Design of

Control Transfer Rituals

for Automated
Vehicles

Automotive HMI & Interior
Design

Delft July - December 2020

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> “Added
> **complexity and difficulty**
> cannot be avoided when functions are added, but with
> **clever design**
> they can be minimized”
>
> \- Donald Norman

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Mediator

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ABSTRACT

In 1886, humanity started a great effort to move away from horseback and build a carriage over which they have full control. A century-and-a-half later, we have succeeded to the degree that we are looking for a way to relax in our automobiles. The MEDIATOR project tackles the transitional period between conventional automobiles and fully autonomous vehicles.
The challenge that arose with this transition is that the vehicle has to be designed for both driving and not driving. This graduation project tackles the very bit that most people will get to know: how to interact with the machine to divide the power of control? And how do we keep re-establishing that balance?

The act of changing control between the human driver and the automation as a driver is to perform a Control Transfer Ritual. With little collected information, this project started with an intensive 45 days of gathering information about interaction between man and machine. The knowledge in fields of feedback, automation levels, input possibilities, legislation, and acceptance by all parties involved combined formed the basis upon which the Control Transfer Rituals were designed.

The Control Transfer Rituals differ based on urgency of the situation, the target and original level of automation , and, in case of MEDIATOR, who instigated the transfer. This led to the development of a total of eleven distinctly different Control Transfer Rituals, and the exploration of Minimal Risk Manoeuvres.

To validate the effectiveness and usability of these designed rituals, a simulator was developed. This simulator uses the C,MM,N prototype vehicle as a base and consists of a dashboard, with integrated controls, a virtual environment built in Unity, and a dummy Decision Logic, the computing unit of the MEDIATOR project.

The prototype allows people to experience how travel will be in the not so distant future. Furthermore, the MEDIATOR project will be able to use it as a base for oncoming development, to ensure that your future travels will be ever more comfortable and safe.

To whom it may concern, I hope this report finds you in good health and inspires you to look ahead.

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Introduction

This chapter gives an overview of why this project was conducted and in what context (figure 1). Furthermore, the basic fundamentals of vehicular automation and the design of a vehicular Human-Machine Interface are explained.

Objective and scope

Project objective

The design objective of this graduation project was to create and communicate the necessary Control Transfer Rituals (CTRs) needed for switching between automated driving levels in automated vehicles. These designed CTRs are the direct result of the functional requirements, which will also be used by the international consortium working on the MEDIATOR project.

Accompanying this report is a simulator in which these Control Transfer Rituals can be tested and evaluated. Furthermore, this will create an environment in which the experiences of these Control Transfer Rituals can be communicated in an interactive and insightful manner.

The research objective of this report was to aid the MEDIATOR project by determining the functional requirements of the design of Control Transfer Rituals. These functional requirements represent a part of the guidelines for the Human-Machine Interface, which in turn can be used in further stages of the MEDIATOR project to create rules for automated vehicle development in the European Union.

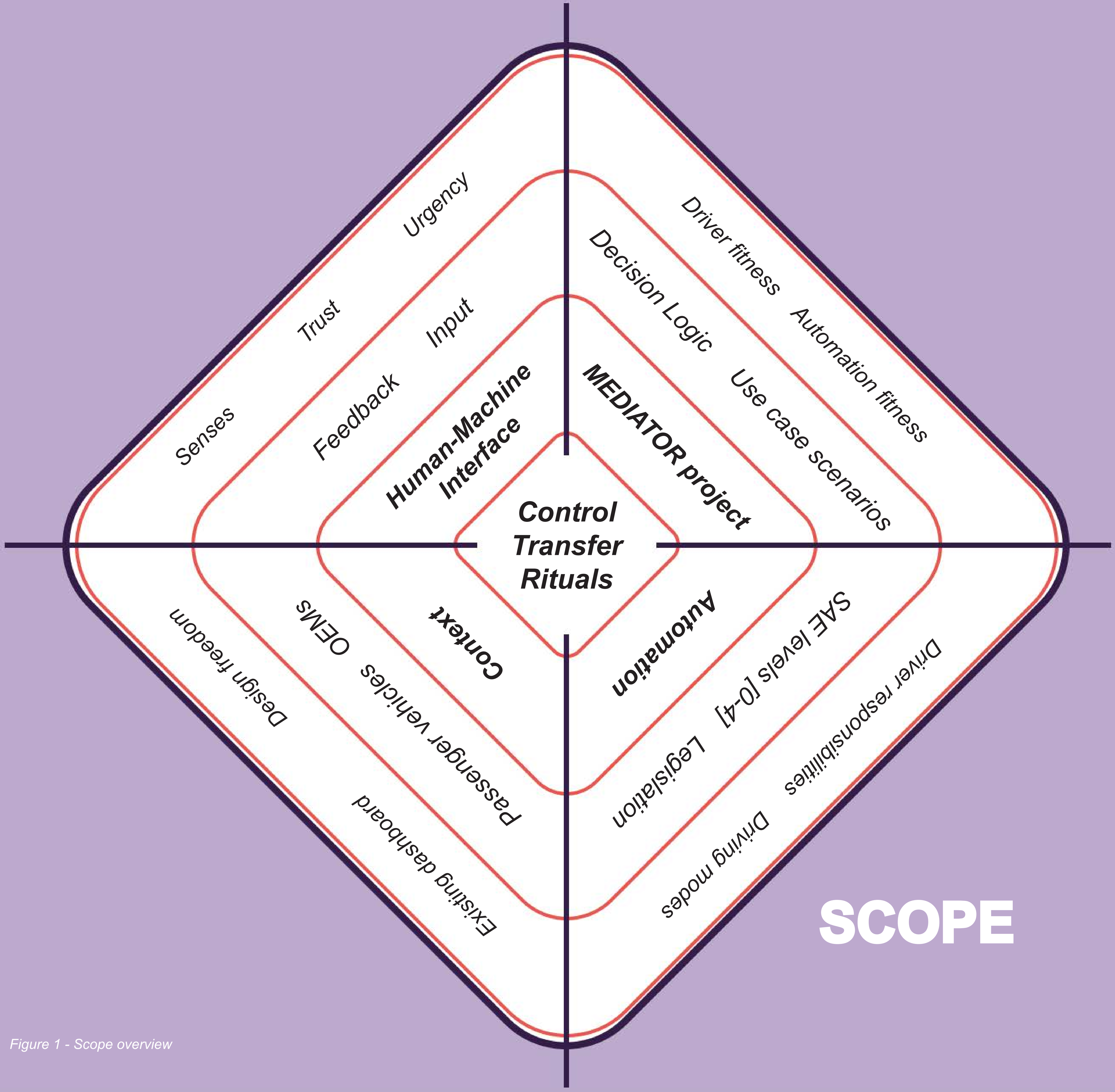

Figure 1 - Scope overview

Current structure

The European Union has started a program to regulate automated vehicles on public roads under their Horizon 2020 research and innovation program: Project MEDIATOR, which is funded under grant agreement no. 814735 (MEDIATOR, 2020). An international consortium coordinated by SWOV is building a way to safely and in real-time switch between a human driver and an automated system based on who is most fit to drive. The project name, MEDIATOR, is an abbreviation for "*Mediating between Driver and Intelligent Automated Transport systems on Our Roads*".

The vision of the MEDIATOR project is to optimise the safety potential of vehicle automation during the transition to full (level 5) automation. The system will aim to reduce risks, such as those caused by driver fatigue or inattention, or on the automation side's imperfect automated driving technology (*figure 2*). Furthermore, MEDIATOR will facilitate market exploitation by actively involving the automotive industry during the development process. To accomplish the development of this support system, the MEDIATOR project will integrate and enhance existing knowledge of human factors and HMI, taking advantage of the of expertise in other transport modes (aviation, rail, and maritime). It will develop and adapt available technologies for real-time data collection, storage and analysis and incorporate the latest artificial intelligence techniques, such as deep learning.

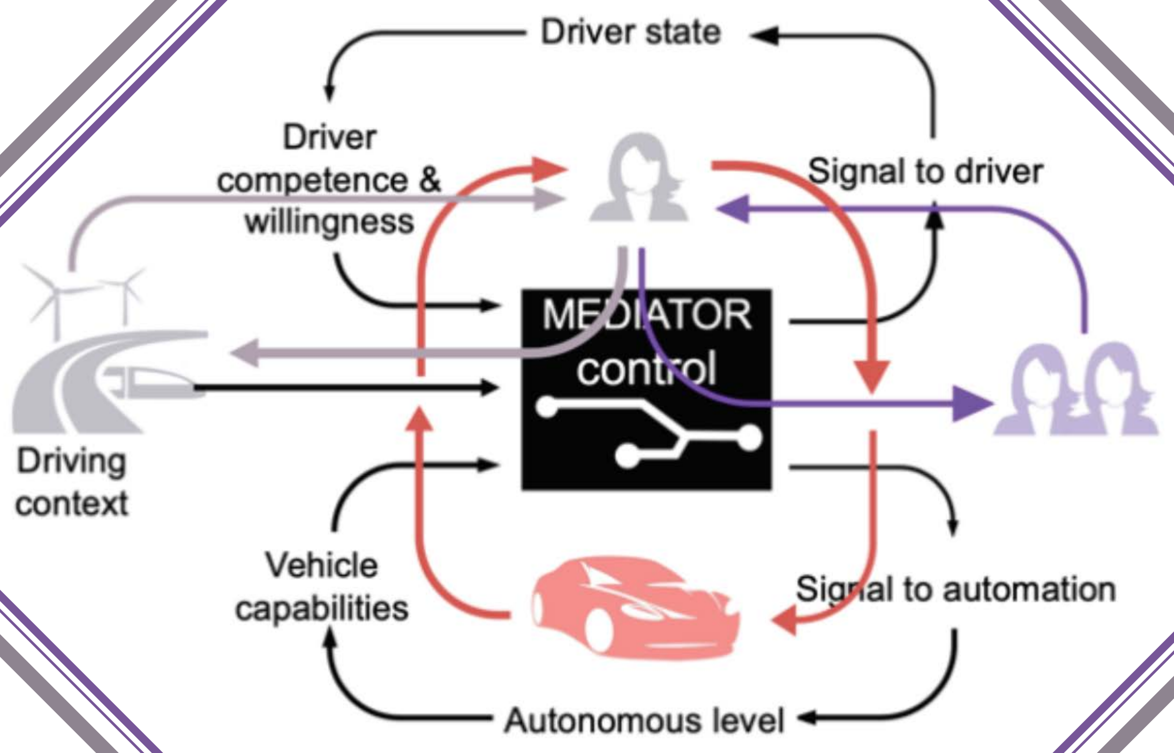

Figure 2 - The global idea of the MEDIATOR system

> **"To intelligently assess the strengths and weaknesses of both the driver and the automation and mediate between them, while also taking into account the driving context."**
>
> **— MEDIATOR project objective**

Within the international consortium, the Technical University Delft is responsible to establish a base upon which Original Equipment Manufacturers (OEMs) can build their own Human-Machine Interface (HMI). This HMI needs to be engineered to communicate the values generated by the Decision Logic, the calculator of risk, efficiency, and fitness, to the human driver. The Decision Logic decides, based on context, who is most fit to drive.
Furthermore, the HMI should allow the driver to interact with the Decision Logic, mainly through the selection of automated driving level. However, the Decision Logic can limit the driver through the HMI to a certain level or range of levels of automated driving.

As mentioned before, this report reflects a segment of the total HMI research, one that tries to understand the interaction of the human driver with the HMI during a switch between levels of automation. This does not include the assessment of driver fitness for either human or automation nor the design of the Decision Logic. This report is strictly limited to filling knowledge gaps in the transfer of control. Thus assessing how the human driver will interact with the HMI to engage automated driving modes and how the HMI will react to the human driver when switching automated driving modes.

Furthermore, definition is needed on how the HMI informs a driver of an upcoming control transfer, one where the Decision Logic determined that the human is most fit or most unfit to drive and how to elicit appropriate driver attention throughout the control transfer.

To answer to these knowledge gaps, Control Transfer Rituals (CTRs) are to be determined. These lay the foundation to the interactions needed to switch modes. As for all segments of MEDIATOR, the CTRs will ensure safety, sustainability, and comfort.

HMI challenges

In Table 1, the identified HMI related challenges and functional requirements of the MEDIATOR system in D1.1 are shown. The scope of this graduation project will solely focus on three aspects of the table which are inherently intertwined with the design of Control Transfer Rituals: Trust, User acceptance, and Industry acceptance. The accompanying challenges were identified as:

1. Elicit trust that the MEDIATOR system informs the driver in time
2. Elicit trust that a forced take-over by automation was justified.

However, more challenges can be identified regarding the design of Control Transfer Rituals:

- Communicate that a level of automation is unavailable,
- Evoke the correct response to a Take Over Request (TOR),
- Allow the human driver to engage automation in an unambiguous yet uniform manner,
- Elicit trust that the selected level of automation, if deemed available by the MEDIATOR system, will engage
- Allow OEM design space within a set boundary.

This number of challenges aid in the definition of the scope. Furthermore, they function as a foundation to define safe and comfortable Control Transfer Rituals that are accepted by both the industry and the user-base.

Challenge	Functional requirements							
	Transfer control automation to human			Transfer control human to automation		Within driving mode		
	Improve human fitness	Voluntary take-over procedure	Forced take-over procedure	Voluntary take-over	Forced take-over	Improve/maintain human fitness	Maintain trust, comfort, transparency	Establish shared control
Trust	1		2	🟨	3		🟨	🟨
Mode awareness						4		4
Fatigue	🟨	5	🟨		🟨	🟨		
Distraction	🟨	5	🟨			6		
Information load	🟨		🟨	🟨		🟨	🟨	🟨
User acceptance	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨
Industry acceptance	🟨	🟨	7	🟨	7	🟨	🟨	🟨
Learning		🟨	🟨	🟨	🟨			🟨
Unlearning		🟨	🟨					

Table 1 - HMI challenges as defined in MEDIATOR deliverable D1.1

SAE levels

To get a grasp on the responsibilities of the MEDIATOR project and its sub-projects it is vital to understand the different levels of automated driving and its implications. As of 2018, SAE International issued “a taxonomy with detailed definitions for six levels of driving automation, ranging from no driving automation (level 0) to full driving automation (level 5)” (SAE, 2018). Within the scope of this research lie no-automation driving level 0 through to highly-automated driving level 4 (hereafter also referred to as “SAE level [...]”) (figure. 3).
Important to realize is that not only the levels of automation are defined, but also the responsibilities. Though SAE does not impose requirements on driving automation systems, these values will be used as guide to discuss the levels of automation.

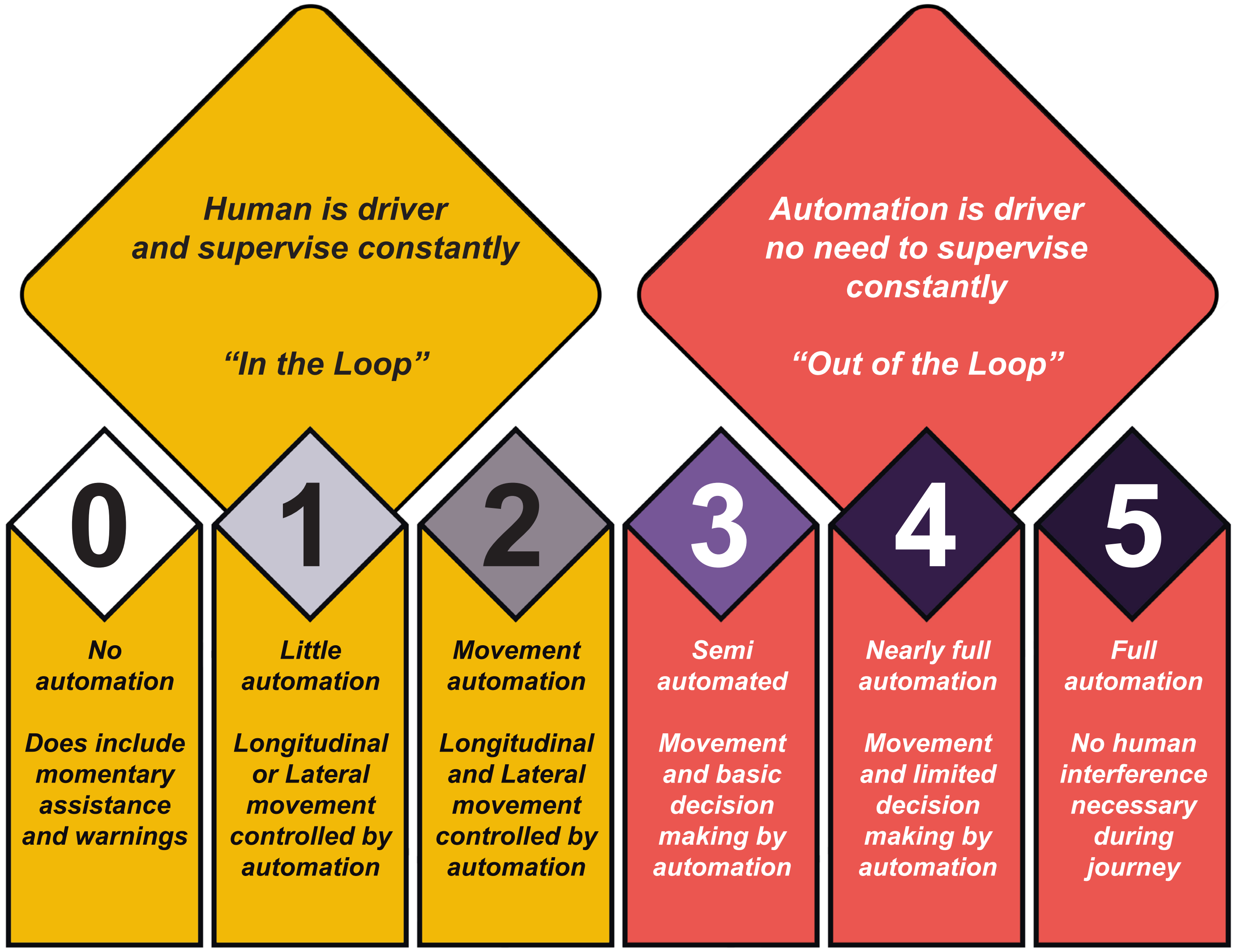

Figure 3 - SAE J3016: SAE Automation levels defined

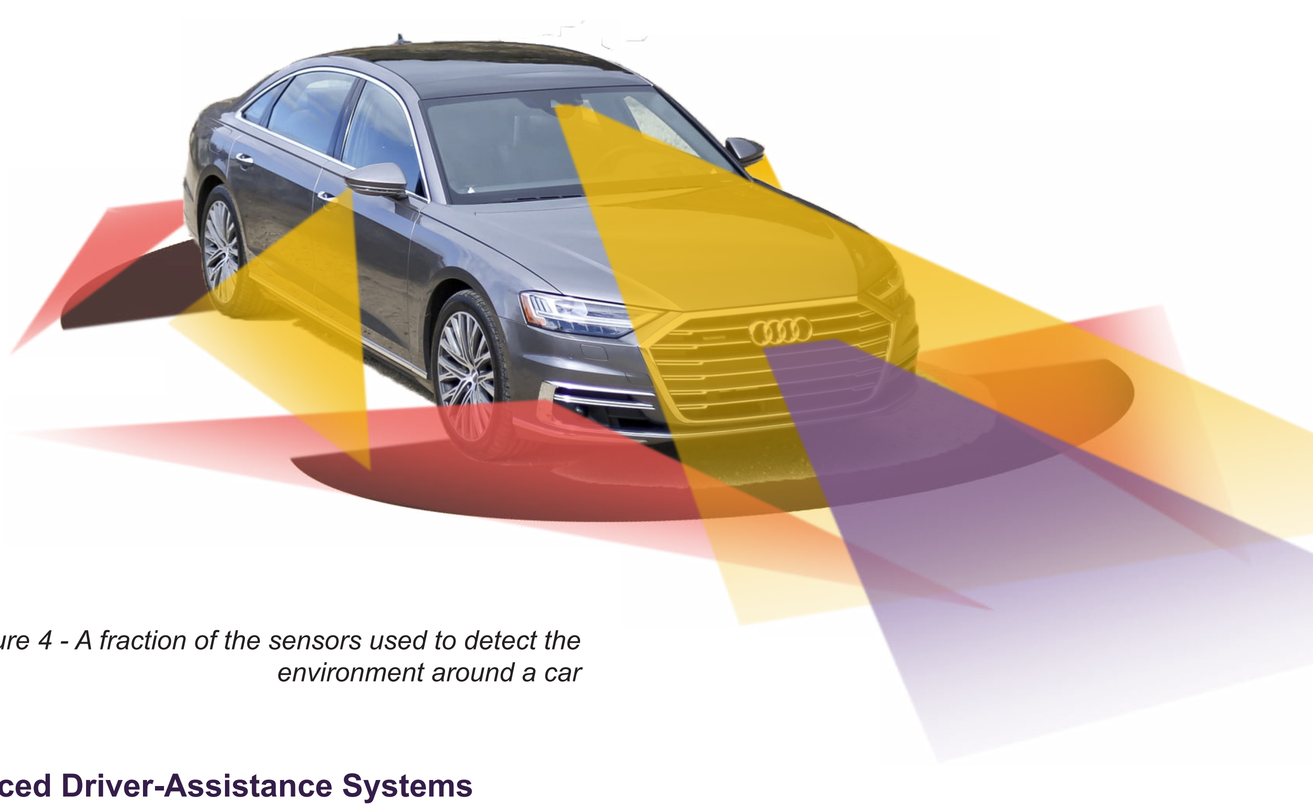

Figure 4 - A fraction of the sensors used to detect the environment around a car

Advanced Driver-Assistance Systems

“The Advanced Driver Assistance System (ADAS) is a collection of numerous intelligent units integrated in the vehicle itself. All these units perform different tasks and assist the human driver in driving.” (Kala, et al., 2016). The distinct number of units and their working principles are not relevant to within this graduation project. However, one needs to realize that the use of ADAS is intertwined with the design of an HMI. Some ADAS are consistently shown to the human driver, whilst others show up in times of required attention. Most of these are communicated visually, such as the disengagement of Traction Control or the Anti-lock Braking System. When designing an HMI, these existing signals are not to intervene with the desired input or output.
To understand the specific changes between SAE levels, the SAE guidelines and taxonomy described in J3016 can be distilled to a set of ADAS that are engaged or disengaged. These changes in used features change the driving task distribution. This includes the scenarios where the automation encounters a problem it cannot solve, e.g. in SAE level 4 and up, the automation is responsible for minimizing risk in these scenarios. In level 0 through 3, this is expected of the human driver.

