/√19), for $\alpha = 0.05$ (publication confidence level). To achieve a reliable margin of error (e.g. 0.05), almost 500 participants are required (Niles, 2006), which is not achievable considering the time given for the project.

Number of simulations
The number of simulations (3) is too low to make conclusions for a broader range of traffic situations. When conducing a follow-up study, it would be beneficial to include situations outside an urban area as well.

Simulation conditions
Since it wasn't possible to use the driving simulator at the campus, I used a video simulation. This is not optimal, because it is less engaging than a real driving simulator. For example, the speed is not displayed, because publicly available footage is used, which doesn't include the current speed. The perception of speed and distance may also be influenced by the simulations. Additionally, the video covers a smaller field of view, making the interface appear smaller than it is. This could have influenced the results. The experiment being video-based poses an additional limitation, since there is no physical risk for the participants. The desire to take over is perhaps lower than in a real car.

Randomization
The participants are not randomly selected. This can result in certain biases. For example, most participants are below 30 years, since most people I know are below 30. Perhaps the HMI works better for younger people, but when extrapolating to the entire population, the results could be less (or perhaps more?) in support of the alternative hypothesis.

Double-blind
Participants were not told when they were tested for p_1 or p_2. This is to avoid 'pleasing behavior': participants want to please the researcher by (subconsciously) implying that the alternative hypothesis is true. This phenomenon is known as the 'social desirability bias' (Krumpal, 2013). However, I was aware of the allocation of measurements to either p_1 or p_2 before the conclusion of the study, which hypothetically results in a bias. For example, during analyzing the quantitative part, I could have had more attention to finding indications that suggest that the alternative hypothesis is true. Additionally, another point of improvement entails sharing the methodology of the study before collecting results, to make sure that the methodology is not (subconsciously) fitted to the results, after the results have been collected (Lindsay, 2015).

Replicability
Since the user study touches elements of social sciences, replicability should be considered. Therefore, another independent body should replicate the study to see if the results remain the same (Schooler, 2014). Alternatively, the hypothesis is to be verified using multiple methods, instead of one, which is called 'triangulation' (Munafò & Smith, 2018).

Information asymmetry
Little people have experienced automated (assisting) vehicles in real life yet. Even fewer people are aware of the classifications by the SEA International (2018). Therefore, it is much harder for the general population to interpret the simulations compared to someone who is familiar with the technical limitations. This information asymmetry could have resulted in an inattentional bias towards a better understanding of the simulations and/or HMI than expected, since some participants of the study have their own project about automated vehicles and HMI.

Subjectivity of interpretation
I have defined the right courses of action for every simulation myself, and verified my interpretation of the traffic simulation with two pilot participants. This is not ideal, because I am not a traffic expert, neither are the first two pilot participants. However, the participants unanimously agreed with the right courses of action. To avoid socially desirable or dishonest answers, I haven't told the pilot participants that I myself defined the correct answers.

Epilogue

In this section the proposed HMI as well as overall developments in the field of automated driving are discussed with Richard Schram, Technical Director at EURO NCAP. The European New Car Assessment Programme (Euro NCAP) is a European voluntary car safety performance assessment programme (Euro NCAP, n.d.). Since 2019, Schram is Technical Director, overseeing test protocols currently in place, as well as the development of future requirements for both passive and active safety tests, and assessment protocols (EURO NCAP, n.d.).

Schram distinguishes two ways an active automated vehicle can reduce emerging external threats: a direct machine response or a (planned) take-over request. Both have very different characteristics. The first is analogous to existing safety features, such as Collision Avoidance Systems (CAS), and Autonomous Emergency Steering (AES), whereas the second is based on the notion that human cognition is not able to monitor automated driving performance sustainably, thus a take-over by the user is required. Simply requesting the user to keep an eye on the road, isn't sufficient. The human attention span is too limited for the machine to rely on.

These two events are collectively exhaustive and mutually exclusive. As long as car manufacturers cannot guarantee automation on a level that is sufficient to remove the steering wheel, implementing planned take-overs remains necessary. A take-over request occurs when the car is not confident enough that it can comfortably retain safety, i.e. without the need to engage CAS or AES. Naturally, CAS and/or AES will be engaged anyhow if human interference isn't achievable anymore in a timely fashion. Therefore, time is the determinant factor.