Currently, SAE level 0, 1 and 2 have been successfully launched on the consumer market. SAE level 0 uses a basic, mostly passive, set of ADAS such as traction control or ABS.

Most drivers have had, or at least experienced, level 1 automation in the form of Adaptive Cruise Control (ACC), which has been around since right before the turn of the millennium in the Mercedes-Benz S-Class W220 in 1999, known as “Distronic” (Verpraet, 2018). Another example is Lane Keep Assist (LKA), which turns the vehicle back to the centre if the vehicle is veering too far to the edge of a lane. These types of features are still considered an ADAS. Once certain ADAS are combined to regulate both longitudinal (i.e. ACC) and lateral (i.e. LKA) movement, the vehicle is considered to qualify as SAE level 2 automation.

As per writing this report, no commercial vehicle has implemented SAE level 3 automation, though is has been promised for years. In 2017, Audi promised SAE level 3 in their upcoming A8 facelift, which was due in 2019 (Automotive News, 2017). This was repeated by Audi themselves a year later: “in just a few months, the cars in Audi Centers will be joined by the all-new Audi A8. This is the first production car in the world to have been developed specially for highly automated driving (Level 3, as it is called)” (Audi 2018). As mentioned, at the moment no level 3 has been proven safe for public road use. Though unlikely, Audi claims that the only setback for the launch of SAE level 3 in the Audi A8 is legislation that prohibits drivers to take their hands of the wheel in the state of New York (Automotive News, 2020).

HMI Design

An HMI is the connecting component between a human and a machine. This term is a subsidiary of User Interface and is often used as synonym of Human-Computer Interface. Functionally, it is the combination of input controls used by the user and output actuators that communicate to the user.

Classic examples of input controls are buttons, levers, keys, and touch-screens. However, it stretches over a wider spectrum of possibilities, such as sound (voice control), motion (motion sensors), balance (accelerometers), or temperature (thermometers). Similarly, examples of output actuators span the multi-sensory spectrum, e.g. auditory feedback (alarms, generated voices), visual feedback (monitors, lights), tactile feedback (vibration), and changes in temperature (heaters).

Within automation, the HMI is defined as a term that is just about any element that a user may interact with to operate a vehicle (Macey & Wardle, 2014). HMI split from ergonomics in 1990 due to the increased number of functionalities in vehicle telematics. With the emerging automated vehicles comes a tremendous increase of the scope of vehicular HMI. Over time, due to slow technological advancement, content and delivery became more important than the communication of function and operation.

With the prospects of automation, the HMI of a vehicle can span further than the interior of a vehicle. As drivers gain the ability to perform Non-Driving Related Activities (NDRAs), the amount of connected devices within the vehicle is likely to increase. As advertised numerously, the use of a smartphone or laptop, and who knows what future devices will be developed, is suddenly a safe possibility. When connected to the vehicle, for example via an application such as Tesla has done (Tesla, 2020), these devices can become an extension of the HMI. A great example has been explored by X. Wang within the MEDIATOR project, where a smartphone can communicate that the human driver will have to take control over the vehicle within a certain time-frame.

Current HMI design

In all existence, vehicles had some form of feedback to keep the driver informed of the state of the vehicle. In the beginning these were as rudimentary as the sounds of grinding gears or the rhythm of the pistons. Over time, a wide variety of systems were added, some for safety (e.g. different levels of lighting or airbags) others for comfort (e.g. climate control or navigation).

All these systems needed, and to a certain extend still need, to be operated by the driver. Other systems are driver supportive, and only come to the driver's attention if they fail (e.g. ABS or traction control). Nowadays, when observing user manuals, there are roughly three approaches to HMI design in person transport. The first two are comparable in approach, where the driver has access to a set of displays, pedals, and a wide range of buttons on the dashboard, centre-console and steering wheel, as well as multiple levers behind the steering wheel that move bi-dimensional and have buttons.

Figure 5 - Two vastly different vehicular HMI designs - Ford F250 (2018) on top, Lancia Ypsilon (2012) on the bottom

The main difference is the location of the gear selector. In most European models, this is found integrated to the centre-console. In some American models, especially those on the American market, this selector can be found as a lever behind the steering wheel, on the right side. A good example is the Ford F250 truck, which is still build with this lever in 2020 (figure 5).

Examples of the more European system spread far and wide, such as the Lancia Ypsilon 2020 (Lancia, 2020) and for comparison sake also the much older 2011 model (Lancia, 2011) (figure 5), as well as the 2020 Jaguar I-pace (Jaguar, 2020).

The third approach can be considered more modern, where buttons are largely replaced by a centre tablet. In the 2020 model of the Tesla Model 3 (Tesla, 2020), this tablet has touch-screen and allows several operations through different menus (e.g. satellite navigation, lights, or windscreen wipers). Next to the tablet, the driver has access to pedals, multi-functional control buttons on the steering wheel and two levers behind the steering wheel. Both approaches rely on an instrument cluster that relays both basic information (e.g. speed, fuel consumption, range) and advanced information (warning icons, gear shift suggestions) to the driver.

There is a middle ground, however, where both traditional and modern control schemes meet and the tablet replaces a more limited set of controls, as can be seen in the 2020 model of Tesla model S (Tesla, 2020). Noteworthy is that Tesla makes use of the American placement of the gear selector.

> **"safe and intuitive, with the elements designed around basic ergonomic requirements, such as reach and visibility of the occupants."**
>
> **— Macey & Wardle (2014) on the basic principles of automotive HMI design**

Generic Control Transfer Ritual

Fundamentally, a Control Transfer Ritual is a set of actions that allow a shift in control over the vehicle. This shift can give control to the automation to relieve the human driver of some, if not all driving tasks and vice versa.

A framework to create Control Transfer Rituals has been generated in MEDIATOR deliverable D1.1 and is to be built upon in this report. The framework structure consists of a sequence of signals and time intervals in order to prepare the human driver for the eventual transfer of control (Figure 6). Important to distinguish is that the actual transfer of control is a single moment in which the control actually shifts, where the Control Transfer Ritual also includes the build-up to- and care after this moment. The framework is defined as the Generic Control Transfer Ritual.

As with all components, this Generic Control Transfer Ritual has a specific place within the MEDIATOR system: signalling the driver (Figure 6).

Next to the placement within the MEDIATOR system and the creation of the Generic Control Transfer Ritual, D1.1 shows preliminary findings that the interactions required in different use cases are desired to be structural applicable and visually consistent to minimize user bias.
Furthermore, these use cases differ based on timing interval, the amount of signals, duration, urgency and triggered senses.

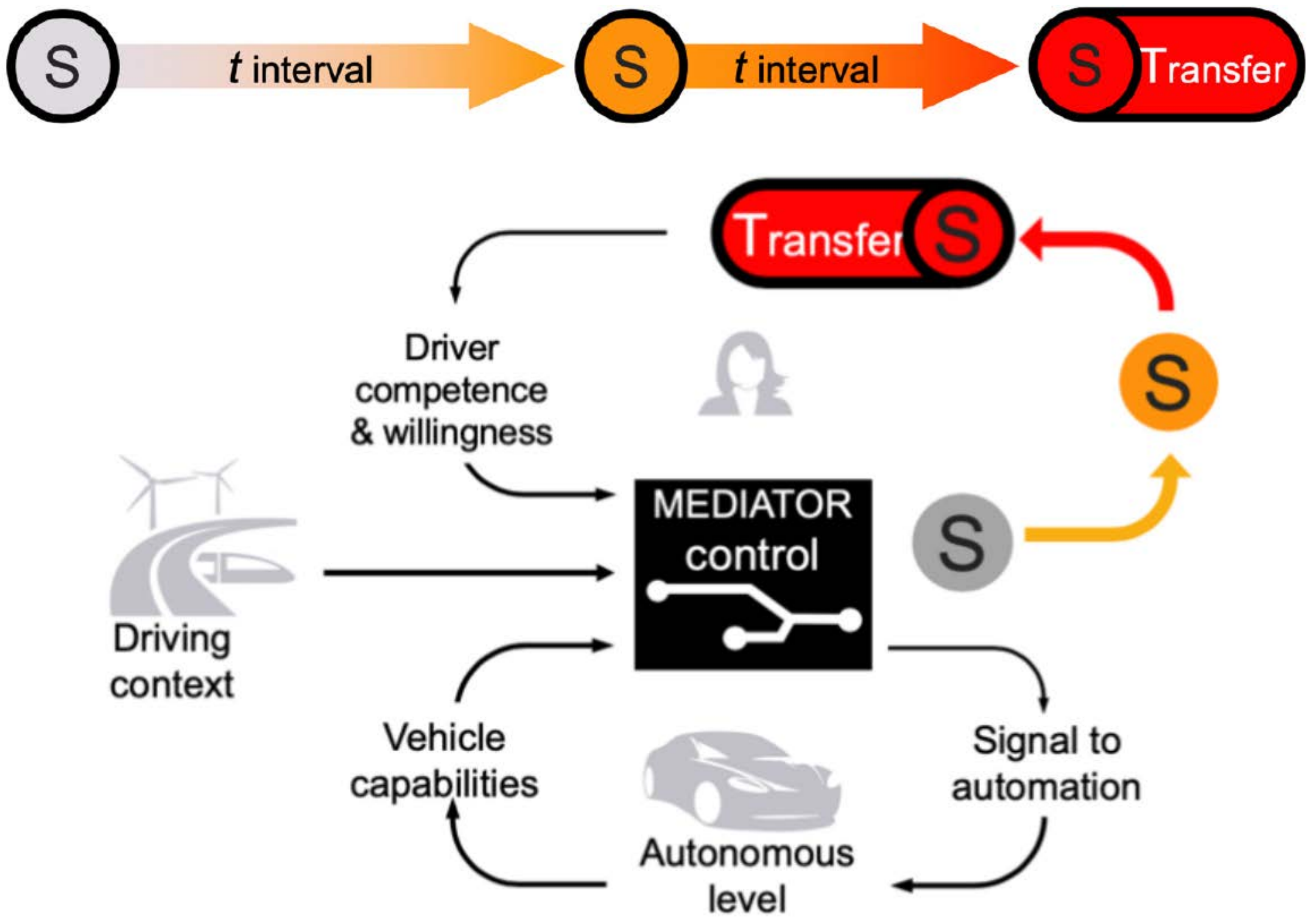

Figure 6 - The Generic Control Transfer Ritual as defined in MEDIATOR deliverable D1.1

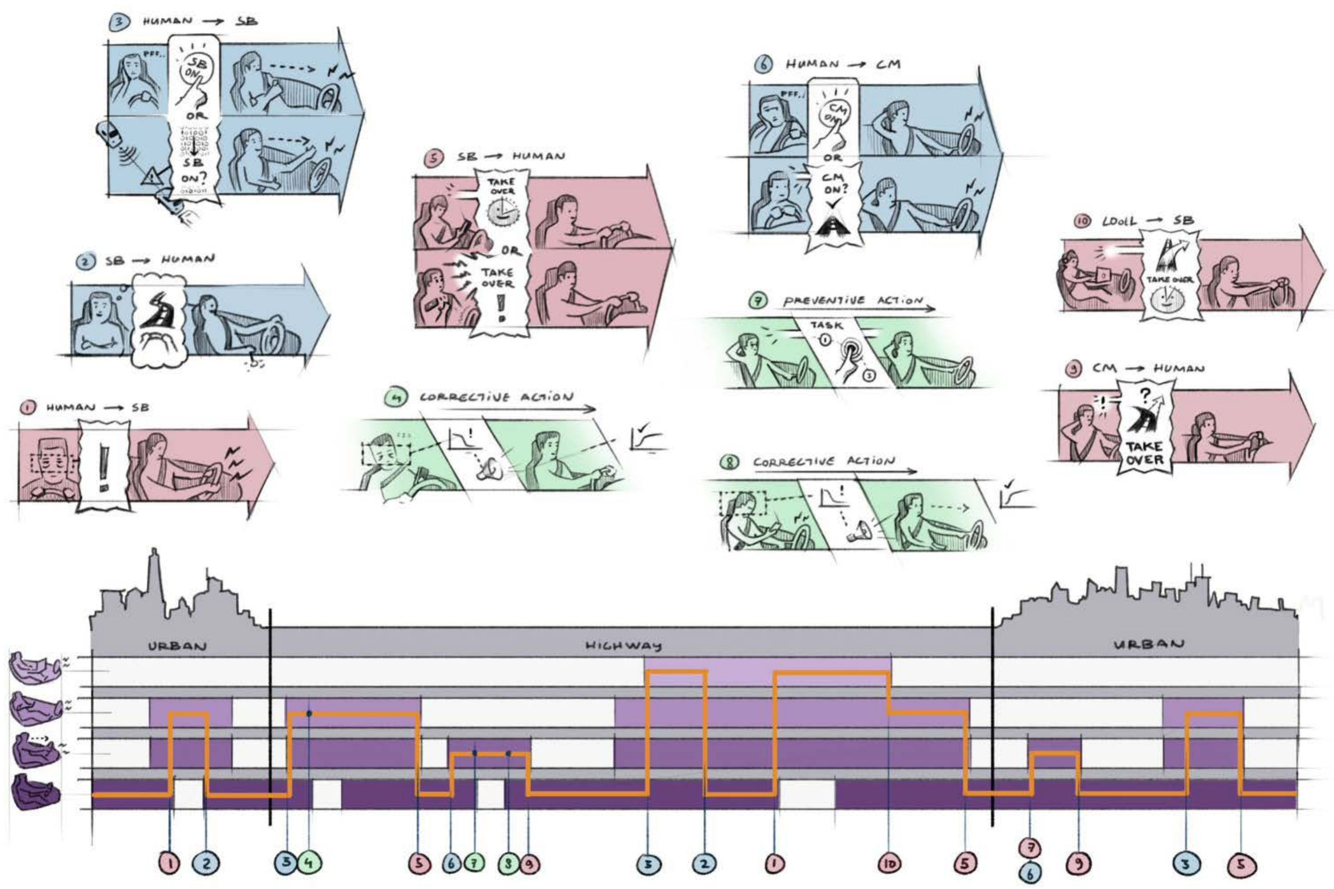

Figure 7 - Use Case Scenarios

Use Case Scenarios

Within the MEDIATOR project, a set of use case scenarios are identified that characterize the use of the MEDIATOR system (figure 7 and Table 2). In respect to these findings, the required Control Transfer Rituals are to be identified. Of these 13 use case scenarios (considering 3, 5 and 6 as doublets), only 7 are relevant to transfer of control. The other cases are focussed on interaction with the MEDIATOR system within a certain level of automation.

Within the use case scenarios, SAE level 1 automation is grouped in with SAE level 0. The result is a 4-stage scale of automation: 1) no automation (human), 2) continuous mediation (CM), 3) driver stand-by (Sb), and 4) driver long out of the loop (LOotL).

Use case scenario	Transition	Situation
1	Human to SB	Forced take-over by Decision Logic (DL)
2	SB to Human	Human want to take control
3a	Human to SB	Human no longer wants to drive
3b	Human to SB	DL suggests take-over
5a	SB to Human	Planned take-over
5b	SB to Human	Unplanned take-over
6a	Human to CM	Human no longer wants full control
6b	Human to CM	DL suggest partial automation
9	CM to Human	Automation no longer functions
10	LOotL to Human	End of the ODD, transition needed

Table 2 - Control Transfer Ritual relevant Use Case scenarios

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Boundaries

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Introduction

This chapter will touch on legislation in both current application and future plans for the automotive industry and automated vehicles.

Other stakeholders, such as the users and industry delimit the near limitless options for HMI and automation design through their needs and desires.

Users limit these options by needing the perception of agency and the ability to trust the system when there is little to none. The manufacturers will produce the vehicles in which the MEDIATOR HMI will be implemented. Though similarities create a clear environment for the end user, the industry wants the ability to remain commercially competitive through adaption and design.

Legislation

European Union

As mentioned, the political legislation differs per country. A recent example is where A German court ruled the use of in-vehicle touch-screens similar to smartphones. Therefore, a Tesla driver was fined as he was trying to adjust the interval of his windscreen wipers, which can only be done through the fixed, in-vehicle touch-screen provided in the model 3 (BBC, 2020).

The European Union, however, operates as an umbrella over the European countries and seeks out to create guidelines as to how a certain laws should be constructed, implemented, and executed. Another approach is to set boundaries in which countries can create their own legislation. When it comes to car design, a long directive can be found: Directive 2007/46/EC. This directive describes i.a. a framework containing general technical requirements, that explains the necessary dashboard signs. ANNEX 1, 9.10 shows a checklist of interior regulations. In which is stated which controls, tell-tales, and indicators, if their features are installed in the vehicle, are mandatory and which are optional. The design of the indicators must be in line with ANNEX II and ANNEX III of Directive 78/316/EEC.

The European Council and Parliament have also been working on the standardisation of car safety features, this is most recently explained in Regulation (EU) 2019/2144. This regulation addresses all type-approval requirements for motor vehicles, and their trailers, and their systems, components, and separate technical specifications intended for such vehicles. This all in the interest of the safety and protection of occupants and vulnerable road users. With this scope, the regulation dictates certain requirements to near-future motor vehicles, such as mandatory use of certain safety features. Next to improving safety in regular motor vehicles, these safety systems are also believed to form the basis of the technologies that are used to develop (semi-)automated motor vehicles. Relevant to this report are article 6 (Advanced vehicle systems for all motor vehicle categories), article 7 (Specific requirements relating to passenger cars and light commercial vehicles), and article 11 (Specific requirements relating to automated vehicles and fully automated vehicles). Where article 6 dictates the mandatory advanced vehicle systems of near-future motor vehicles, the paragraphs 1 and 2 are especially interesting to the design of CTRs. They dictate what systems are mandatory (all systems in Figure 8) and set boundary conditions on the user interaction with the intelligent speed assist: 6.2.b and 6.2.d. where 6.2.b. dictates that the user should be able to switch off the system and 6.2.d. dictates that the system should not interfere with the execution of the wish of the human driver to exceed the vehicle speed prompted by the system.

Paragraphs 7.2 and 7.3 state that passenger cars should be equipped with advanced emergency braking systems and emergency lane-keeping systems. They also state certain boundary conditions on the implications of these systems on driver autonomy and signalling. According to paragraph 7.4, the driver should be able to switch these systems off, one at a time. They will, however, operate in normal operation mode (turned on) upon each activation of the vehicle master control switch. The full functionality of these systems must incorporate the ability for the human driver to override the system. Audible warnings may be suppressed by the user and both systems should accommodate the possibility for the driver to override these systems.

Article 11 states that in addition to the systems mentioned in article 6 and article 7, additional regulation is needed for a large set of systems (11.1). These regulations are not yet defined, but the commission will implement additional acts to adopt provisions regarding uniform procedures and technical applications for these systems (11.2). Due to lack of tangible, practical implications that specify any useful boundaries for CTRs design, these systems are not listed. What should be taken from this article is the implied desire of the Union to regulate the systems used for automated and fully automated vehicles.

Figure 8 - European Union: New safety features in your car in accordance with article 6 of (EU) 2019/2144

United Nations

The Economic and Social Council of the UN published a framework document on automated/autonomous vehicles that was on the provisional agenda of the world forum for harmonization of vehicle requirements in Geneva (United Nations, 2019). This framework document shows the goals of this worldwide regulatory forum (WP.29) and one consists of producing regulations regarding Automated Lane Keeping Systems (ALKS), that allow for SAE level 3 and 4 automation. As of March 2020, the Informal Working Group (IWG) on Automatically Command Steering Function (ACSF), revised by the Working Party on Automated/Autonomous and Connected Vehicles (GRVA) at UNECE, for a new UN regulation has created a proposal: GRVA-06-02-Rev.4. Though the document is labelled as informal and is not by any means in force, it allows insight into possible future scenarios regarding legislation. The proposition states that vehicles equipped with ALKS should have some ground rules to comply to. In short, an LKS should keep a vehicle within the limits of its own lane. In this proposal (article 5), however, they talk about ALKS and it is proposed that these systems “shall perform the DDT, shall manage all situations including failures, and shall be free of unreasonable risks for the vehicle occupants or any other road users.”. Their definition of DDT (paragraph 5.2) includes the adjustment of lateral movement and/or speed. Furthermore, it dictates that within the DDT the control over the distance to the next vehicle and risk management in both braking and manoeuvring.

The regulations regarding these ALKS define situations such as “transition demand”, “transition phase” and “transition” without explicitly defining the required actions (paragraph 5.4). Though paragraph 6.1.4. states that during NDRA, the on-board displays that are available during the activation of the ALKS should be suspended. Suggesting that these ALKS allow at least level 3 automation.

The definitions of paragraph 5.4 do support the ground rules within the MEDIATOR project and sketch the same course of action: the system has to recognise all situations in which a transition of control to the human driver is necessary and initiation of a non-critical transfer should provide sufficient time for the human driver to take over control, therefore ensuring safety. If a driver is not responding to a transition demand, or as known in this report as a TOR, the vehicle by deactivating the ALKS system the within at least 10 seconds, a Minimum Risk Manoeuvre (MRM) shall be initiated. This Minimum Risk Manoeuvre will safely put the vehicle to a stop and apply the warning lights.

The proposition of the IWG also includes propositions about the HMI and operator information. Relevant to this report is their proposal for the activation and deactivation of the system as well as the implantation of a TOR. Activation and deactivation should be possible through the same dedicated means, implying an on/off button/switch/lever/… . The default state of the system is off and must be initiated every new start/run cycle of the engine, with the exception of i.a. stop/start systems. Manual take-over can be done by manually steering, braking, or accelerating the vehicle, thereby implying the want to take over. This feature will improve user acceptance as this is a natural method of taking over and is common practice with the current generation SAE level 2 automation (e.g. the Tesla model 3) and has been for ACC. If the system is unavailable but the human driver wishes to active it anyway, the driver must be informed at least visually that this transition is unavailable. The TOR is designed as a visual icon of hands on the steering wheel. This icon can be accompanied by text, auditory or haptic feedback. Noteworthy is that the warning of a TOR must contain a continuous or periodic haptic feedback at the least 4 seconds after initiation of the TOR. Also after 4 seconds, the signals given by the TOR should escalate and remain escalated until the TOR ends.

Furthermore, one of the boundaries of using the system is that the human driver must occupy the driver seat and a seatbelt must remain fastened. The system would initiate a TOR if either there is no human driver detected in the driver seat for over 1.0 second or the seatbelt of the human driver were to become undone.

User acceptance

Though seemingly obvious, for a product to be successfully implemented in society it needs a consistent customer base. Though attracting customers is not the main goal of MEDIATOR, their needs and wants are not to be ignored. As people will not be buying the MEDIATOR system directly, they are to be referenced as users. Sufficient needs and wants are to be fulfilled in order for these users to accept the MEDIATOR system in their personal vehicles.

To understand the potential impact of a MEDIATOR system, or the implementation of SAE level 3 or 4 automation in general, the current mood within the drivers community can be assessed. Henceforth, a user centred test was conducted where both insight in the functionalities of current generation automated vehicles and into their users was collected (Appendix 1). A small collection of Tesla drivers showed the capabilities of their vehicle in real-life traffic situations. Furthermore, they answered a questionnaire that allowed for more in-depth insight into the trust in the autopilot system.

Current generation vehicles are equipped with sensors that allow up to SAE level 2 automation, a technology that is currently starting to solidify itself in personal vehicles. As with all new technology it should be noted that user acceptance comes with time; initially people will be turned off by the idea of highly automotive driving. This is perfectly described by Evans et al, (2019) with the adapter categories during a product life-cycle. This effect can also be seen in the different answers acquired from the questionnaire of the test drives; some are willing to accept full automation as soon as possible, others do not deem it likely to give all control to an automated vehicle.

As determined in D1.1 section 5.4.2., the user needs to agree with the decision of the MEDIATOR system within his vehicle. This decision-making part of MEDIATOR is called “Decision Logic” and computes all signals to assess who is most fit to drive. In the diagram below (Figure 9), the driver preference, as described in a preliminary report on the MEDIATOR Sharepoint shows a scale of 1-7. At 1, the human driver must take control over the vehicle, whilst at 7, the automated driver must take control. At 2-6, however, the choice is to the human driver, where the MEDIATOR system creates an advice based on who is estimated most fit to drive.

It is stated in D1.1 that to create user acceptance, in the context of the control transfer scenarios associated with the MEDIATOR system, the system must facilitate a high level of perceived autonomy. The only exception are the extremities where either the driver or the system must take full control for safety reasons.
At the centre of the scale, at 4, the system will not suggest a driver. This is where the perceived autonomy of the human driver is the highest, as the choice of driver is completely his to make. Though the MEDIATOR system will only dictate the driver under extreme circumstances, the driver will be pushed to make a certain choice. At 3, the human driver receives the suggestion to take control. Opposite of that, at 5, he is suggested to give control to the system. At 2 and 6, these suggestions turn into persuasive measures, that indicate a higher level of urgency to transfer control to either human driver or the system. This approach dictates that the HMI must balance the actual autonomy and automation dictated actions to create safe, sustainable scenarios. The understanding, and more importantly the accommodation of this balance creates perceived autonomy and is one of the building blocks to the design of the Control Transfer Rituals.

During the creative session held by Benedetta Grazian, on the topic of mode awareness, an interesting development came to be. As per mistake of the participants, everyone acknowledged that the users main concern, whilst driving at level 4, would be the time to the next TOR and what signals would be needed to communicate a TOR. Within this short segment of transfer to Control Transfer Rituals, it became clear that one of the main concerns was the annoyance of the warning. The logic was that user acceptance would increase if the warnings were not only proper but also pleasant. This is enforced by the paper of Blanco et al. (2016), that found that TOR and system prompt warning systems should balance conspicuity*, urgency, and annoyance.

X. Wang (2020) also conducted user research among Tesla owners. Conclusions of her research, on the topic of notifications, argues that a notification at a higher level of automation will be perceived more annoying due to the increased dissonance between the driver’s attention and the task of driving as the driver has been out of the loop for a longer period of time. Though an interruption of Non Driving Related Activities (NDRA’s) are indeed arguably more annoying if one has spent more time on the NDRA, it is up for discussion whether that is the most significant factor to determine annoyance of a signal. Next to sound design, of which parameters have been defined by Marshall et al (2007) an important factor is the duration between alerts as a whole. During SAE level 2 driving, a driver is not supposed to have any NDRA’s, as it compromises the DDT, thus safety. Therefore it is within reason that the driver is annoyed to the extent that NDRAs are not engaged during level 2 driving by the sheer frequency of notifications. At higher levels, however, this frequency will arguably very much decline, as the driver can engage NDRA’s, thus significantly decrease the annoyance by notifications.

In the context of hospitals, alarm fatigue is an important issue to solve. Kristensen et al (2016) define alarm fatigue as “[...] the situation in which (sheer) exposure to a high number of (non-actionable) alarms causes an alarm user to be desensitised / sensory overloaded / overwhelmed, which might in turn cause the user to not respond adequately to alarms (e.g. miss or display delayed responses, ignore alarms, turn off alarms)”. In addition, they identify that a cognitive burden is applied to the recipient of the alarm if the sound is urgent, even more so if the source is unknown. In the design of vehicular HMIs, this is a potential risk: with the addition of alarms for automotive driving, a driver might become confused as to what response is required to the warning signal. An example would be the alert of a take-over request sounding at the precise moment that the driver decides to unbuckle their seatbelt. This would simultaneously sound the seatbelt and the take-over warning, resulting in a situation in which the human driver has to decide which signal has the highest priority.

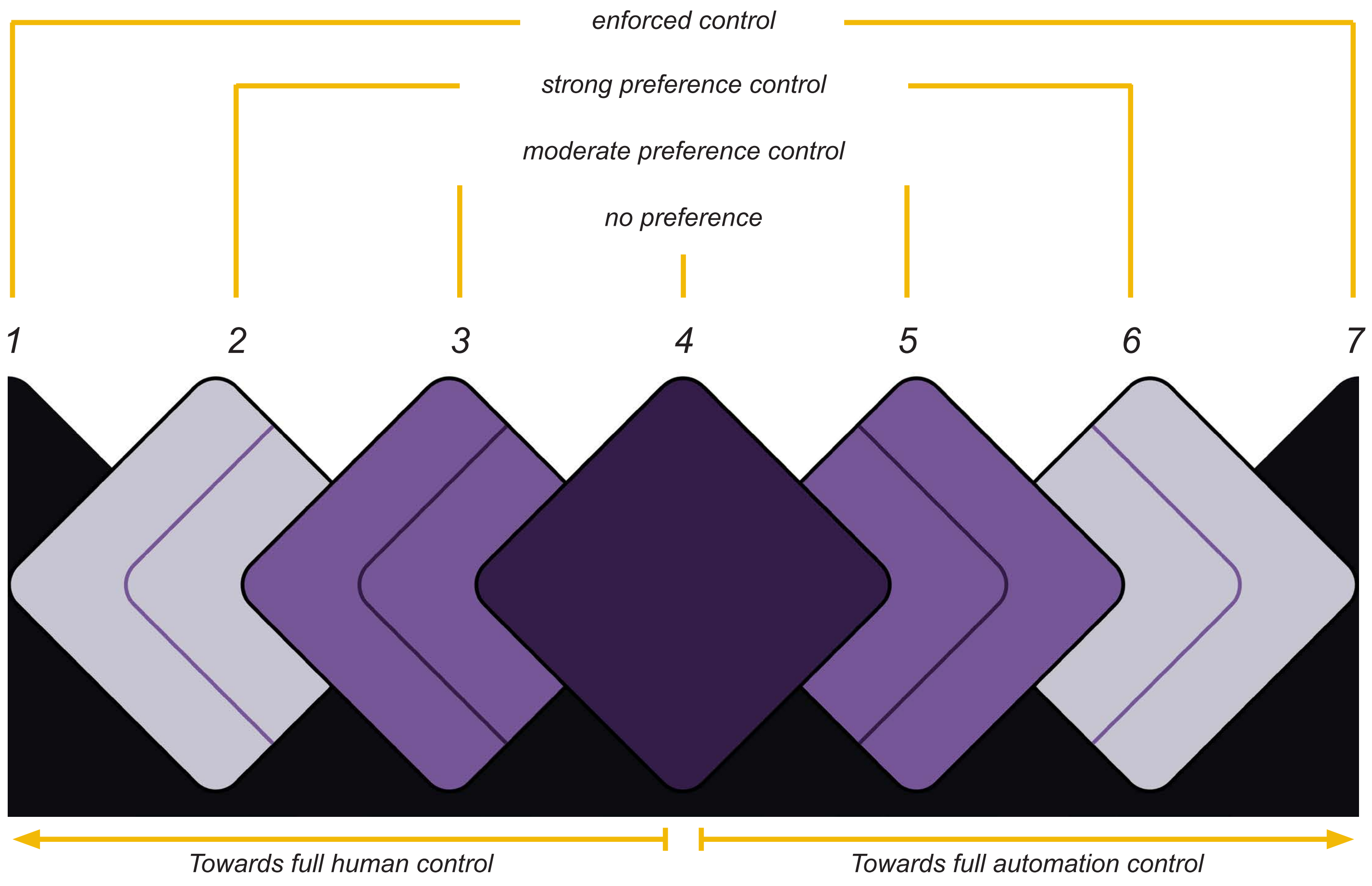

Figure 9 - User acceptance

Trust

In his master thesis to design an AI companion for Audi, Mösinger identified that the human driver must trust their lives to the automation and that without a pleasant user experience this might not happen. Therefore, not only perfecting technology and feedback methodology will be defining factors to create user experience, but trust as well.

According to the research of Mösinger, human-automation trust is equal to interpersonal trust, where the trustor (the person who trusts) has the intent to accept vulnerability based upon positive expectations of the intentions or behaviour of a trustee (the person who is trusted). Therefore, if the performance of a system does not match the intended goal, the user might lose his trust in that system.

In the domain of the MEDIATOR system trust could be defined as the belief of the human driver that the MEDIATOR system can determine the designed limits of the automation levels, thus adequately choose the correct driver to operate within the ODD. However, trust also works between the human driver and the automation, where trust can be defined as the belief of the human driver that the automation can operate the designated DDT within its ODD.

These beliefs can be translated to behaviour via the theory of reasoned action and the theory of planned behaviour (Ajzen and Fishbein, 1980, Ajzen 1991). In these theories, it is argued that belief forms an attitude towards the subject. Together with perceived behavioural control, this could turn into an intention to perform an action or show certain behaviour. If all conditions fit, the decision to act on the intention is made. This theory proves that trust (belief) is a fundamental value that needs to be established before technology can accommodate the intention to act.

Noteworthy is that perceived behavioural control and the contextual factors of the jump between intention and behaviour are influenced by the feedback on which the human driver relies. Mösinger summarized this as “the framework makes clear that trust affects reliance as an attitude and reliance is equated with behaviour”. Mösinger shows that trust naturally develops with time and experience. Initially, trust is based on predictability and/or consistency of the automation’s behaviour. However, due to events, both critical and non-critical, the trust develops according to the perceived dependability of the automation. With more experience comes greater trust in the automation, as the user believes to know how the automation will behave. Hoff and Bashir (2013) identify this as trust based on pre-existing knowledge (static trust) and trust by experience (dynamic trust).

To design for trust, however, is different. In order to evoke trust where there is no understanding, the driver needs to be informed. Hoff and Bashir identify transparency, ease-of-use, and appearance as key factors to elicit trust in automation. Variables such as provided feedback, communication style and level of control are also deemed significant in these information systems. The user’s interpretation of information, thus level of trust, will differ per scenario. This can be during a malfunction, due to the nature of the error and the perceived difficulty of that error, or during regular operation, where reliability, validity, predictability and dependability are identified as key antecedents of trust in real-time performance of the automation.

In short, if the human driver fully understands the automation by understanding all given information and perceiving to know all underlying reasoning, he will trust in the automation to perform its designed task. Trust develops when the driver perceives to understand, and agrees with, the automation’s decision making. Though one must add that a wrongful perception of knowledge about the automation can lead to over- and undertrust in the automation, causing hazardous scenario’s which can lead to mistrust in the system due to unexpected outcomes (dynamic trust) or in worst case fatal accidents (news about them can harm static trust).

Finally, on a level of feedback, Mösingers research determines that anthropomorphism, the attribution of human-like features, increases trust and help build a bond between man and automation. This can be implemented by creating a personality for the vehicle, by giving it a name, voice, and gender.

Furthermore, if the personality is perceived as patient and competent, the trust levels increase. De Visser et al. (2015) also conclude that the implementation of anthropomorphism can lead to heightened trust in automation. However, they also state that adding anthropomorphism lowers initial trust in the system. This can be beneficial if the system is expected to fail often, as is expected from new technology, as the trust in the system will be more resilient. In essence, an error would be considered clumsy at heightened levels of anthropomorphism. This ties in with the notion that humans do make mistakes and automation does not and thus users will be more forgiving to errors.

Hoff and Bashir (2013) contradict de Visser et al. by stating that the addition of an expert to the display increases trust in younger audiences. In the end, one can conclude that anthropomorphism is a tool to create trust, but the implementation should be chosen carefully to create the right balance of trust resilience and initial trust.
The information, given in a manner that no surprising actions are undertaken by the automation, thus timely, concisely, and clearly, should be able to inform the drivers at all times. Thus before, during, and after a CTR, the driver needs to be informed of the decisions by the automation. However, as also identified by Mösinger is that an overflow of information will degrade user acceptance. As a limit of information is very personal, it would suggest that given information should be optional to the human driver. In this case, certain information can be requested before of after a CTR and/or be displayed if the driver chooses so in the system settings.

To summarize, trust is key to make people switch to automated driving. Feedback and information are key factors in eliciting trust, if used correctly.

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Driver Override

The key to user acceptance is to find the balance between actual autonomy and automation dictated actions. This balance creates user acceptance. In all levels except for the extremities the human driver needs to have the ability to take control. This is also mentioned as a mandatory feature in the current legislation regarding automated vehicles.

Currently, control is instantaneously taken by deactivating the automation as if with a manual override. This manual override, or basic form of control transfer, can be done in various ways as discovered during the test drives. To easily shut down SAE level 2 automation, or Autopilot, in a Tesla model 3 (2019) the human driver has several options such as steering beyond a threshold, braking, or pushing the autopilot lever up. The model S (2018) with Lane Change Assist uses the same mechanisms: steering beyond a threshold, braking, or pushing the autopilot lever back. In both cases, the user was alerted of the change in control via an audible warning and the disappearance of the autopilot icon from the dashboard. In the theorized pilot control of Mercedes-Benz, an equal interaction as de-activation of the system is theorized; pushing the activation/deactivation button, braking, accelerating, or steering (Daimler, 2019). In this case, it is mentioned that accidental brushing or bumping of these controls should be filtered and omitted as deactivation input.