Assuming that this is the case suggests only three driving modes: the user is in control, the user collaboratively operates the vehicle, or the machine is in control. A mode in which the user is requested to monitor the machine is not inherently different from the user collaboratively operating the vehicle, since the outcome is the same: either the user or the machine reduces emerging external threats. A monitoring mode or phase isn't desirable for multiple reasons: overtrust, automation surprise, and cognitive limitations. It is unavoidable that at some point the machine's capabilities and the user's expectations are mismatched, potentially resulting in automation surprise; i.e. not understanding what the machine is capable of. Furthermore, monitoring the machine is not sustainable, since human attention will fade over time.

It is the manufacturers' responsibility to correctly define their driving features as either assisting, automated or autonomous. Currently, Euro NCAP has only tested vehicles that deliver assisting driving features, but automated driving features are currently in development. However, the word 'automated' implies that some form of responsibility is also transferred to the machine (i.e. the manufacturer). If manufactures are not willing to accept this, then the car is not truly automated yet, according to Schram. Automation is not meaningful if the user remains in control from a legal and/or theoretical perspective. Effectively, the machine is in this case still assisting the user, although perhaps quite extensively.

In the near future, partially automated vehicles will not offer additional safety benefits compared to traditional cars. The driving features that effectively result in higher safety, are not reliant on automated driving features. For instance, a Collision Avoidance System is engaged regardless of automated driving features being active or not.

Schram advocates an HMI that is collaborative in nature, as long as fully autonomous driving is not yet achievable. The reasoning behind this is twofold. Firstly, although the machine may sometimes drive safely, it may not always drive in the safest way. For example, a car in front of you drives behind a slow-driving truck. You are about to pass this car on the left lane. In this scenario the human driver understands that the car in front also wants to pass the truck, therefore lets the car in front pass the truck first. A machine however probably tries to overtake the car in front without waiting, since it isn’t capable (yet) of predicting the car’s course of action. As soon as the machine initiates passing the car in front however, the car in front initiates an overtaking maneuver as well. This results in the machine having to brake firmly, illustrating that although the situation is safely handled by the machine, a human driver can sometimes outperform the machine, at least considering current technology.

Secondly, programmed behavior can deviate from desired behavior. To illustrate this, consider the scenario in which a pothole on the road results in an unpleasant shock of the vehicle. A human driver would try to avoid the pothole by deviating a little bit from the center of the lane. The machine however remains centered. The actual desired behavior is when the human adjusts the path a little bit, the car returns to its original path shortly after. These two reasons explain why an HMI should remain collaborative in nature, also if the machine is able to drive safely.

In conclusion, although a machine may be capable of driving safely in many scenarios, it is still wise to design the HMI in such a way that it is assisting to the user, partially because the user may otherwise overtrust, misinterpret or ignore the machine, and partially because an automated system may not necessarily result in increased safety and/or comfort.

This interview has been edited and condensed for clarity. Interview questions can be found in Appendix C.

PDP Goals Reflection

At the start of this project I've defined five SMART goals (page 12; Doran, 1981). In this section, I discuss to what extend I've reached my goals.

User & Society
I've conducted multiple user tests, both formally and through guerrilla UX tests (Nielsen, 1994). A total of five UX Guerrilla tests were carried out (page 31), as well as a study with 19 participants (page 32). I consider this goal fully reached.

User & Society
I've stated that I want to analyze how not having to drive your car all the time may introduce new opportunities and challenges from both a technical and societal perspective. Technological advancements and societal changes go hand in hand. What does this mean for the proposed interface? I have to some extend considered broader societal implications of new technology, by paying attention to accessibility (page 22) and cross-cultural differences in for example reading direction (page 18). However, I haven't discussed what not having to drive your car means for society. In retrospect, this goals might be outside the scope of my project. However, for fair measurements, I consider this goal partially reached.

Technology & Realization
I've conducted multiple (4.5) iterative cycles in pursue of a better HMI, based on the outcomes of the preceding iterations and the user tests. This goals has been reached.