Guo, et al. (2019) investigated the possibility to balance automation and user input by testing a driver override over steering assist as found in lane change assist models. In their design, the steering wheel functioned as input and output source at the same time. Torque input was measured to determine a take-over request from the user, whilst the system used the rotation to indicate that the automation was making a curve. The HMI included graphics that communicated the mode (e.g. fully automated) and direction of the manoeuvre. Through testing four interactions with the steering wheel where evaluated, the most promising is a system with shared control features. In this model, in the context of lane changing, the automation briefly turns the control to the human driver during lane change. This determines that if the user wants to change lanes, he/she does this manually. The vehicle, that was functioning with LKA capabilities prior to the user input, will resume the LKA capabilities automatically after the initiated lane change.

Insights from the aviation industry suggest a split in approach for a manual override. In an interview flight commander and instructor Arno Keijzer, from the Dutch aviation company KLM, explains that Boeing and Airbus have polarizing opinions. Where Airbus claims that their technology is superior to the intuition and problem solving capabilities of a trained pilot, Boeing chooses the latter.

Whether Airbus or Boeing is in the right cannot be judged as both remain reputable aircraft building companies with planes across the globe. However, the consequences of certain mentalities can be all too real. A clear example is what happened in 1988, when Airbus A320 flown Air France flight 296 went down after a fly-by. Though the circumstances were far from normal, the system of the Airbus had the last say. In this case, due to alpha protection, a part of the stall prevention system. Next, the Airbus crashed in the treetops, causing the first lethal crash of an A320.

Boeing was embarrassed just a year ago, in march of 2019, when all 737 MAX models were grounded due to a faillure in the MCAS (Maneuvering Characteristics Augmentation System). Two 737 MAX had crashed (Lion Air flight 610 and Ethiopian Airlines flight 302), because Boeing left the description of the MCAS systems out of the flight manual for this aircraft type (Figure 10) . With pilots unaware that this anti-stall mechanism activated due to faulty sensors, the aircraft pushed itself towards the earth with little indication of the cause (AlJazeera, 2019).
The most important of lessons learned here is that transparency of information to the pilot is key to the prevention of accidents.

Figure 10 - Remainder of Ethiopian Airlines Flight 302
Source: Tiksa Negiri / Reuters

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Industry acceptance

As determined in D1.1, for the MEDIATOR system to be adopted, it must be accepted by both the user-base and the industry. Three main concerns arise when industry acceptance is brought up: manufacturability, design freedom, and competitive advantage. The manufacturability of a CTR is dependent on the necessary technology to accommodate the interactions. For example, mind-machine communication equipment would be an excellent solution but, for now, is only possible in science fiction. The realistic approach is a physical interaction, which must fit inside the confined space that is available from the driver's seat. Furthermore, it must comply to safety restrictions, such as rounded edges and no, or at least very limited, possibility to impale, cut, or warp (e.g. "submarining") the driver during impact scenarios. In short, the higher the manufacturability - the more realistic and less complex the product - the higher the industry acceptance.

D1.1 states that to attain acceptance in the automotive industry the design freedom is to be considered. The more design freedom, the higher the industry acceptance. However, it should be noted that full design freedom in control transfer is not always possible and certainly not preferable. As with user acceptance, a scale of 1-7 can be used to describe preferable design freedom (Figure 11). At 1 and 7, at no automation and full automation respectively, the design freedom of OEMs should be limited for reasons of safety and vehicle performance. An example is that Minimum Risk Manoeuvres should be standardized for all brands to heighten predictability and thus safety. The possibilities as to when and why a certain level of automation is available should be consistent between brands. As with user acceptance, in the middle of the scale, at 4, where the MEDIATOR system has no preference to the driver, the OEM design freedom is expected to be highest.
Design freedom comes with brand differentiation. Each OEM has the need to distinguish themselves from their competitors by brand identity. In automotive interiors the driver's relationship with the instrument panels can be considered quite intimate. Therefore brand identity boils down to design, materials, and component layout Macey (2014). As mentioned in D1.1, van Grondelle (2000) and Person et al (2007) determined that brand differentiation between automotive manufacturers lies no longer on unique, technological qualities, such as power, performance, or safety, but shifted to interaction and form. With strategic use of this brand differentiation, a competitive advantage can be created and with that comes economic viability.

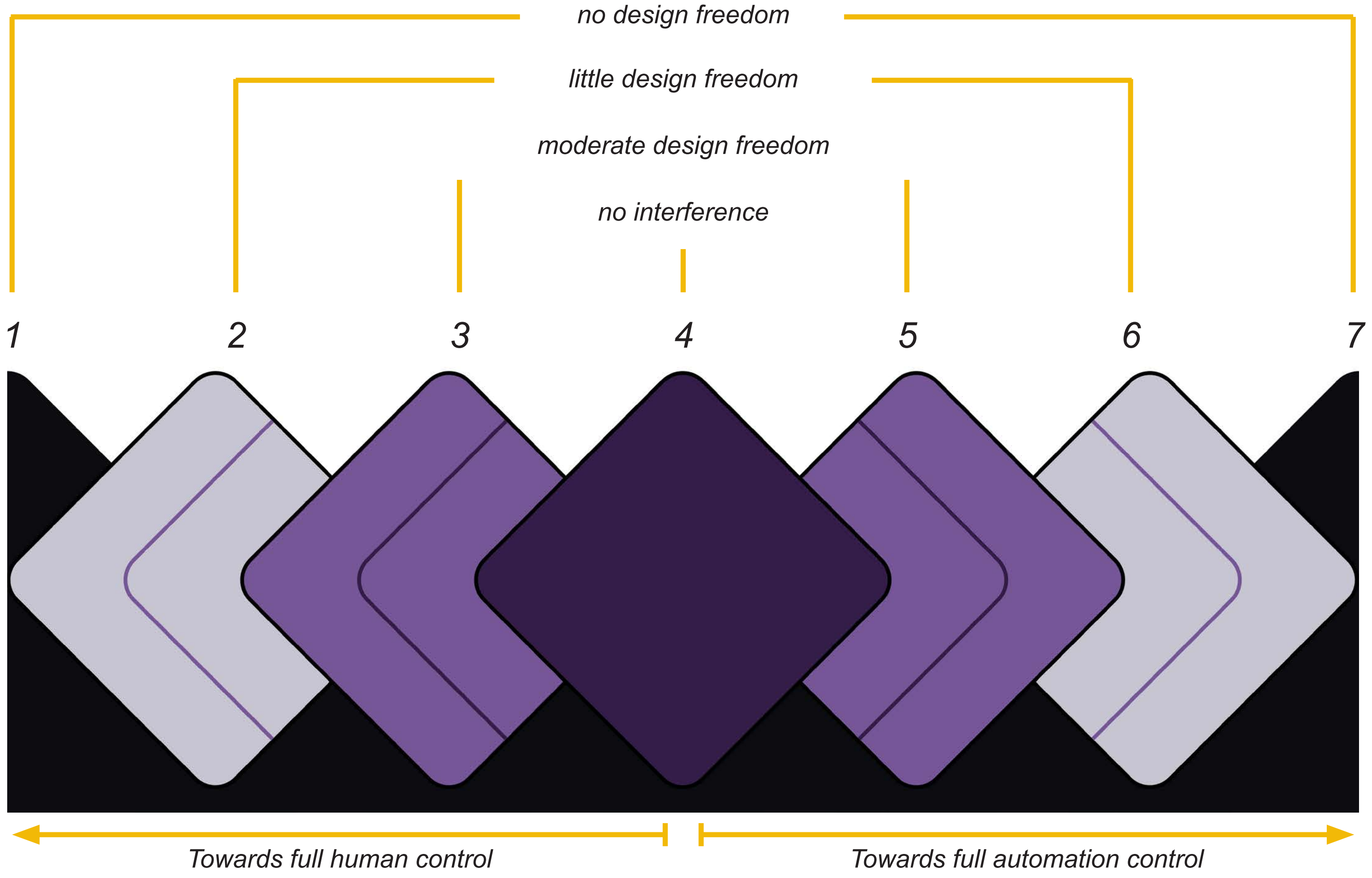


Figure 11 - Industry acceptance

In terms of HMI design, the fundamentals for brand identity still hold true. Though the nature of the design element changes a bit, where shape and colour are supplemented by signal design.

Signals can vary in modalities as discussed. Important is that safety is still paramount, and intuitiveness is a close second. A CTR consists of two information streams: from human to automation and vice versa. Feedback to the human in terms of for example sound design, design of visual stimuli, and comfort and specific position of the vibrotactile feedback should be up to the OEM, as long as it complies with the legislation. This would also apply to input devices used to communicate the human drivers wishes to the MEDIATOR system and automation. However, the information and 'nature' of the input and feedback that needs to be conveyed to and from the Decision Logic in order for the MEDIATOR system to work is not up to the OEMs.

In a recent development, Daimler announced midway of 2020 that Mercedes-Benz and NVIDIA started a cooperation to create an automation structure that allows them to implement offer and implement add-ons via over-the-air updates (Daimler, 2020). This allows for automation of level 2, 3 and, with automated parking features, even 4. To map regions, thus updating the ODD, they have implemented the DRIVE Interface, developed by NVIDIA, that will use data driven- and deep neural network development.

Trends like this would suggest that technology could still be a distinguishing factor between traditional automotive OEMs. Considering all variants of autopilot, however, paints a different picture. Though they are named differently and are most likely different in coding, design and interaction, they function roughly the same. The cooperation of Mercedes-Benz and NVIDIA will likely be no different and show again that technology is no longer the distinguishing factor; user perception is.

Finally, according to Evans et al (2009), the credibility of a source is a factor in conveying and accepting information. As with celebrities selling an expensive watch, the vehicular brand will sell its version of automation. Even if the information conveyed is exactly the same, trust is determined by the credibility of the source. An example is given in the research by Pilditch et al. (2020) where equal information regarding a disease given by a drunkard and a nurse is perceived at different levels of credibility. This credibility is attributed to perceived expertise and trustworthiness (motive to communicate honestly) of the source, which operate independently, and the perceived strength of the argument. Therefore, differentiation between automotive OEMs will increase based on the perceived trustworthiness of the brand and the perceived trustworthiness of the automation within the vehicle. A partnership between a traditional automotive OEM and a producer of automation technology, such as Mercedes-Benz and NVIDIA, does influence the brand identity for both and is dependent on the performance of the combined product.

3

Control Transfer Rituals

Structure

Introduction

In order to create effective Control Transfer Rituals, the aforementioned boundaries and Generic Control Transfer Ritual are simply part of the solution. In this chapter, these first findings are combined with potential steps between automation levels to create a set of effective, theoretical Control Transfer Rituals.

The general structure

Control Transfer Scenarios

The Generic Control Transfer Ritual holds true as a baseline for the design of the final Control Transfer Rituals. It has been specified that certain distinctions have to be made in separate Control Transfer Rituals, without losing a cohesive foundation. Cohesion will allow the users to understand all situations and scenarios, which in turn allows for better decision making.
Similar to the Generic Control Transfer Ritual, the final set will consist of a series of signals back and forth to communicate information between human driver and automation, as expected from an HMI.

These signals will differ slightly based on the context of the given signal. As discussed, important factors to determine the time interval between signals is urgency of the situation, the drivers reaction time. However, other factors such as current and destined automation level influence this factor as well. Furthermore, as determined within the MEDIATOR project, Control Transfer Rituals can be split between comfort-driven and safety-driven takeovers. Though safety is naturally key in the execution of all takeovers, a key difference is that some transfers are voluntary, initiated by the human driver with or without provocation from the Decision Logic, or forced by the Decision Logic.

Current driver	Destined driver	Initiator	Urgency
Human	Automation	Human	N/A
Human	Automation	Decision Logic	Low
Human	Automation	Decision Logic	High
Automation	Human	Human	N/A
Automation	Human	Decision Logic	Low
Automation	Human	Decision Logic	High

Table 3 - Control Transfer Scenarios

Automation flow diagram

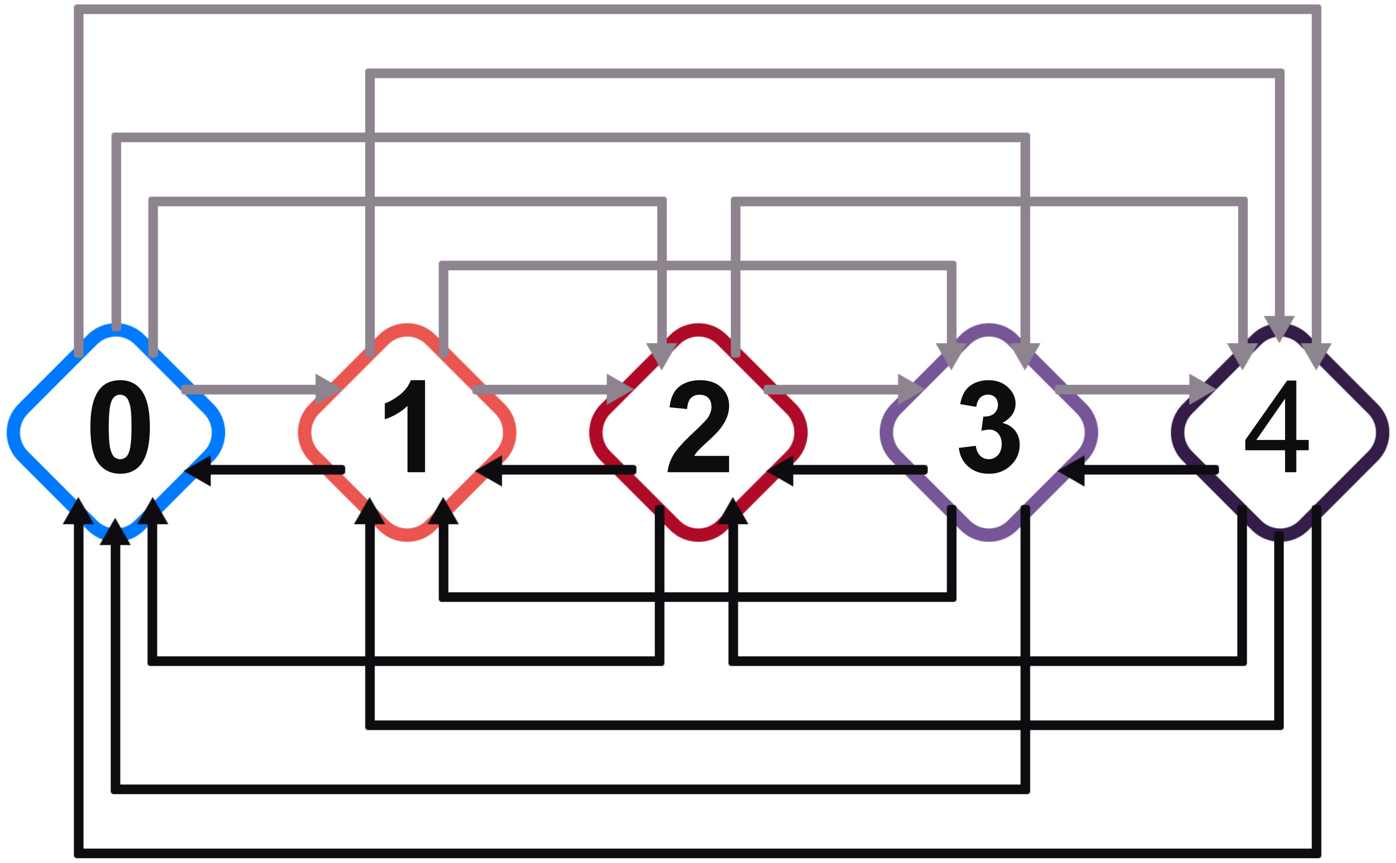
One can take the SAE automation levels that are within the scope of the MEDIATOR program, level 0 to level 4, as five separate driving modes within a vehicle. The responsibilities of the driver, being human or automation, changes per mode. This switch between driving modes is defined in this report as a flow in automation. With five modes able to switch to four other modes, twenty flows of automation can be determined. To comprehensively summarize mode switch actions, an intricate diagram is built that displays all possible automation flows between levels; the General Automation Flow Diagram (GAFD) (fig. 12). In this diagram, the twenty mode switches are represented by arrows leading from one automation level to another.

Regarding safety, a known discussion is whether drivers are supposed to be able to switch freely within the available levels of automation. Concerns exist as to whether safety is compromised if done so, which is why, according to E.D. van Grondelle, BMW is considering a mandatory reset to manual control before a switch between levels. They deem this safer. Debatable is whether this is the case and whether it might confuse people as to why such elaborate steps need to be taken; as one could argue that more steps to switch between automation leads to more attention to the actual transfer of control than to current road conditions.

As determined in the GAFD there are 20 flows of automation, each switching between two levels of automation. The different situations in which a switch or set of switches between levels can or cannot be made can be calculated with the use of a binomial coefficient, this results in 1048576 Automation Flow Diagrams (AFD). The vast majority of these diagrams are utterly useless and practically impossible (e.g. only allow a switch to 0 from 4, without allowing any switch to 4).

In these AFDs, the main differences are determined by the allowance of jumping levels (i.e. skipping a level or set of levels) and allowing incremental change between modes. Because level 3, and more significantly level 4, influences driver attention to the road, thus impacting safety, there are distinct potential AFDs regarding the limitations of these levels.

Figure 12 - Generic Automation Flow Diagram



Simplification for human use

In practice, safety is paramount, and the available flows of automation should be adjusted as such. Therefore, it is important for drivers to understand what their own responsibilities are and what is done by the automation. This relates to the definition of the SAE automation levels, where a clear distinction between levels 0-2 and 3-5 is made; who is driving? D.1.1 made these distinctions in regard to all of the MEDIATOR project by setting up the use case scenarios, where SAE level 1 automation is grouped in with SAE level 0 to create a 4-stage group of driving modes. Again, a distinction can be found between level 0-2 and 3-4, because of drivers being in-the-loop or not.

As can be observed in numerous videos, photos and articles of people sleeping in their Tesla, humans are more likely to switch between driving or not driving. This lack of distinction has also been observed by Banks et al (2018). With driving responsibilities not clearly communicated or simply ignored, it would be safer if people have a mode for driving and a mode for non-driving. However, as SAE level 1 and 2 have proven, the active fatigue of the human driver over a journey decreases significantly. This has been mentioned during the Tesla driving tests and is verified scientifically by Gastaldi et al (2014). However, Körber et al (2015) identified that passive fatigue occurs when drivers are placed in a position of monitoring, as is done in during SAE levels 1, 2, and partially in level 3.
This raises the question whether the possible switches in between the driving modes should be limited or the driving modes themselves.

Combining the SAE levels with the human capabilities, a selection of driving modes can be narrowed down to regular driving (level 0), In-the-Loop automation (level 1 and 2), and (Semi-) Out-of-the-Loop automation (levels 3 and 4).
This would significantly limit the available mode switches from twenty to just six, three modes jumping to two others. Such limitations would simplify a journey and lower the chance of mode confusion as there are fewer modes to mix up.

To communicate these levels clearly to the user, these levels are to be renamed. Within a vehicle, sequential numbers are associated to the selection of gears in a gearbox. Other numbers, such as speed, radio frequency, and time have a vastly different magnitude and association to arouse confusion. Even when gears are growing obsolete due to the up-and-coming use of electric vehicles without gearbox, the association will persevere under veteran drivers.

The proposal in this report is to rename the different driving modes from numbers to names. With this distinction, not only the confusion with gears is avoided, but meaning can be given. This is key to communicate responsibilities clearly to the human driver and allows a formal distinction.

First, driving without any automation as done in SAE level 0 is little different to classic driving as taught in driving schools around the globe. A fitting term to apply to this driving mode is “Manual driving”. Though not to be confused with a manual gearbox, this term is defined as a synonym of “nonautomated”, the opposite of automated.

Next, the automated driving modes in current use, SAE levels 1 and 2, are a combination of ADAS, Advanced Driver Assistance Systems. Combined with other terms for this level of automation such as Pilot Assist, a representative term is “Assisted” driving mode. The benefit of this term is that it creates the necessary notion that the user is not fully out of the loop and has to maintain certain responsibilities, or DDT. With proper feedback, this can be steered towards the monitoring tasks of the driver.

Lastly, as can be observed by the Non Driving Related Activities performed in Tesla’s nowadays, the term Autopilot does not communicate clearly that the human driver has the responsibility of monitoring the road. Without proper communication of this Designated Driving Task to the user, the term Autopilot is not in line with the desired behaviour. This is due to the notion that an autopilot in aviation takes full control from the pilot and that also applies to their Autopilot in the Tesla.

Due to this misleading term, Tesla had been restricted in the use of their term Autopilot in for example Germany (Kolodny, 2020). This is not a call to remove the term altogether, but to apply the term to automation that correlates with the perceived responsibilities. In that case, the autopilot would be more suited to level 3 and level 4 automation. However, as Autopilot is trademarked by Tesla, the general term could turn to “Piloted” driving mode.

This rounds out the scale to Manual, Assisted, and Piloted driving modes.

Figure 13 - Automation levels to driving modes

The basic structure of the Control Transfer Rituals will describe the required steps in interaction between the human driver and the Decision Logic in order to transfer control in a qualitative manner. In general, the Decision Logic communicates to both the human driver and the automation and calculates values in order to determine who is most fit to drive. Within the scope of this report only the communication with the human driver is included. To communicate with the human driver, the Decision Logic is expected to give clear signals to the driver and receive clear input from the driver, all through the HMI.
If all is right, the interaction will be a predictable path that alternates between action from the human driver and feedback from the Decision Logic. If an error occurs on either the driver side or the automation side, the driver needs to be informed that a deviation from this predictable path is necessary.

As mentioned, control transfers originate from either comfort- or safety driven motivations. The comfort driven takeovers would be planned/expected, and the safety driven ones unplanned/unexpected. In this report, these categories are rewritten to urgent takeovers and non-urgent takeovers. In the case of a non-urgent takeover, a comfort driven takeover, the driver has either chosen to transfer control for his own comfort or the Decision Logic suggests a takeover. The decision to rewrite these terms is that in the execution of Control Transfer Rituals, there is no distinction between the Decision Logic initiated and human initiated comfort driven takeover. Though a message will be shown by the HMI that a takeover could be made, the decision is up to the human driver. If he/she decides to follow up on this suggestion, a human initiated takeover will commence.

Error messages

If the human driver wants to activate a certain level of automation, though that level can be no automation, whilst the Decision Logic determines that the desired level is unavailable the action must be terminated and an explanatory message should inform a to why it was terminated.
This error can occur by numerous means, but these can be categorised in two sections: driver fitness related and automation fitness related. In the first case the Decision Logic determines that the driver is unfit to take a certain responsibility onto himself. This is a switch downward in automation. The latter case occurs when the automation is not fit to take over certain responsibilities. This covers both the instances where the automation is broken and where the automation cannot handle the current domain.

Minimum Risk Manoeuvre

In some cases, the automation loses the ability to continue driving. If that happens, the human driver is tasked to take over and continue the drive. When the driver fails to take over or is deemed critically unfit, a Minimum Risk Manoeuvre (MRM) needs to be executed. This term, mentioned in WP.29 of the United Nations (Chapter 2; Legislation), describes a safe stop and the application of the warning lights. However, a different approach can be learned from the aviation sector. Their autopilot systems are magnitudes more complex than currently implemented in consumer vehicles, but offer valuable insights to safety and emergency situations.

In the interview with Boeing 747 captain A. Keijzer of the Koninklijke Luchtvaart Maatschappij, we discussed the use, training, and HMI of these systems (Chapter 2). Evidently, a plane cannot be stopped mid-flight above an ocean and a car can be stopped virtually everywhere but an example of a great insight for emergency situations, such as where an MRM needs to be applied, is that different levels of failure can be approached differently. Where in aviation a minor error can eliminate the automated control over pitch and a major error can force a plane to fly straight (no pitch, roll, acceleration or yaw) in order to give pilots the ability to assess the situation. This can be applied in personal vehicles by changing the MRM dependant on which sensors fail and what information is missing or corrupt. An example would be that a vehicle can continue driving on the same road, at the same speed, but cannot plan a new route, switch lanes or take an exit ramp. The vehicle would be in containment, without the need to terminate the drive as soon as possible. In this state, it is still wise to engage the warning lights to inform other road users of the malfunction.

Basic structure

The basic structure of a Control Transfer Ritual is, as mentioned, a series of signals between the human driver and the Decision Logic. In figure X, the very basic structure of the Control Transfer Ritual for switching from Piloted driving to Manual driving in a non-urgent scenario, initiated by the Decision Logic. An example of this situation would be the approach of the exit ramp of a highway, use case scenario 10 in MEDIATOR D1.1.

In this example, the sequence starts with the signal from the Decision Logic that the exit ramp is approaching in some time, allowing the human driver to finish a NDRA and assess the road conditions. After some time or after the human driver indicates that the control can be transferred, a warning message will occur that the transfer is initiated. When properly executed, the driver is guided through the process and knows his new responsibilities. Finally, the take-over is completed, which is confirmed by the Decision Logic. If anything fails, an MRM will secure a safe solution that might result in the termination of the drive or a detour.

The triangles in figure 14 represent an MRM or Error, the diamonds represent a signal from the Decision Logic and the squares represent the actions performed by the driver. These figures are aligned left to right in order of time of event. The arrows display the sequential scenario. A dotted arrow indicates a non-critical event, where both time passed and input delivered can continue the Control Transfer Ritual. The coming pages describe 11 different Control Transfer Rituals, each applicable to a different scenario. Furthermore, the structure of an MRM and Error message can also be found.

The next pages will illustrate what the basic Control Transfer Ritual structures are for the events varying on intitiator, current driving mode, destined driving mode, and urgency. In Appendix 4, these processes can be found conform Flowchart standards.

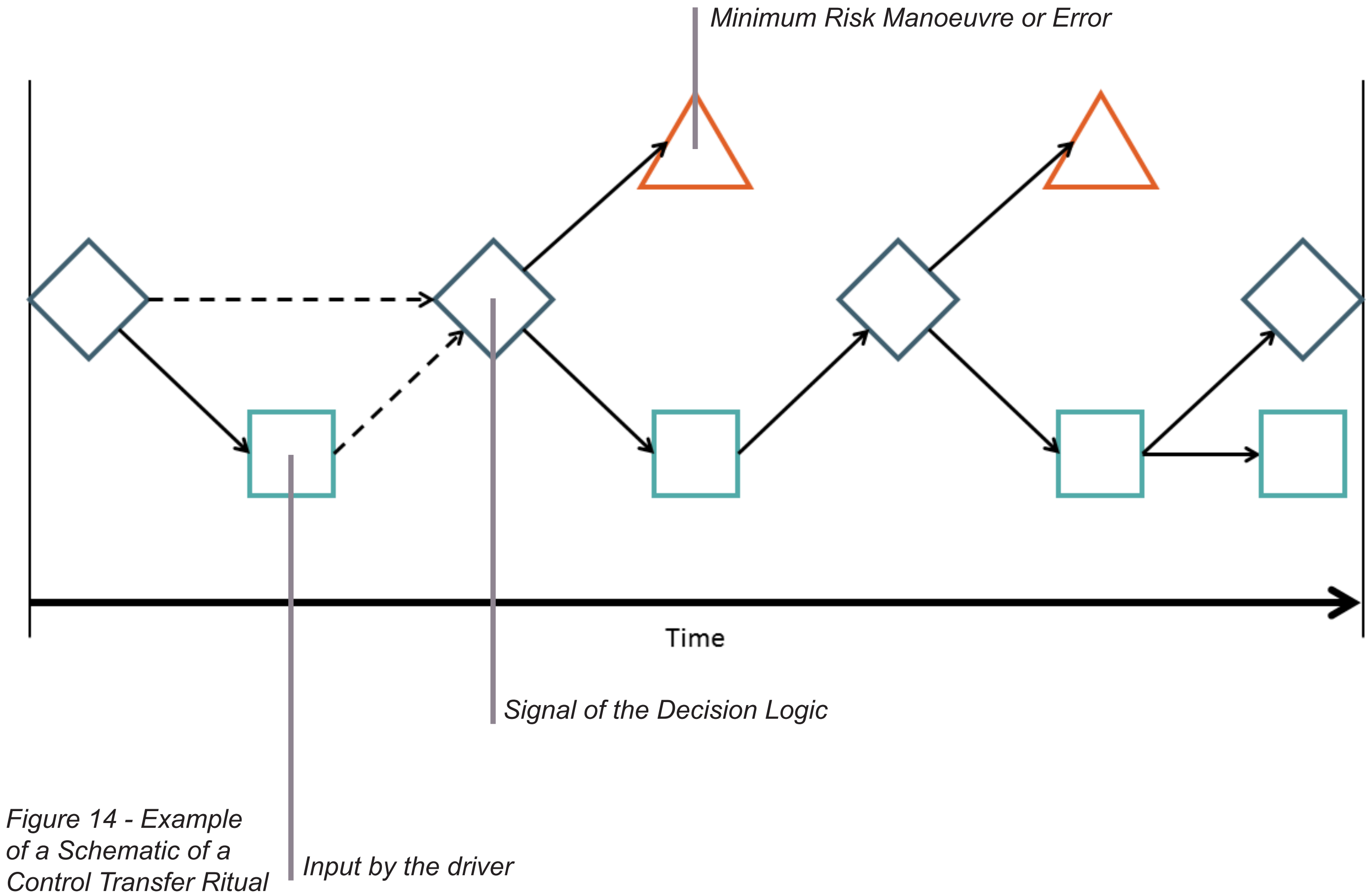


Figure 14 - Example of a Schematic of a Control Transfer Ritual

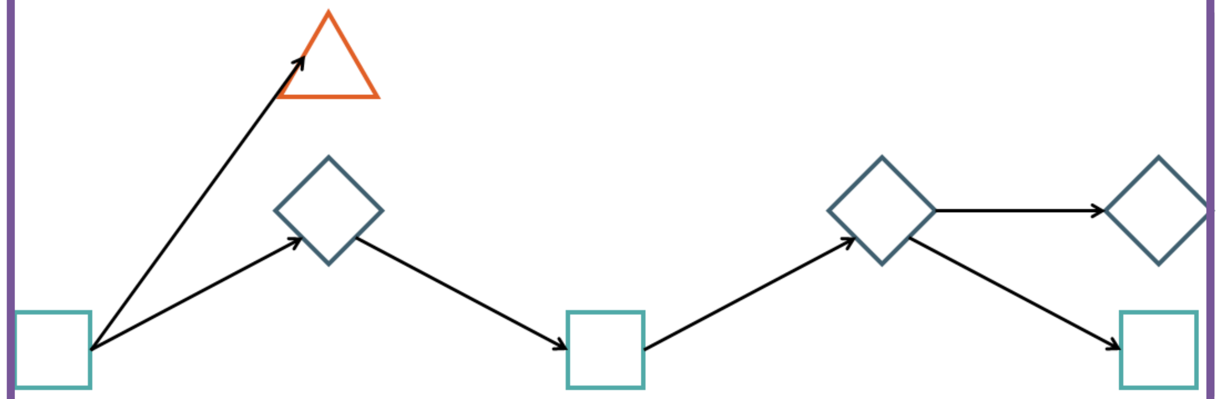
Low urgency, human driver initiated Control Transfer Rituals

Manual to Assisted driving

These interactions build on the premise that the driver would like to switch to an assisted level of automation. However, when the Decision Logic decides that these levels are not available, due to a mechanical error, wrong ODD, an error message should be displayed and automation is not activated. When accepted, the Decision Logic shows that the activation is in process and finally confirms the change.

Actions by the human driver:
Engage, Monitor, Select mode

Actions by the Decision Logic:
Alert, Pending, Confirm, Error

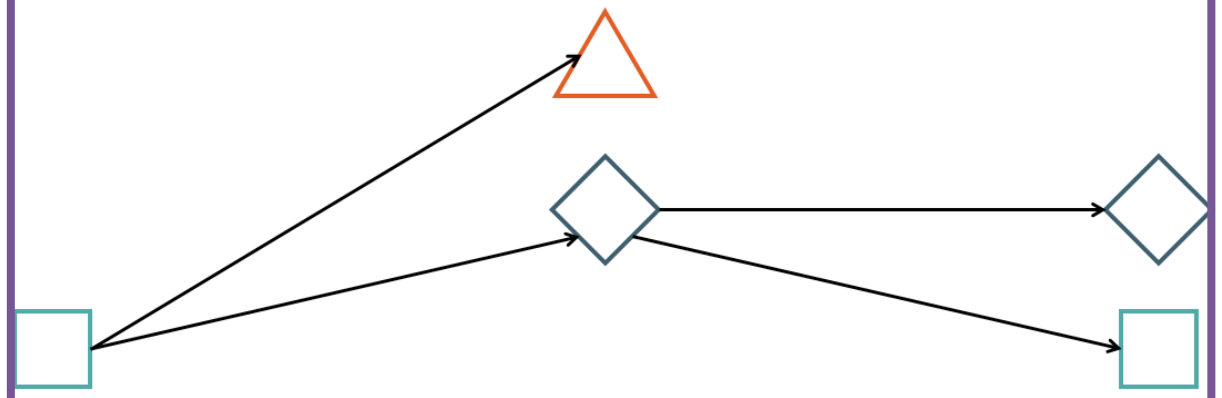


Assisted to Manual driving

These interactions show that the driver wants to switch out of an assisted level of automation. The Decision Logic decides whether the human driver fitness is adequate. If not, an error message is displayed and the automation is kept active. When accepted, the Decision Logic shows that the automation is deactivated and the driver can continue his journey in full control of the vehicle.

Actions by the human driver:
Disengage, Drive, Select mode

Actions by the Decision Logic:
Alert, Human fitness check, Confirm, Error

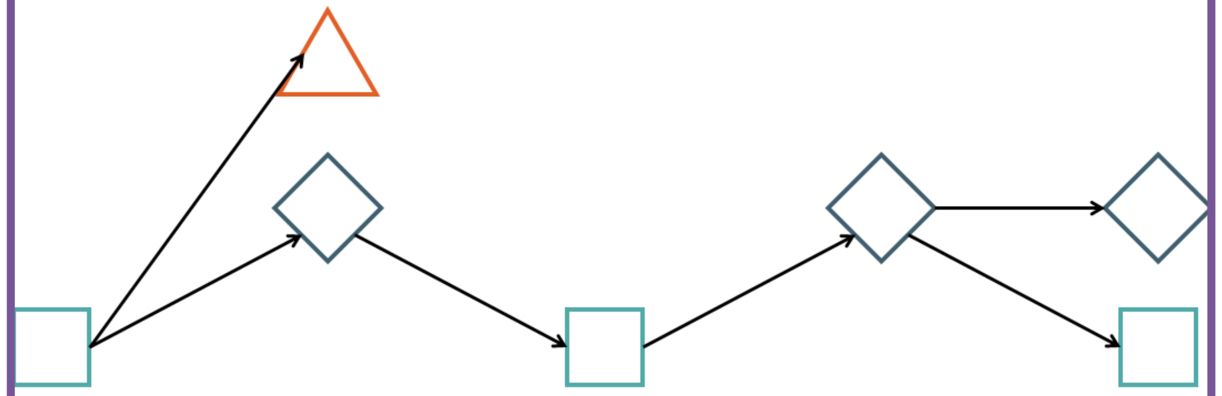


Manual or Assisted driving to Piloted driving

When a driver needs time to engage an NDRA, the automation of a higher level has to be enabled (3 or 4). This shifts responsibilities of the drive from the human driver to the automation. If the Decision Logic affirms that the option is available, the driver needs to be made clear of these changes in responsibility. After affirmation, the Decision Logic shows that the activation is in process and finally confirms the change.

Actions by the human driver:
Engage, Confirm, Select mode

Actions by the Decision Logic:
Alert, Confirm, Pending, Responsibilities check, Error

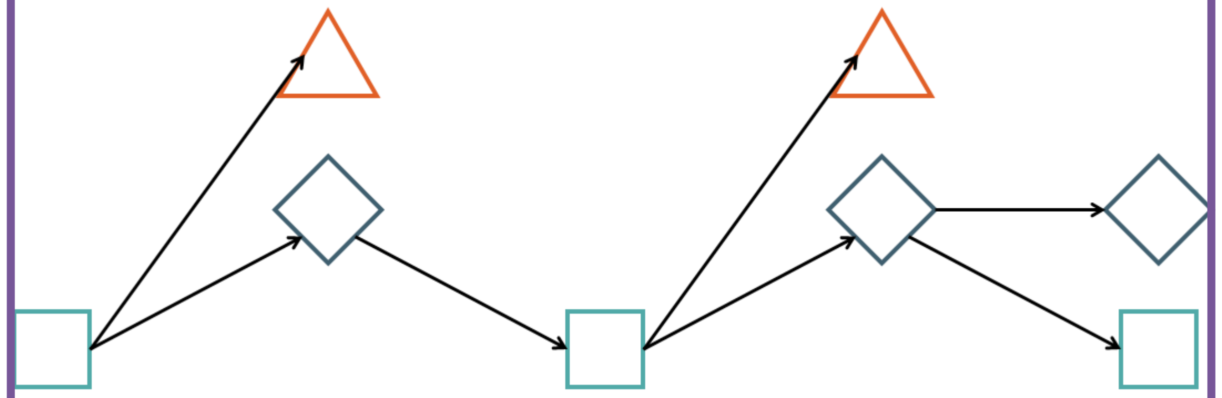


Piloted to Assisted or Manual driving

If the driver wants to take back responsibilities from the automation, the Decision Logic has to confirm the drivers fitness. After that, the driver also needs to prove that he/she understands the shift in responsibilities.

Actions by the human driver:
Disengage, Monitor, Confirm, Select mode

Actions by the Decision Logic:
Alert, Confirm, Responsibilities check, Human fitness check, Error

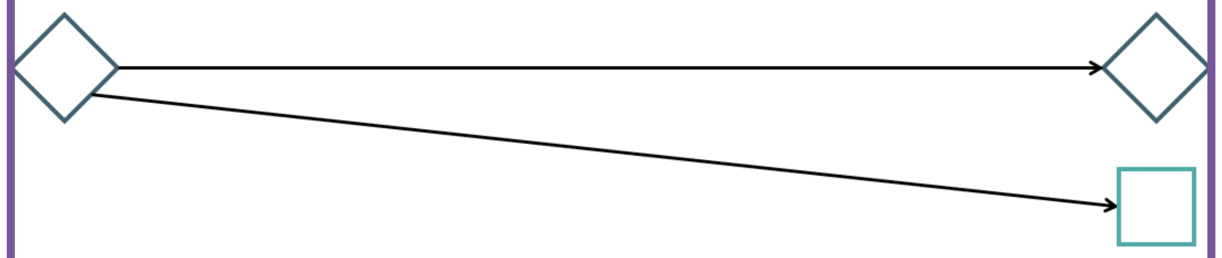


Minimum Risk Manoeuvre and Error messages

Both MRMs and Error messages have the same simplistic interaction diagram. Both start with an message of the problem and finish with explanatory feedback. Where the drivers input at the end of an error message is to continue as before the message, the input at the end of a MRM is to fix the problem that occurred. The latter can range from simply waking up and taking control to calling ANWB/AAA.