Math, Data, & Computing
I've worked as a student assistant for the course Data Analytics for Engineers. This has given me a deeper understanding of data analytics. This goal has been reached.

Creativity & Aesthetics
I've designed two new websites: sentielwatches.com (e-commerce initiative) and nijsbouman.com (portfolio). I've experimented with different tools, explored various UI-elements, icons, text elements, audio, and looks & feels. Each iterative cycle has been started with a brainstorming session. This goal has been reached.

In summary, four of the five goals are achieved, and one goal is partially reached.

Reflection

This project has taught me a lot, both in relation to my development as a designer, as well as in relation to my professional identity. In this section, I reflect upon my personal and professional development, and relate this to my goals, growth in expertise areas, attitude, skills and knowledge, and learning outcomes. To conclude this section, I look back on my years at the TU Eindhoven, and take a look into the future.

This was my first design project that I did by myself, and I didn’t enjoy this particular aspect of the FBP. I have already learned that I prefer working in teams. For this reason I discontinued my web design business (Bouman Design, 2019) and started working more in a team (Sentièl Watches, 2020). This view has now been endorsed. You have much less resources and brain power working alone, which makes it less enjoyable. Additionally, working in a team forces you to continually rethink and discuss, which comes less natural working alone. Problems also feel less like problems, because you’re not the only one having the problem. This has taught me a valuable lesson: I am the kind of person that functions best in teams, provided that the team members actually bring something to the table.

Figure 25 demonstrates the effect of my Final Bachelor Project on the development of expertise areas (quantitative estimation). I have added a horizontal line to indicate what I think would be considered a good level of competence at the end of my Bachelor. I believe that I have reached a sufficient level of competence across all areas of expertise.

Notably for Business and Entrepreneurship (B&E) and Design Research Processes (DRP), I’ve surpassed the required level by a large margin. My Professional Identity and Vision (PI&V) is still something I find difficult to define. However, I’ve made improvements, since I have found a common denominator across my work: my preference for application-driven design, as well as team work. I enjoy seeing a design come to life, from its earliest sketches, explorations, in-depth research, to its final touches and market introduction. Furthermore, I am better able to distinguish critique on my work from critique on me as a designer. Seeing critique as opportunities for your design is the right mindset.