Actions by the human driver:
Confirm, Continue to drive

Actions by the Decision Logic:
Alert, Swerve/Brake, Feedback



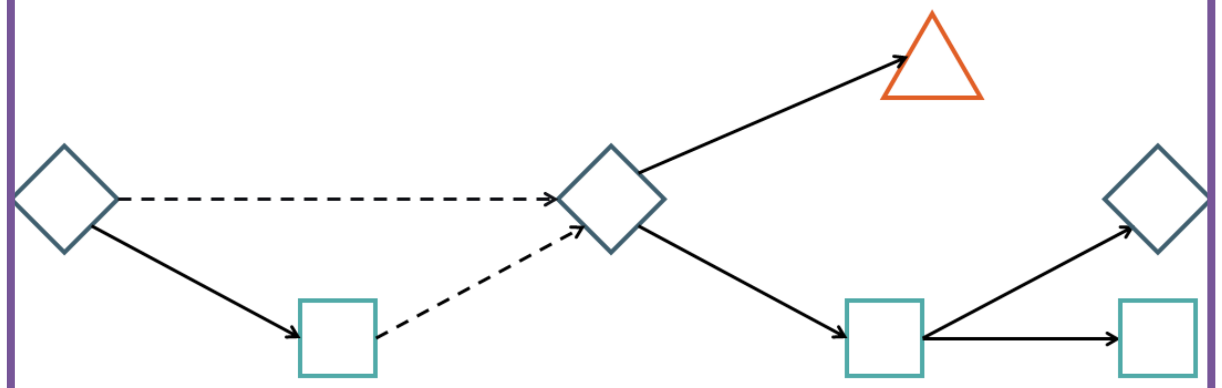
Low urgency, Decision Logic initiated Control Transfer Rituals

Assisted to Manual driving

If the Decision Logic decides that the end of the ODD of assisted driving is approaching, the driver should be informed that he has to take over in a certain time frame. After acknowledging this, the Decision Logic informs the driver of the change when necessary. If the driver does not comply or is deemed unfit, an MRM has to be undertaken. When the driver does take control, the Decision Logic will affirm the takeover and the driver will continue the journey manually.

Actions by the human driver:
Confirm, Assume driving position, Continue to drive

Actions by the Decision Logic:
Alert, Inform, human fitness check, Feedback, MRM, Confirm

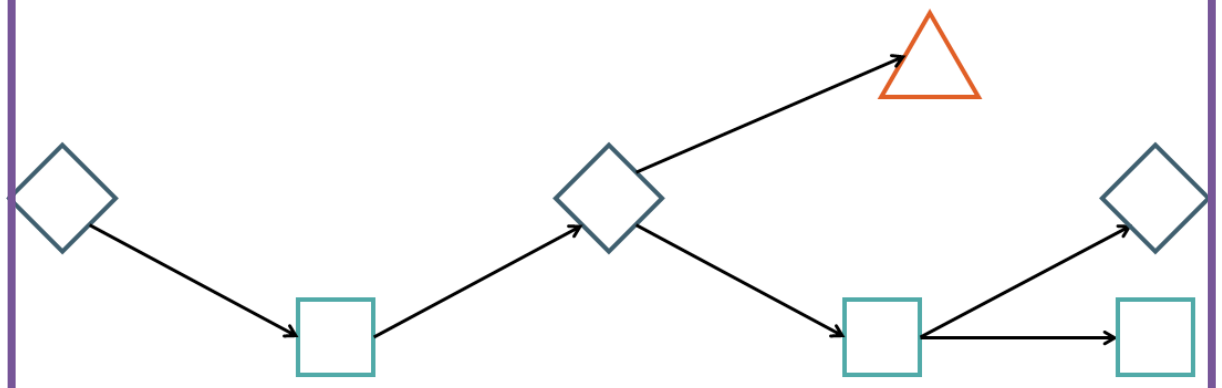


Manual or Assisted to Piloted driving

If the Decision Logic deems it necessary for the automation to take over a significant portion of the driving responsibilities, thus switching to Piloted driving mode, the automation is checked for availability. If this is unavailable, an MRM is engaged as neither driver is fit to continue. If available, the driver can choose whether the automation is engaged and the responsibilities are transferred. When declined an MRM is performed as, again, no one is allowed to drive. In the case that the driver agrees with the change to the Piloted driving mode, the Decision Logic starts to engage the automation and finally confirms the change. The driver can engage in NDRAs.

Actions by the human driver:
Confirm, Decline, Engage in NDRAs, Monitor

Actions by the Decision Logic:
Alert, Inform, Pending, Fitness check, Responsibilities check, MRM, Confirm

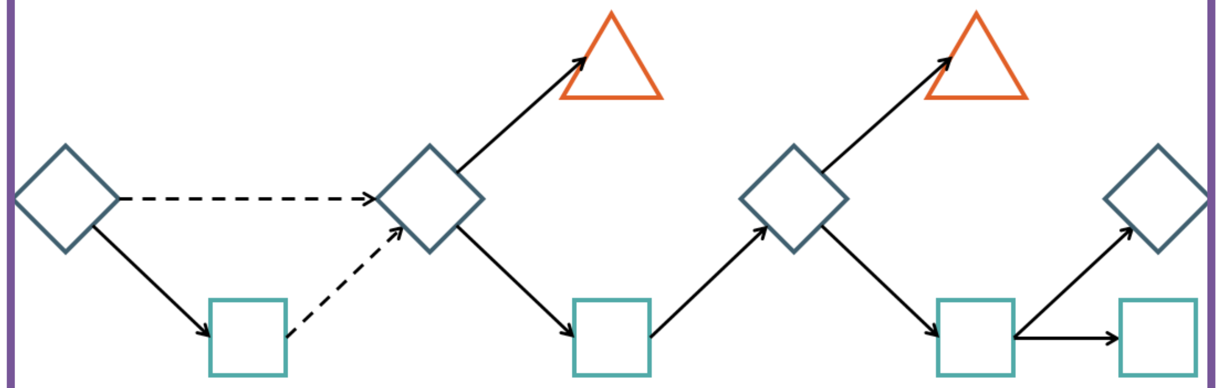


Piloted to Assisted or Manual driving

If the driver needs to take over some or all of the driving tasks in a sizable time frame, the Decision Logic will alert the driver in advance. After that, the drivers fitness is checked. When failed, an MRM will be performed. When passed, the process will continue and the driver must acknowledge that he has to take on more driving responsibilities. When declined an MRM must be performed, when accepted the driver will continue the journey in the loop.

Actions by the human driver:
Confirm, Decline, Assume drivers position, Continue to drive

Actions by the Decision Logic:
Alert, Inform, Responsibilities check, Human fitness check, MRM, Confirm



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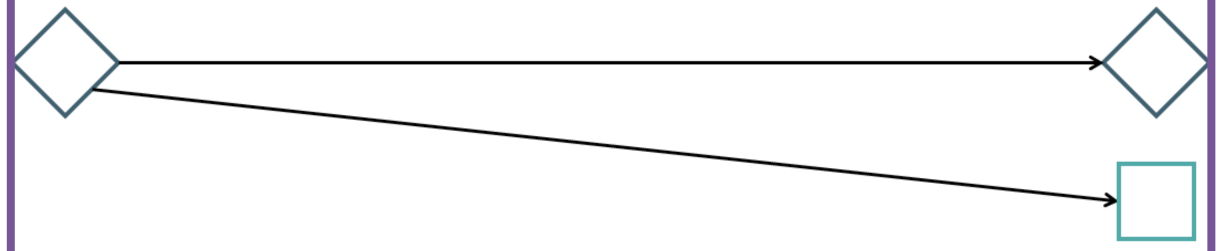
High urgency, Decision Logic initiated Control Transfer Rituals

Manual to Assisted driving

In urgent scenarios, the decision to either switch responsibilities or engage an MRM has to be made much faster in order to ensure a safe environment. If the driver is responsible for the drive, but does not respond safe enough, the Decision Logic will force the automation to perform an MRM. After safety has been achieved, feedback will inform the driver why this action had to take place.

Actions by the human driver:
Confirm

Actions by the Decision Logic:
MRM

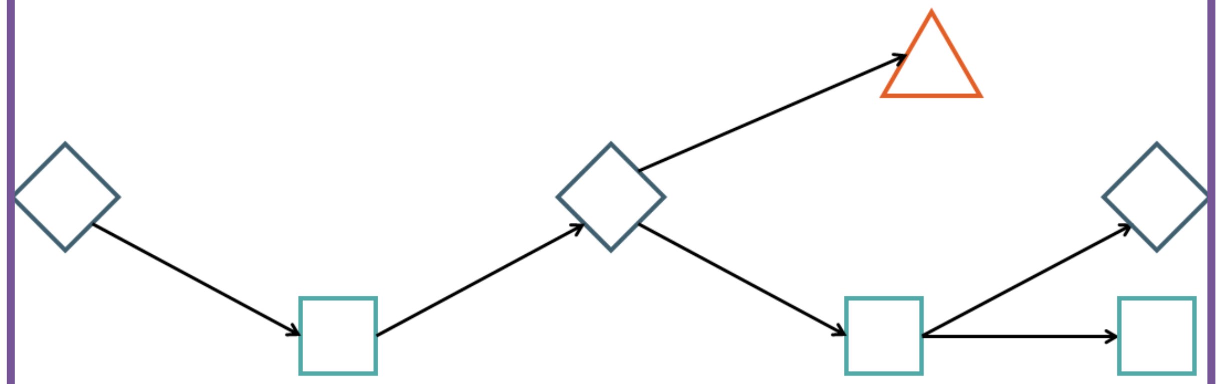


Assisted to Manual driving

This is one of the two scenarios where the reaction time of the driver is vital. The driver is prompted to take over control over the vehicle, because the Decision Logic does not deem the automation fit to continue the drive. The driver is informed that he/she needs to take over control. If the driver cannot respond fast enough or is not fit to drive, an MRM will be performed. If the driver did take over control in time, the drive will continue manually and the driver is informed that he has taken control.

Actions by the human driver:
Assume driving position, Confirm, Continue to drive

Actions by the Decision Logic:
Alert, Inform, Human Fitness Check, MRM, Confirm

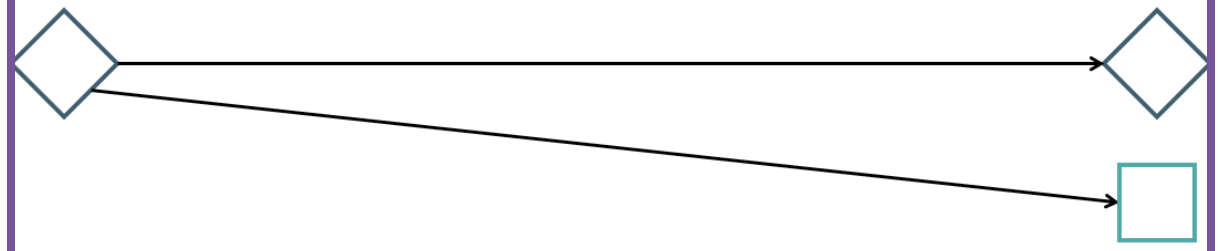


Manual or Assisted to Piloted driving

When higher levels of automation become more capable of taking over the MRM scenarios, this scenario will take over from “Manual to Assisted driving” and allow for a better controlled and wider spectrum of MRMs. However, for the drives perception and the structure of the Control Transfer Ritual nothing changes. The automation is engaged when the driver is deemed incapable of ensuring vehicle safety by the Decision Logic and received feedback in hindsight as to what happened.

Actions by the human driver:
Confirm

Actions by the Decision Logic:
MRM

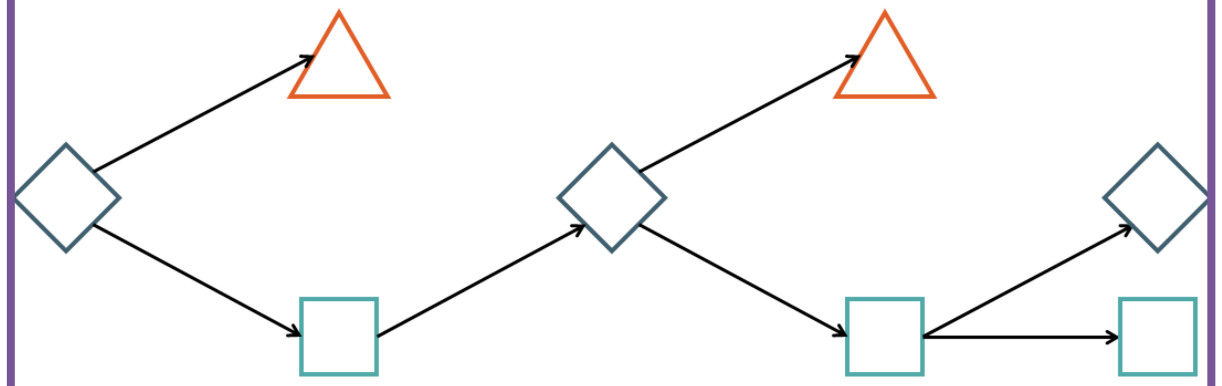


Piloted to Assisted or Manual driving

This is the other scenario where the drivers reaction time is vital. Next to that, because the driver was not in the loop, the driver has to assess the situation properly for a qualitative takeover. Therefore, both driver fitness and driver assessment are to pass the values given by the Decision Logic, otherwise an MRM is necessary. If both are passed, the human driver will be informed that the control has been taken over and what his new responsibilities are.

Actions by the human driver:
Assume driving position, Confirm, Continue to drive

Actions by the Decision Logic:
Alert, Inform, Responsibilities check, Human fitness check, MRM



4

Control Transfer Rituals

Feedback

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Introduction

As discovered in the previous chapter, the Control Transfer Rituals mainly consist of feedback from the Decision Logic to the human driver and input from the human driver to the Decision Logic. This chapter is set up to discover what feedback possibilities can be implemented in the HMI to convey the necessary information for a safe and comfortable journey.

Feedback moments

One of the key aspects to HMI design is to communicate the information gathered and processed by the decision logic to the human driver. This process of communication from machine to human is called “feedback”. Feedback, however, is broad and rather unspecified. This chapter aims to narrow down the possible solutions to communicate key information to the driver, in order to create a safe and comfortable driving experience.

As mentioned before in MEDIATOR D1.1, Naujoks and his team have developed a set of guidelines, or rather a checklist, to HMI design for automated vehicles (Naujoks, F. et al., 2019) (Appendix 6). A separate case study has empirically validated that the use of this checklist is beneficial to user acceptance (Lilis et al., 2019). Though not all are relevant for the development of the Control Transfer Rituals, some give valuable insight in basic principles, current knowledge gaps, use of uni- and multi-sensory signals, and implied urgency in textual messages. The theory dictates that clear feedback results in user understanding creates trust and will adhere to user acceptance. As mentioned, feedback should be given clearly, timely and should be available if desired.
Five phases of feedback during a CTR can be determined, which are in chronological order: Set-up, Motivate, Guide, Confirm, and Evaluate. Though they are not all applicable for all take-over scenarios.

The most critical point of feedback is when the transfer of control is initiated by the Decision Logic and directs vehicle control to the human driver. In such case, the term used is to initiate a Take Over Requests (TOR). However, as seen in the previous chapter, the Decision Logic can also initiate other changes in driving mode or suggest a transition which is then in turn fulfilled by the human driver. In this latter case, the actual control transfer ritual is initiated by the human driver.

In the example of a TOR, the feedback, or initiation, can be done with a wide variety of actuators and over different levels of urgency. Correct use of the actuators can speed up reaction time and enhance the quality of the takeover. Urgency is a key factor in safety related Control Transfer Rituals and must be communicated to the human driver to allow him/her to respond accordingly.
To communicate urgency, perceived urgency (i.e. the perception of the urgency by the human driver) is equally, if not more, important as the urgency of the situation.

Feedback modalities

As organisms, we humans take in information through our senses. Five primary senses have been identified in taste, hearing, sight, touch, and smell. However, this field of knowledge is constantly expanded by the discovery of senses that define variables such as velocity, balance, time, and temperature. Within the context of HMI design, the literature steers towards five potential stimuli: visual, thermal, olfactory (smell), auditory, and haptic.

Auditory

Warning sounds are, in nature, divided over a spectrum of high-urgency and low-urgency signals. In research was found that civil aircraft auditory warning systems could be defined over a set of parameters, some having a direct effect on [perceived] urgency (Patterson, R., 1982). Though much research has been done to further explore options, claims and conclusions found in Patterson’s paper, many parameters are still sound. He identified parameters of power (i.e. intensity), Inter-Pulse Interval (i.e. ISI), pulse duration, vocal communication, spectral characteristics (i.e. tone and tune), ergonomics, and pulse shape. A technical note that combines Pattersons paper and research done by E. Hellier between 1989 and 1993 distils the parameters to create perceived urgency (Hellier, E. et al, J., 1997) (Formula 1). These warning parameters are pitch [Hz], speed (pulse-rate), repetition (number of repetitions of a unit of pulses), in-harmony (amount of in-harmonic partials between the fundamental frequency and the first harmonic), and length (total signal duration). Four out of five, with the exception of length, are proven to have an additive relationship when used as power functions based on Stephens Power Law. The additivity of these warning parameters dictates that one can predict perceived urgency based on power functions in order to create corresponding signals. Hellis and Edworthy also reason that these additivities allow for different urgency level within a particular warning (e.g. low-medium-high urgency). These can be used for either guiding a user through an action (reduce or elevate perceived urgency when the required user attention is met or not within a certain time-frame) or communicate different actions through urgency mapping (i.e. matching urgency of the situation to the urgency of the signal) (Edworthy, 1994). The latter implies that urgency can be situational, which is another guideline for design of auditory warning systems as proper urgency mapping will stimulate priority and meaning of a warning signal (Hellis et al., 1997).

Vocal

The textual form of auditory signals is vocal communication. Therefore, part of guidelines stated by Naujoks on textual signals are relevant: keep messages clear and concise. Again, language in both native tongue and refrain from the use of technical terms. It can be reasoned that where colour, size, and font communicate further values such as required attention in text, intonation and volume do in vocal signals.
An advantage of vocal communication is that it is a form of anthropomorphism, the attribution of human-like features. Both Mösinger, and Hoff and Bashir conclude that a personality, and therefore voice, elicits trust when it is perceived as patient, capable, and knowledgeable. Waytz et al (2014) identified that the spoken accent influences trust levels, where a spoken voice in the user’s native accent can heighten trust levels. Perceived urgency is influenced by speech rate, average fundamental frequency, warning message, message format, and interval between warning messages (Jang, 2006). This can be linked to both other auditory parameters such as ISI and pitch, and other textual parameters, such as Naujoks guideline that the semantics of the message should be in line with the urgency of the signal. Jang, just like Hellier et al., refers to Stephens Power Law as a method to quantify the effect of acoustic changes on perceived urgency. Jang theorizes that the gender of the voice can influence the perceived urgency, although no conclusive evidence has been found.

$$U_{pe} = k\left(W_{pa}\right)^{m}$$

Formula 1 - Perceived urgency
- *Upe is Perceived Urgency*
- *Wpa is Warning parameter*
- *k is the intercept of the best fit, a constant in this case (1.65)*
- *m is the slope of the best fit, dependant in this case on total time of the stimulus [ms]*

Visual

Visual feedback can be split in two categories: visualized and textual feedback. As mentioned, Naujoks managed to compile guidelines on textual feedback. Text can be a very explicit signal to communicate actions, reasoning, warnings, and urgency if used correctly. Therefore, the guidelines state that textual signals should be as short as possible, without losing the message. Furthermore, text should be legible and in the language of the user. Language is not just native tongue, but also the avoidance of technical terms and symbols.

On the level of urgency, their guidelines state that the semantics of the text should be in line with the urgency of the situation. Alongside Naujoks, Wickens and Hollands (2000) dictate that design factors such as font, colour, and size of the text can influence the attention that the user gives to the textual feedback.

Visualized feedback is done through colours, shape, brightness, and frequency. Most known are symbols as used in current vehicle HMI design, which are regulated by the EU (Chapter 2). As of today, no icons have been standardized for both SAE level 2 and up and TORs though the regulations can guide in development and restrict in colour and shape. Urgency through visual feedback can be perceived by the flashing frequency and brightness of the light.

Haptic

Though perceived urgency through text messages has been touched upon by Naujoks, the perceived urgency of vibrotactile and auditory signals are defined by others. It can be concluded that vibrotactile signals, e.g. applying torque to a steering wheel (Talamonti, W. et al., 2017), are suitable for communicating urgency. Talamonti concluded that signals with high peak amplitude of 5.0 [Nm], high frequency of 0.36 $[s^{-1}]$ perceived as more urgent than signals with a low peak amplitude of 2.5 [Nm] and a low frequency of 0.5 $[s^{-1}]$. The preferred signal by the user, however, was a mid-way of medium peak amplitude and frequency. Another research validated the claim that urgency through tactile patterns can be communicated by change in the Inter-Stimulus Interval (ISI) and the intensity (White, T.L. et al., 2014), where a higher intensity, combined with a shorter ISI, communicated higher urgency.

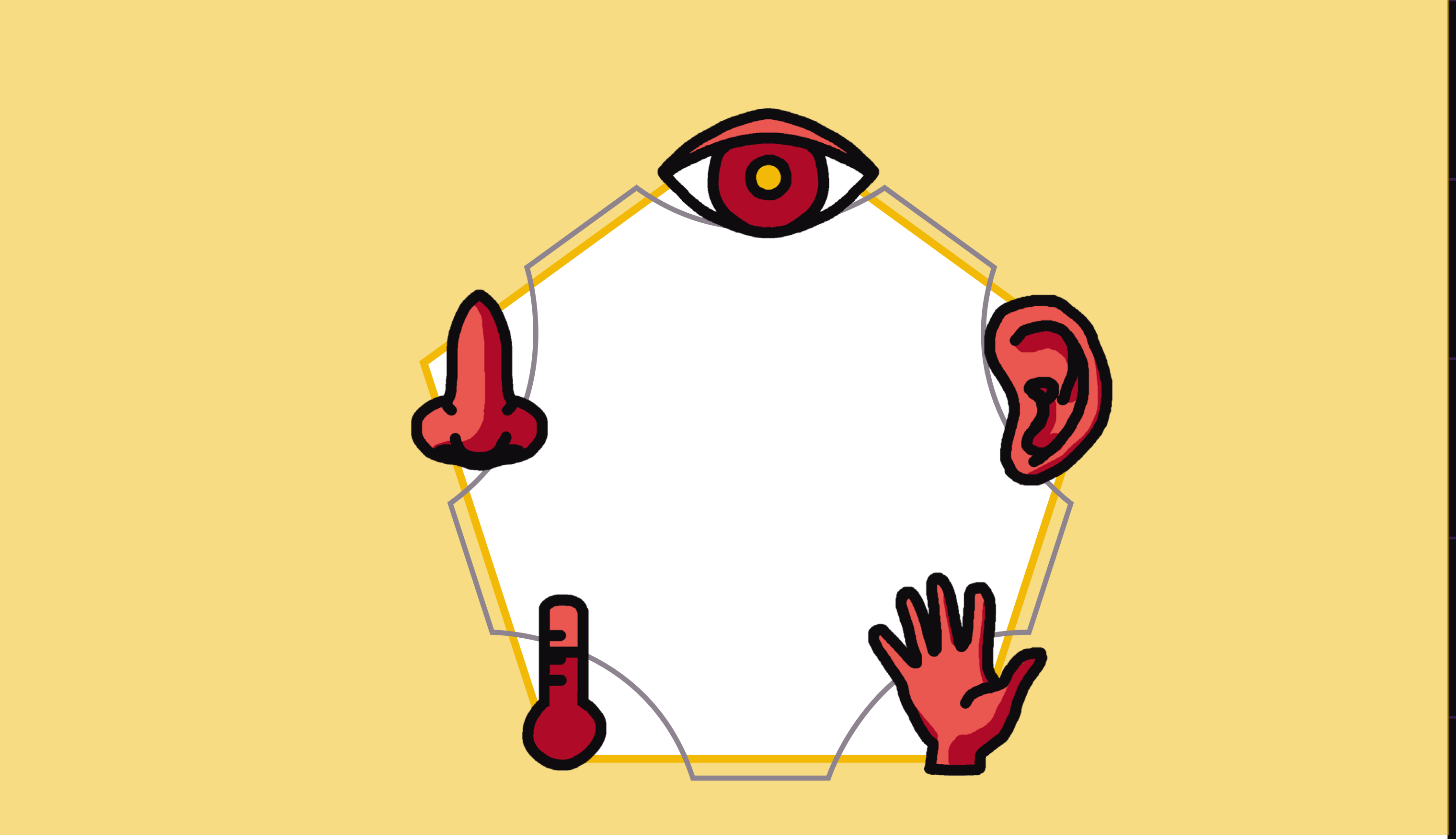
Meng et al. (2015) identified that secondary tasks rarely involve the sense of touch.

Physical incentives

An extreme method of communicating through haptic feedback that an action is required by the human driver is to physically move objects in the vehicle. These objects move to elicit a takeover by either moving the human driver or object to or from the driver’s position. This can be applied in numerous manners, such as a collapsing steering wheel, a reclining seat, or portioning off certain switches. In contrast to haptic feedback that relies on the sense of touch, moving objects also triggers the sense of vision, space, and, in limited cases, the sense of balance. A perceived sense of urgency can be attained by moving the objects faster, comparable to how high frequency combined with high amplitude does for vibrotactile haptic feedback. A risk arises, though, that moving objects can harm the occupants of the vehicle. Therefore, safety should not be compromised by these movements. An example is a retracting steering wheel that needs to accommodate airbags at all times, even during transition, and must not impact, or worse impale, the driver in case of an urgent TOR.

Temperature

It is widely known that environmental temperature affects human behaviour and therefore there is a potential this can be utilized to prompt a TOR. An optimal comfortable temperature to work in is observed to be 25°C (Lan et al. 2009), where 24 and 26 were regarded as comfortably cool and comfortably warm respectively. These temperatures were not found as the optimal performance range, as this varies over time. Short-term tasks were relatively better with a lower environmental temperature. However, a higher temperature was advantageous to maintain attention at prolonged exposure of 25 minutes, in extreme conditions, or 30 minutes, in moderate conditions (Choi et al., 2019). Higher temperatures dictated a lower perceived attention level, where lower temperatures corresponded to lower brain activity (shown on an EEG). At prolonged periods of time (50+ minutes), people perceived an optimal work temperature range of 24 – 27 °C, where the EEG showed an optimal attention ability at 27 °C. Both extreme warmth (34 °C) and extreme cold (15 °C) had a negative effect on the attention ability. In the first 15 minutes, temperatures of 18 – 21 °C shown the highest attention ability. Within the first 5 minutes, no effect can be derived from temperature change.



Motor skills have a reduced accuracy at lower temperatures (19 °C), attributed to dexterity loss in the fingers (Lan et al. 2009). More research confirms that dexterity does decline at lower temperatures (18 °C) and performance can drop by 5-15% (Seppänen et al, 2004). This latter research concluded that productivity is not affected at an optimal range of 21-25 °C. At short time intervals, motivated people can maintain a high productivity even under relatively high or cold environmental conditions if they are trying to do their best (Lan et al., 2009).

Combining all research would suggest that temperature is a sub-optimal actuator as the effect of change in temperature changes over time. Furthermore, temperature change has minimal initial effect, does not communicate a specific task, and has no short-term effect if the person is already motivated to act. This concludes that temperature change has no use for high urgency situations. However, for specific use cases, temperature can be used to increase take-over quality as a lower temperature range of 20+1 does increase the driver’s attention ability within the first 15 minutes. This is will apply for the quality of a non-urgent take-over from 4, as it allows the TOR to take 15 minutes and be initiated at least 5 minutes prior to the actual take-over. In contrast to olfactory signals, temperature-based actuators are already developed and implemented in vehicles, as climate control systems.

Noteworthy comment on these temperature ranges is that they were derived from Chinese citizens, which raises the question whether preferred temperatures are influenced by geographical location of the research. It could be that the range shifts in accordance with average temperatures of the location/region/country (e.g. northern Sweden vs. Spanish Mediterranean coast). If this is the case, it could be argued that not a set temperature would change the optimal attention ability nor the optimal motor functions, but a difference to the defined optimum. In extension of this philosophy, the driver should experience an increase in attention ability at a temperature difference of -3 to -5 °C for the first 10 minutes after a 5-minute initiation period. The reduction of motor performance is not necessarily affected parallel to the attention ability.

Olfactory

A few researchers have even considered the possibility of using olfactory warnings (Baron and Kalsher, 1998; Ho and Spence, 2005; Raudenbush et al., 2005; Schuler and Raudenbush, 2005 see Spence and Ho, 2008c, for a review). For instance, Grayhem et al. reported that the presentation of both cinnamon and peppermint odour led to improved alertness while driving (Grayhem et al., 2005). Meanwhile, others have reported that 'unpleasant' smells, such as (synthetic) body odour, might be even more effective in terms of alerting people than pleasant odours (Chen et al., 2006). Such results would appear to hint at the promise of olfactory cues as a novel and potentially subtle means of keeping the drowsy driver alert (Baron and Kalsher, 1998; Schuler and Raudenbush, 2005; Spence and Ho, 2008c; Susami et al., 2011). Ambient odours (no matter whether they are pleasant or unpleasant) can also be used to reduce people's reaction times (RTs) to visual or auditory stimuli (e.g. Millot et al., 2002), and give rise to an increased accuracy of responding to tactile stimuli (Ho and Spence, 2005). However, given the fact that olfactory stimuli are difficult to perceive in a timely manner, at least when compared to visual, auditory, or even tactile cues (Spence and Squire, 2003), they do not really represent a plausible alternative for time-critical collision avoidance situations. Hence, olfactory warning signals will not be elaborated on further within the scope of the present report.

Feedback variations

Multimodal stimuli

A unimodal stimulus affects one sense, multimodal stimuli trigger multiple senses for the same message. The use of unimodal feedback is limited due to drawbacks related to all modalities (Meng et al., 2015) (Table 4). The required modality and its intensity could differ per TOR due to the nature of the NDRA (Petermeijer et al,2016). They also found that both auditory and vibrotactile feedback are effective to warn drivers of a TOR and a combination of these modalities will improve reaction time.

Research at TNO evaluated the effects of temporal parameters and sensory modality on the perceived urgency of warning signals (van Erp, J.B.F., et al, 2014). Visual stimuli (V) were signalled by an LED, auditory stimuli (A) by a single tone speaker, and tactile stimuli (T) with a vibration actuator. They state that bi- and trimodal signals are perceived as more urgent than their unimodal constituents, most significantly VT and VAT. Furthermore, their research is in line with the findings of Talamonti et al. and White et al. by concluding that both a short ISI over a fixed timeframe and a higher signal rate result in higher perceived urgency. A note is that this is not a monotone increasing relation and that pulse duration has less effect than ISI. Their findings confirm these trends across all modalities.
The same effect has been tested by Blanco et al in 2016, where their findings suggested that most effective hands-off strategies to communicate a TOR were those that incorporated non-visual components.

In conclusion, unimodal feedback usually lacks to convey information both quantitively and qualitatively. In the guidelines of Naujok et al., guideline #18 dictates multimodality as a key factor in HMI design. It attributes this to an increase in reaction time and notes that, in high urgency scenarios, auditory and haptic feedback should be combined with visual feedback in order to retain auditory/haptic information in the short term memory and reduce serial information processing. Multimodality is advised to both increase reaction time and allow a better understanding of the feedback.

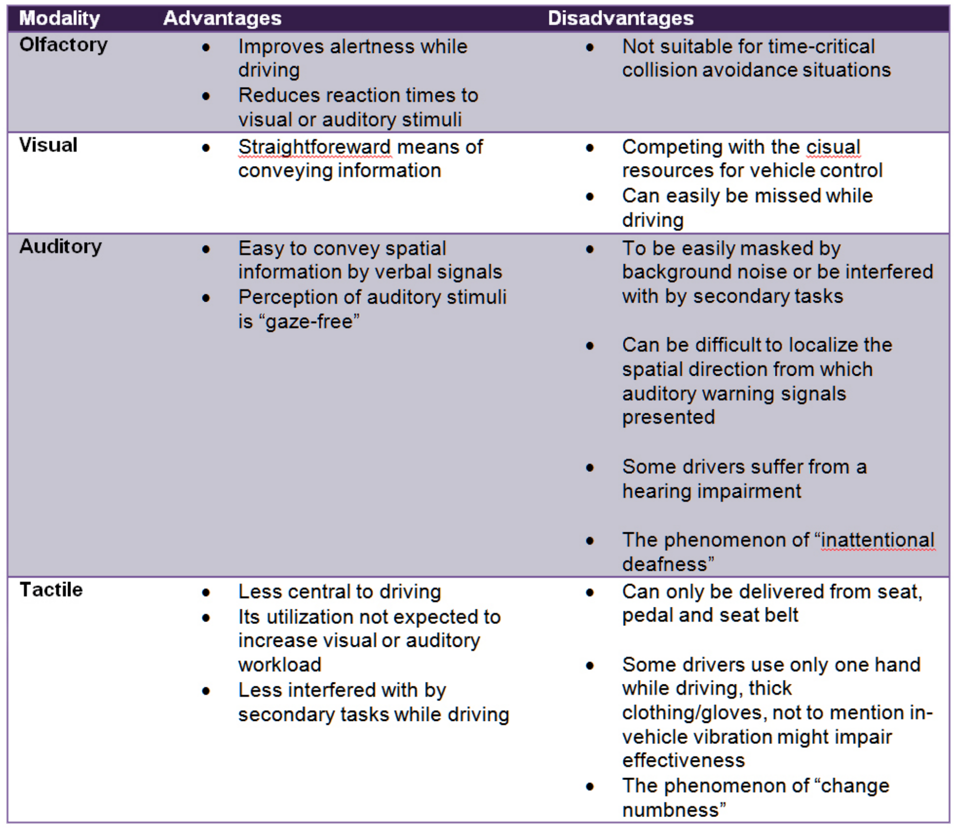
Staged stimuli

To communicate a TOR, it is possible to use staged signals where the signal becomes more urgent after a short while. The effectiveness of a staged signal to warn a human driver at level 3 automation was evaluated by Blanco et al (2016) and came back with mixed results. Blanco tested a signal of 4 phases that increased urgency with each phase: an informational message for 20 seconds, two 10 second cautionary alerts, and a final 10 second imminent alert with the highest urgency. Their findings showed that all participants reacted to the signal before the final phase. However, it was found that staged signals prompted a slower reaction than others, presumably due to overtrust in the system, compared to a singular high urgent warning. As the warning signal lengthens and builds, and the user is used to this, the first signals can be ignored, until the human driver deems the signal urgent, or annoying, enough to react to.

Directional stimuli

Across modalities, directional signals can significantly reduce the Time to Take-Over (TTO) (Bella and Silvestri, 2017; Cohen-Lazry, et al., 2018). By alerting the direction of an oncoming obstacle in relation of the vehicle, users have been found faster to react appropriately. In the simulator study of Bella and Silvestri was found that directional auditory feedback allows for the fastest reaction time when compared to directional visual feedback and no feedback at all. Vocal identification of the oncoming obstacle was found most suitable for reduction of reaction time, which allowed for sooner braking thus increased the speed reduction time. This is argued to help prevent rear-end collisions, because the vehicle's stop is more controlled.
In terms of swerving, instead of braking Cohen-Lazry, G. et al. (2018) found that in a participant-based test where actuators were placed in the seat-pan of a driving simulator, the location of a signal can influence reaction time if paired correctly with the direction of an obstacle. They also found that corresponding tactile impulse allowed the driver to assess and respond more appropriate to the scenario. An example where this is useful is in highly automated driving scenarios (≥ SAE level 3), where the driver is not expected to continuously monitor the road. A Take Over Request (TOR) can prompt the human driver to avoid an obstacle that the automation cannot handle.

However, Petermeijer et al (2016) found that directional auditory- and vibrotactile warnings do not elicit a specific directional swerve in lane change scenario's . This is attributed to the fact that, when given the option, directional warnings were overruled by habit and regulations. In this case, participants swerved left, likely due to German laws that dictate overtaking along the left side of a vehicle. However, further research showed that when instructed prior to the event, 80-90% will follow the directional warning (Petermeijer et al (2017). This latter indicated that vibrotactile feedback in the driver's seat is an effective method, but all research considered, the use for directional vibrotactile feedback in TORs might be limited.



Modality	Advantages	Disadvantages
Olfactory	• Improves alertness while driving • Reduces reaction times to visual or auditory stimuli	• Not suitable for time-critical collision avoidance situations
Visual	• Straightforeward means of conveying information	• Competing with the cisual resources for vehicle control • Can easily be missed while driving
Auditory	• Easy to convey spatial information by verbal signals • Perception of auditory stimuli is "gaze-free"	• To be easily masked by background noise or be interfered with by secondary tasks • Can be difficult to localize the spatial direction from which auditory warning signals presented • Some drivers suffer from a hearing impairment • The phenomenon of "inattentional deafness"
Tactile	• Less central to driving • Its utilization not expected to increase visual or auditory workload • Less interfered with by secondary tasks while driving	• Can only be delivered from seat, pedal and seat belt • Some drivers use only one hand while driving, thick clothing/gloves, not to mention in-vehicle vibration might impair effectiveness • The phenomenon of "change numbness"

Table 4 - Advantages and disadvantages over modalities Meng et al (2015)

Cognitive processes

The human brain is remarkable at problem solving. However, during a drive the interactions should not be a problem. In the case of mass market use, the question is whether the product should facilitate all novice users or should allow frequent users to interact rapidly with a product. In other words, should every action and step be explained and enforced or not? In the gaming industry, the fundamental interactions are usually taught through a tutorial. This is a safe-haven in which the user can accommodate to the game and learn all the basics. As consequences of error in automotive use can have deadly outcomes, the user must learn how to drive in supervised lessons and graduate a drivers exam. Automated driving, especially during the transition from currently available technology to fully automated vehicles, will add an extra layer of complexity to the HMI, thus to the elements that one must learn.

In essence, humans can learn what to do and do not want to be retaught every single step every single time. That is why it is important to design an HMI that allows previous knowledge to be used and new knowledge to be easily picked up. In the actual use of the product, it must be expected from the user to have done a tutorial/ lessons and knows the basic interactions.

In a conversation with Dr. René van Egmond, cognitive models were discussed. Models such as the Human Information Processing model and Rasmussens Action Control Model. These models identify a hierarchy in behaviour based on knowledge.

In general, Rasmussen identifies that when learning a skill, the time shortens and efficiency rises when executing associated tasks. This is due to the behaviour when performing these tasks, which can be distinguished in three levels: knowledge based, rule-based, and skill-based. The more one learns, the less cognitive processes one has to go through to execute an action.

The HIP model agrees with these findings, but explains better how mental resources are allocated and how memory is handled. In figure 15 the HIP model is used to describe the cognitive process of a human driver during a control transfer ritual.