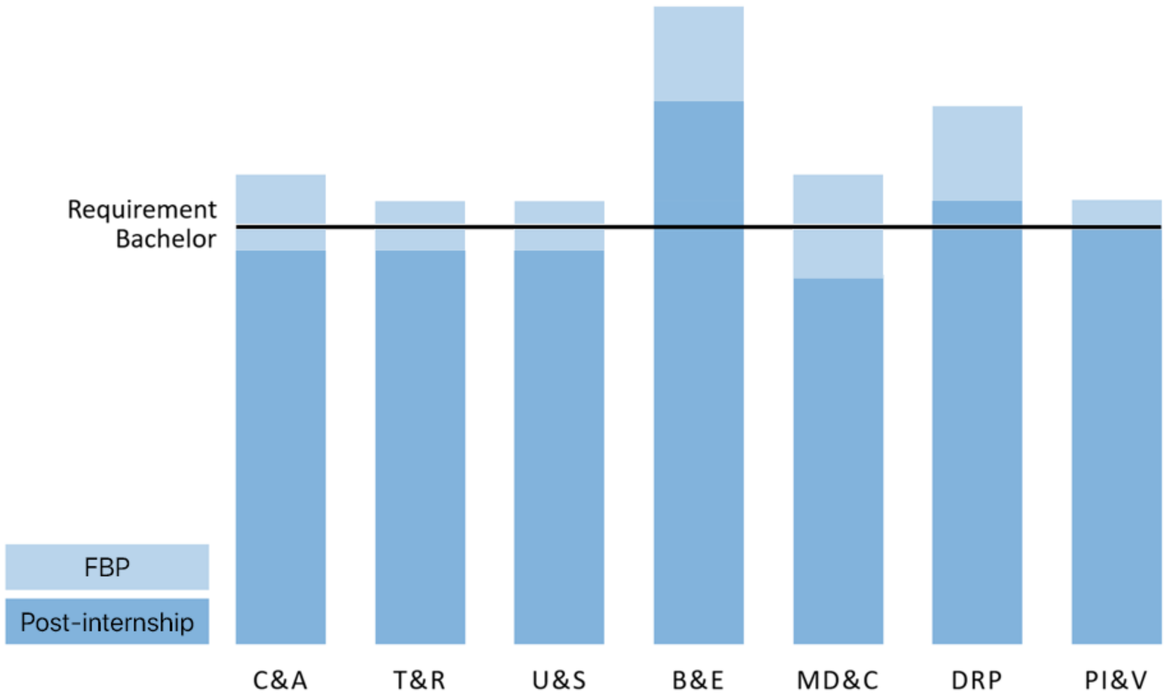

Figure 25: Expertise Area development during final Bachelor semester

With regard to MD&C (Figure 25), I've done a student assistant job for the course Data Analytics for Engineers (TU/e), which helped me to refresh and deepen my knowledge, as well as my tutoring skills.

I've learned new tools to create prototypes (page 21), which explains my growth in Technology and Realization (T&R). Still, I was hoping to bring the digital prototype to the physical world, for example using a car simulation, or an actual car. This is why my growth remained limited compared to for example for B&E.

The iterative cycles during this project show functional improvements, as well as aesthetic improvements. However, I am not fully satisfied with the looks. Although the final prototype looks nice, I wasn't able to transfer my personal design style, as can been seen across my websites (nijsbouman.com, 2020; boumandesign.nl, 2019; sentielwatches.com, 2020; fotografie.tips, 2020). On the other hand, I've used the power of iterative designing to come up with clever and creative solutions, building strongly on the creative design process. I therefore consider my growth in C&A to be intermediate.

As addressed before (page 43), through different user tests (page 31) and a user study (page 32) I have been able to improve my ability to learn from users. However, the societal aspects of designing are not very articulate during this project. I have addressed why designing the proposed HMI is relevant (page 25), and how the proposed HMI fits in the transition towards automated driving (page 13).

The study setup (page 26) and discussion (page 39) demonstrate that I am aware of good practices in scientific research. The execution of these practices can be improved. From a statistics point of view, the user study is insufficient, but from an exploratory point of view, the user study is a success. I've experienced to run an experiment on my own, and I've learned a great deal in the process. I now have a better understanding of hypothesis testing, and how the hypothesis relates to the study setup. With regard to the design process, I have successfully designed 4.5 iterations, each building on the preceding iteration, and growing knowledge.

One point of improvement is the involvement of third parties in my project. Looking back on my process, big influencers are my coach, the participants, and fellow students. Adding an additional perspective, for example from a field expert, could have improved the design process. However, in the epilogue (page 41), I discuss my HMI proposal with Richard Schram, a field expert.

Extracurricular
I've co-founded my second company, Sentièl Watches, which is about to launch its first product line-up (Sentièl Watches, 2020). Additionally, I've written papers on this topic (Bouman, 2019; 2020). Furthermore, I have followed the track 'Technology Entrepreneurship', with grants an additional certificate on my diploma. Meanwhile, I work as a freelance web designer (Bouman Design, 2018). My interests heavily lean towards entrepreneurship, and product development in relation to business viability. Consequently, my development in this area is higher than in other expertise areas.

Strategic Product Design
At the time of this writing, I am strongly considering pursuing a master's degree at Delft University of Technology. The master program 'Strategic Product Design' has my interests, because it focuses more on the business side of design compared to the TU/e master for Industrial Design. An upcoming online event (2020, June 11) will tell me more about this master, as well as the differences between other TU Delft master programs and the TU Eindhoven master program.

Bachelor at TU Eindhoven
Having followed over 25 courses and projects, conducted an internship (Bouman, 2019), and of course the Final Bachelor project, has been a valuable learning experience. The educational setup at the TU/e is well thought-out. All the collaborative projects also improved my collaboration skills. However, the master program presentation hasn't convinced me to stay in Eindhoven. It seems too similar to the Bachelor program, although more in-depth.

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Appendix A: Questions after each of the six tests

Did you take over? * 1 punt

- ◯ Yes
- ◯ No

If so, when did you take over?

Tijd

__ : __

Why have you decided (not) to take over?

Jouw antwoord

How certain are you that you've made the right decision? *

	1	2	3	4	5	
Very uncertain	◯	◯	◯	◯	◯	Very certain

Appendix B: Ethical Review Form

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Ethical Review Form

(Version 27.06.2019)

This Ethical Review Form should be completed for every research study that involves human participants or personally identifiable data and should be submitted before potential participants are approached to take part in the research study.

Part 1: General Study Information

1	Project title and project number	Designing Phased Transitioning of Control in Highly Automated Vehicles - DFP006 Adaptive Mobility
2	Researcher name and email	N. L. J. Bouman, n.l.j.bouman@student.tue.nl
3	Supervisor	Prof. dr. M. H. Martens
4	Faculty/department	Industrial Design
5	Research location	At home - online
6	Research period (start/end date)	2020/05/22 - 2020/06/03
7	Funding agency	n/a
8	[If Applicable] Study is part of an educational course with code:	DFP006
9	[If Applicable] Proposal already approved by external Ethical Review Board: Add name, date of approval, and contact details of the ERB	n/a
10	Short description of the research question	Do driver take-over understanding and performance improve by adding a monitoring phase in-between full automation and a take-over request?
11	Description of the research method	Survey Design and Randomized Experiment
12	Description of the research population, exclusion criteria	People known by the researcher (friends, family) who are in possession of a driver's license.
13	Description of the measurements and/or stimuli/treatments	Participants will watch a video and are asked to choose action a) take over, or action b) not take over. Some scenarios require a take-over and others don't.
14	Number of participants	At least 10
15	Explain why the research is socially important. What benefits and harm to society may result from the study?	A better understanding of transitioning of control in highly automated vehicles may results from this study. No harmful impacts on society are expected or foreseen.
16	Describe the way participants will be recruited	People known by the researcher (friends, family) will be causally asked to participate due to Corona and the impossibility to run an experiment with participants at the TU/e.
17	Provide a brief statement of the risks you expect for the participants or others involved in the research or educational activity and explain. Take into consideration any personal data you may gather and privacy issues.	The only risk is violation of privacy and/or anonymity. Steps are taken to avoid these risks. All data gathering is compliant with GDPR and the reporting of the results will be done in an anonymous manner.

Part 2: Checklist for Minimal Risk

	Yes	No

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Ethical Review Form

1	Does the study involve participants who are particularly vulnerable or unable to give informed consent? (e.g. children, people with learning difficulties, patients, people receiving counselling, people living in care or nursing homes, people recruited through self-help groups)		X
2	Are the participants, outside the context of the research, in a dependent or subordinate position to the investigator (such as own children or own students)?		X
3	Will it be necessary for participants to take part in the study without their knowledge and consent at the time? (e.g. covert observation of people in non-public places)		X
4	Will the study involve actively deceiving the participants? (e.g. will participants be deliberately falsely informed, will information be withheld from them or will they be misled in such a way that they are likely to object or show unease when debriefed about the study)		X
5	Will the study involve discussion or collection of personal data? (e.g. name, address, phone number, email address, IP address, BSN number, location data) or will the study collect and store videos, pictures, or other identifiable data of human subjects?. Please check the FAQ's on the intranet. If yes: please follow the procedure. Make sure you perform a Data Protection Impact Assessment (DPIA) and make a Data Management Plan if necessary and let the data steward check it. Please attach these documents with this form (see part 5; enclosures)	X	
6	Will participants be asked to discuss or report sexual experiences, religion, alcohol or drug use, or suicidal thoughts, or other topics that are highly personal or intimate?		X
7	Will participating in the research be burdensome? (e.g. requiring participants to wear a device 24/7 for several weeks, to fill in questionnaires for hours, to travel long distances to a research location, to be interviewed multiple times)?		X
8	May the research procedure cause harm or discomfort to the participant in any way? (e.g. causing pain or more than mild discomfort, stress, anxiety or by administering drinks, foods, drugs)		X
9	Will blood or other (bio)samples be obtained from participants (e.g. also external imaging of the body)?		X
10	Will financial inducement (other than reasonable expenses and compensation for time) be offered to participants?		X
11	Will the experiment involve the use of physical devices that are not 'CE' certified?		X

Important:
If you answered all questions with ''no'', you can skip parts 3 - 4 and go directly to part 5. Check which documents you need to enclose and continue with signature and submission.

If you answered one or more questions with "yes", please continue with parts 3 – 5.

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Ethical Review Form

Part 3: Study Procedures and Sample Size Justification		
1	Elaborate on all boxes answered with “yes” in part 2. Describe how you safeguard any potential risk for the research participant.	All data will be deleted after the project is finished. The data will not be traceable to individuals.
2	Describe and justify the number of participants you need for this research or educational activity. Also justify the number of observations you need, taking into account the risks and benefits	

Part 4: Data and Privacy Statement		
1	Explain whether your data are completely anonymous, or if they will be de-identified (pseudonymized or anonymized) and explain how.	
2	Who will have access to the data?	Only the researcher will have access to the data. The data will be deleted after the project has been finalized.
3	Will you store personal information that will allow participants to be identified from their data? See VSNU draft.	☐ No ☒ Yes, and I declare I will follow the general data protection regulation (GDPR).
4	Will you share de-identified data (e.g., upon publication in a public repository)?	☒ No ☐ Yes, and I will inform participants about how their data will be shared, and ask consent to share their data. I will, to the best of my knowledge and ability, make sure the data do not contain information that can identify participants.

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Ethical Review Form

Part 5: Closures and Signatures		
1	Enclosures (tick if applicable): ☒ Informed consent form; ☐ Informed consent form for other agencies when the research is conducted at a location (such as a school); ☐ Text used for ads (to find participants); ☐ Text used for debriefings; ☐ Approval other research ethics committee; ☐ The survey the participants need to complete, or a description of other measurements; ☐ Any other information which might be relevant for decision making by ERB; ☐ Data Protection Impact Assessment checked by the privacy officer ☐ Data Management Plan checked by a data steward	
2	Signature(s) Signature(s) of researcher(s) Date: 22-05-2020 Signature research supervisor Date:	Nijs Bouman

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Ethical Review Form

PLEASE READ THE FOLLOWING INFORMATION CAREFULLY:

Participation:
Participation is voluntary. It is your own choice to participate. You can withdraw from the questionnaire and test environment at any moment, without stating your reason. Your data will be processed anonymously.

Risk:
The study does not involve any risks or detrimental side effects.

Duration:
The questionnaire and test will last around 10-15 minutes.

Confidentiality:
This questionnaire will collect personal data. Your responses will be saved anonymously, and are not traceable. The collected data will be analysed in a confidential way. The information that is collected for this study is used for writing a graduation thesis, and designing a car interface. By participating in this study you provide consent to such use of your data. This questionnaire complies with GDPR legislation.

If you have any questions regarding the conduct of this study, please send an email to Nijs Bouman (n.l.j.bouman@student.tue.nl).

The online test and corresponding questionnaire are conducted by:

Eindhoven University of Technology
Department of Industrial Design
Building 3, Atlas South
P.O. Box 513
5600 MB Eindhoven

This study is part of the graduation project of Nijs Bouman.
Supervision: prof. dr. Marieke Martens.

5

Appendix C: Interview Questions Richard Schram

Level 3 of automation implies that you don't have to keep your eyes on the road. Do you think that this is a feasible scenario in the near future?

It will take many more years to achieve level 5 of automation. In the meantime, lower levels of automation will be available. Do you believe that adding a 'monitoring phase' can improve car safety?

Accidents have occurred, for example with Tesla's, where drivers falsely believed that the car was in control. Mode confusion is perhaps what caused these accidents. Can displaying modes more clearly reduce these kinds of accidents?

Should the car user always know what the car can and cannot handle, or it this something that the car should communicate to the user when the car requires assistance?

Will future cars have transition phases, as proposed with the final design (Figure 16)?

Euro NCAP also assesses the car interface, when determining the car's safety rating. To what extend is the interface determinate for the final rating?

How is Euro NCAP going to assess the HMI?

As cars become more and more safe, do you believe that software/HMI will be the driving factor for car safety?

From a human factor's perspective, will people have the discipline to scope with everything a car urges the user to do, although no imminent treats are present?