To take away from this conversation is that the idea that humans respond better and faster with learned skills is true. However, also true is that some skills must be unlearned in order to learn a new one. Dr. van Egmond gives a great example: the scroll direction of the Macbook changed with an update, without clear mention of that change. Instead of sliding up to scroll up, it would scroll down. This makes sense if you are used to an iPad or other touch-screen devices. However, in order to use the touchpad efficiently, one has to unlearn to scroll up and learn to scroll down.

This also fortifies the argument that a change in interaction during Control Transfer Rituals has to be somewhat familiar to the human driver, but an 'overwrite' of an existing skill should be avoided.

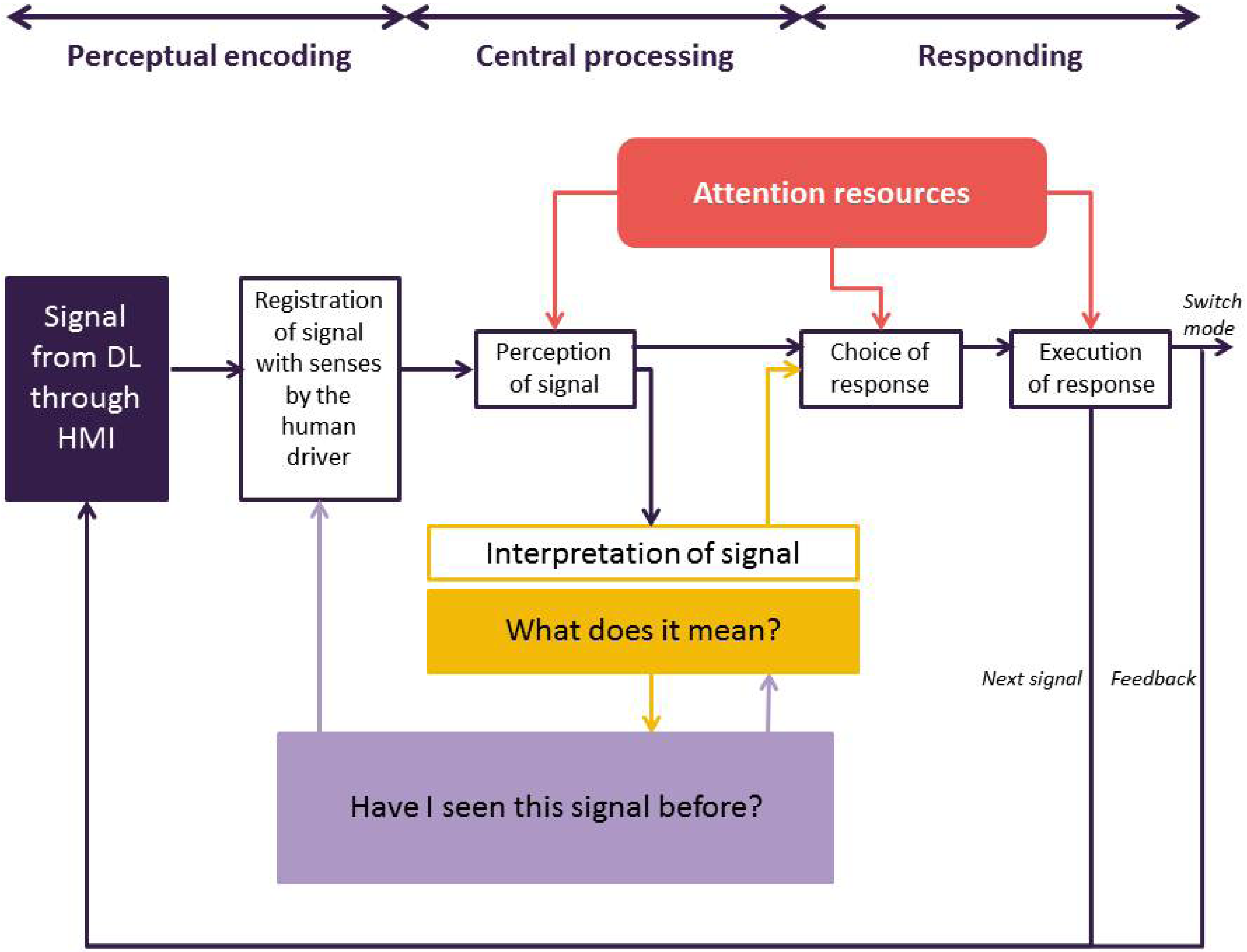


Figure 15 - Adjusted Human Information Processing model to Control Transfer Rituals

5

Control Transfer Rituals

Input

C
1
2
3
4
5
6
7
R
A

Introduction

Up to now, the information stream from the Decision Logic to the human driver has been assessed. However, to create a functional HMI, the user has to be able to communicate information towards the Decision Logic. This information stream is the input and will be the topic of this chapter. Duly note that this is conscious user input, where sensors for factors such as fatigue, stress, and distraction are not included. Though the Decision Logic will need this information to assess the fitness of the human driver, it is not deemed part of the HMI.

Existing HMI designs

In order to assess current philosophy behind interaction design required for automated driving, the current and conceptual designs produced by OEMs can provide some insights. The design components and non-automation related buttons, switches, and screens can be stripped to create schematic overviews that are comparable to one another.

Current HMI design

As is the case with regular HMI design, current generation automated vehicles provide insight in today's practical view on interaction with vehicular automation. In modern day vehicles there is little change in interaction design compared to regular vehicles. Currently up to SAE level 2 is available and appears to build on the deployment of ACC. As mentioned before, SAE level 2 is the combination of lateral and longitudinal movement. This is in all practice the combination of ACC and LKA, which is in modern cars available in separate packages of ACC, LKA, and a combination (Tesla Model S, Aston Martin DBX, Audi A4/A8) or as combined packages that only offer ACC or a combination of ACC and LKA (Model 3, Volvo XC60).

In terms of interaction design, three distinct models can be categorized:

1. Activation through separate buttons
2. Activation by pressing the same button twice / incremental settings
3. Scrolling through modes to select a desired one

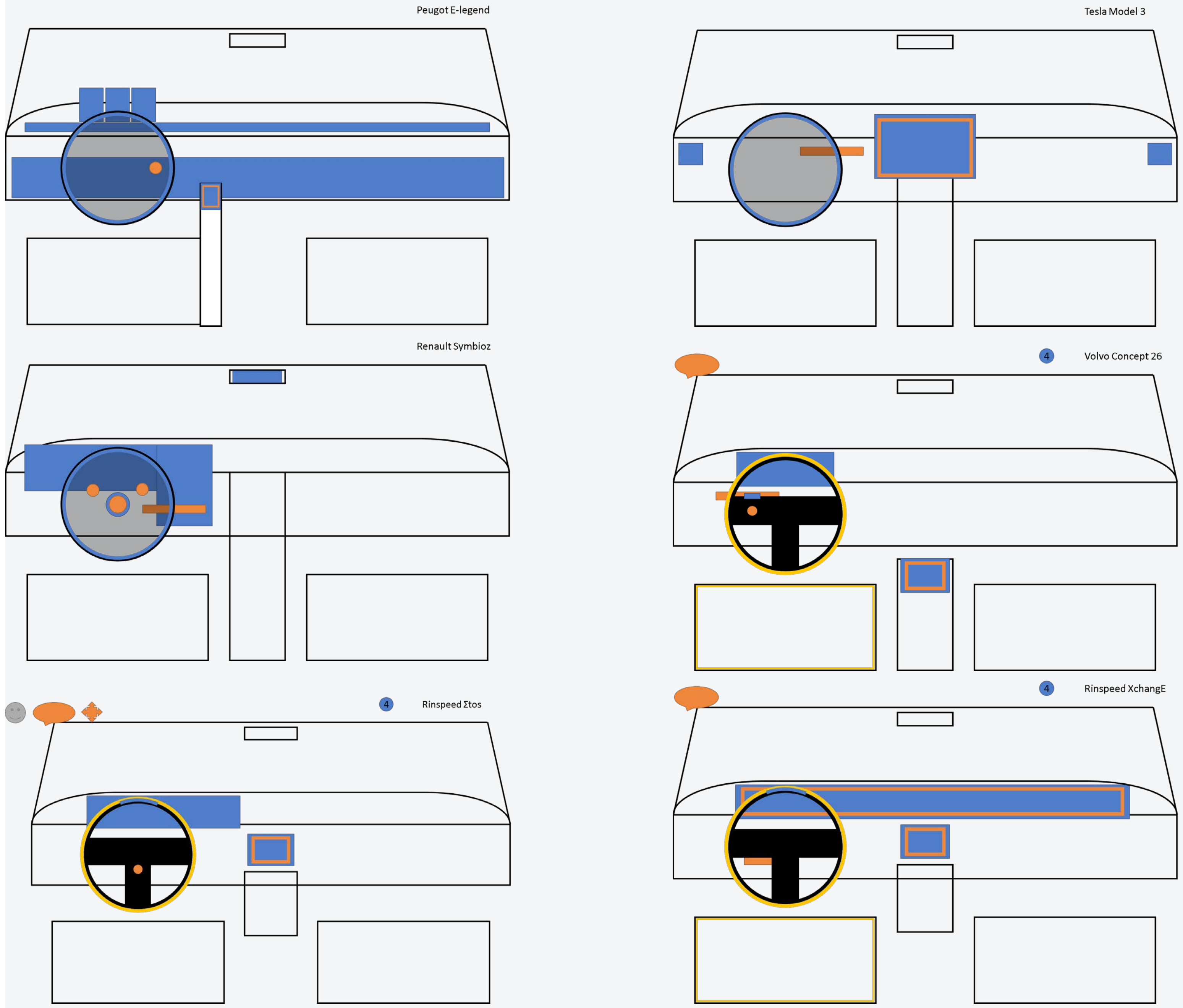


Figure 16 - Schematic dasboards

Conceptual HMI design

An analysis of concept vehicles allows for insight into modern thoughts on higher tier automation. In most cases the interaction is a second or third priority (after technology and design), though more brands are looking into the perception of the interior. In many cases, the perception is that automation allows vehicles to turn from obligated transport cocoon into a living room of freedom.

Now, this mentality is idealistic and mostly related to SAE level 5 autonomous vehicles, in which not even a steering wheel is necessary (i.e. Volvo 360c (Volvo, 2020) or Audi AI:CON (Audi, 2020).

More interesting are the conceptual HMIs that have been developed for both up to level 3 automation, such as the TANGO and Byton M-Byte, and up to level 4, such as the Toyota LQ, Honda ADC, and Renault Symbioz. Again, to assess these HMIs and make them comparable, these are schematized (Appendix 2). Now, there is a large variety of design choices that influence the interaction and placement of relevant buttons, switches, levers, and screens that is not yet seen in current vehicle design, such as the addition of armrests and foldable/movable steering wheels or omittance of a centre console. Furthermore, there are two different interpretations to user interaction with onboard technology, where one is prompted by switches, levers, gestures or touchscreens and the other is based on an artificial intelligence (AI) companion that users can converse with. These methods, however, fall under the same CTR scheme.

What most companies seem to agree on is that the steering wheel and foot pedals are an instrument to dictate the driver; available and within reach of the driver seat indicates that the driver is responsible. The Honda Augmented Driving Concept and Rinspeed XchangE take this to a new level, where the steering wheel moves to a central, neutral position that allows even a switch of control between human driver and passenger. The place of the steering wheel is a possible solution to communicate whether a vehicle is driving autonomously and seems to work as a pointer to show who is in control.

A development that is also very prevalent is the upcoming use of touchscreens over physical buttons, levers, and switches. Though the Germans would not approve (see Chapter 2), these appear to have a use in automated vehicles. Screens and lighting are found to work very well for communicating information but lack the ability to draw immediate attention (Chapter 4).

Interaction complexity

To make product interaction from the user point of view an explicit, discussable subject the ease of use is an excellent method. An easy to use product would benefit the user to understand the functionalities of a product, what actions are required and how to perform them. In general, for HMI sake, D. A. Norman (1988) identified that the complexity of appearance appears to be determined by the number of controls. The duality lies in the difficulty of operation, which is both determined by finding the correct control and the execution of the function. The first correlates negatively with the increase of controls, the latter correlates positively. This dictates that fewer controls, merging multiple functions under one control, would make the HMI appear easier to use, but oversimplification can lead to wrongful execution as the user cannot find the correct input.

Use is one directional, user to product actions or influence. In automation HMIs, the communication goes both ways, they interact. Due to this step, ease of interaction would be more fitting. However, as to rate the interaction on a scale of use, the choice has been made to invert the scale. This leads to the term interaction complexity. With low interaction complexity, the ease of use is high and vice versa. This term is not a unit with fixed numbers and cannot be measured as so, but it can be scaled from high (too complex) to low (negligible).

The ease of use can be split into twelve factors that each influence the usability of a product (Simplicable.com, 2016). However, when transcribing these fundamentals to automation related fundamentals, a set of six key factors can be identified:

- Control placement (accessibility)
- Control grouping (convenience)
- Type of control (ergonomics)
- Feedback methodology (information)
- Feedback placement (information/ accessibility)
- Intuitiveness (learnability).

Combined with the identified factors by Norman (1980) of number of controls and the appearance of complexity, a set of eight fundamental factors define interaction complexity.

In Figure 17 and Figure 18, the interaction complexity (y-axis) is set to the levels of SAE automation (x-axis). Based upon the previously mentioned fundamentals, vehicle HMIs can be plotted to show relative differences in level of interaction complexity. To correctly use the vehicular HMIs of both regular vehicles and concept vehicles (Appendix 2), the x-axis has been set to SAE levels 0-5. A detailed variant is portrayed on the next page.

At the upper limits of the scale, the interaction is too complex and is dangerous for use as the driver will be either too distracted by the interaction that it impacts road safety or the interaction is too complex to figure out and will never be used. In this case the fundamentals are applied poorly or not considered at all. Where it becomes uncertain that all fundamentals are properly implemented, it is considered a concerning level of interaction complexity.

At the ideal standard, all fundamentals are taken into account and allow a driver to operate the vehicle at a safe, controlled manner whilst being informed in the processes that the automation undertakes. This can be considered the proper interaction complexity. At this point, the vehicle can be operated by a driver that is fully in the loop.

In the lower limit, the complexity of the interaction drops to an extend that is impossible as added features will add more interaction. However, as the level of automation advances past SAE level 2, the required amount of controls dwindle, especially between SAE level 4 and level 5. Because the functionalities are largely taken over by the automation and the mandatory amount of controls can lower.

Artificial Intelligence is a much thought up methodology to allow a relation between the human driver and the automation. This usually lowers the interaction complexity, as control is mostly shifted to vocal commands. Even if the A.I. does not interact with the driver directly but instead functions as a learning computer, certain interactions can be streamlined and personalized. This also adds to the ease of use, or lowering the interaction complexity.

Questions raise whether companion A.I. is a viable, wanted technology or that people prefer not to talk to their vehicle. Furthermore, a rising use of vocal input and feedback would compromise the deaf and people with a speech impediment that are able to drive vehicles with physical controls. Arguments to rate A.I. interaction as more complex are that the user has to remember commands over physical controls, which are less arbitrary, and that a dialogue would take more time than pressing a button. However, it would improve the trust in the system (Chapter 2 - User acceptance).

On the x-axis, the level of automation tells the level of automation that the vehicle, thus the HMI, is designed for. The HMIs are not rated at an exact level of automation, because the technology and the implications of the SAE levels are different. A vehicle only capable of Lane Keep Assist and Adaptive Cruise Control is rated as level 2 automation, but so is a vehicle that is also equipped with Lane Change Assist. Again at level 4, the vehicles are capable of almost fully autonomous driving where the Designed Operation Domain can differ. A vehicle that allows level 4 on highways is less advanced that one that can do highways, inner-cities, and provincial roads but cannot drive in rural area, though they are both rated SAE level 4. Which is why the scale goes out to SAE level 5, at which (nearly) all functionalities are taken over by the automation and the interaction, thus the interaction complexity can drop to negligible. Furthermore, certain vehicles are currently equipped with level 3 hardware according to their manufacturers, but are simply legally not allowed to use it (Audi, 2018).

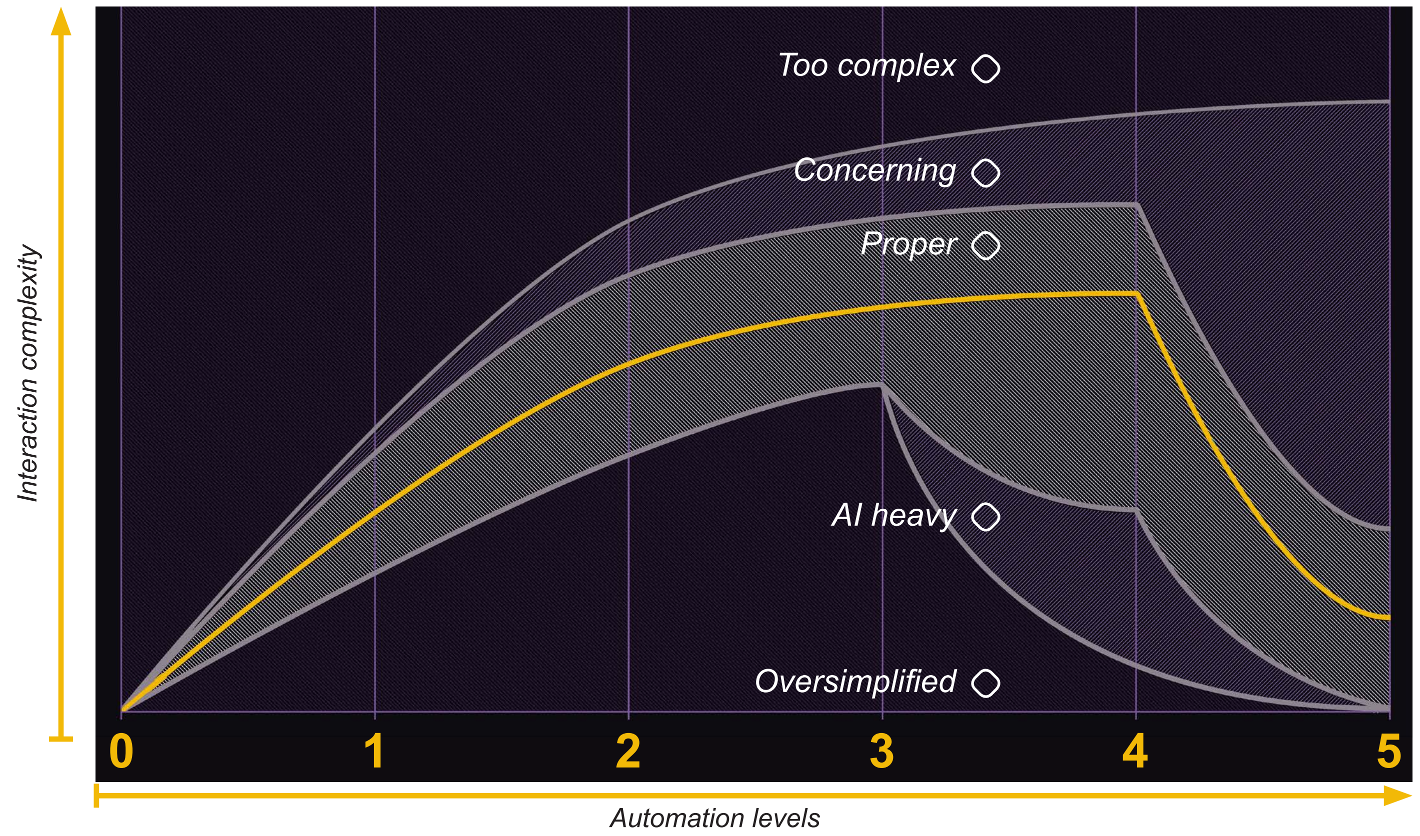


Figure 17 - Interaction complexity graph

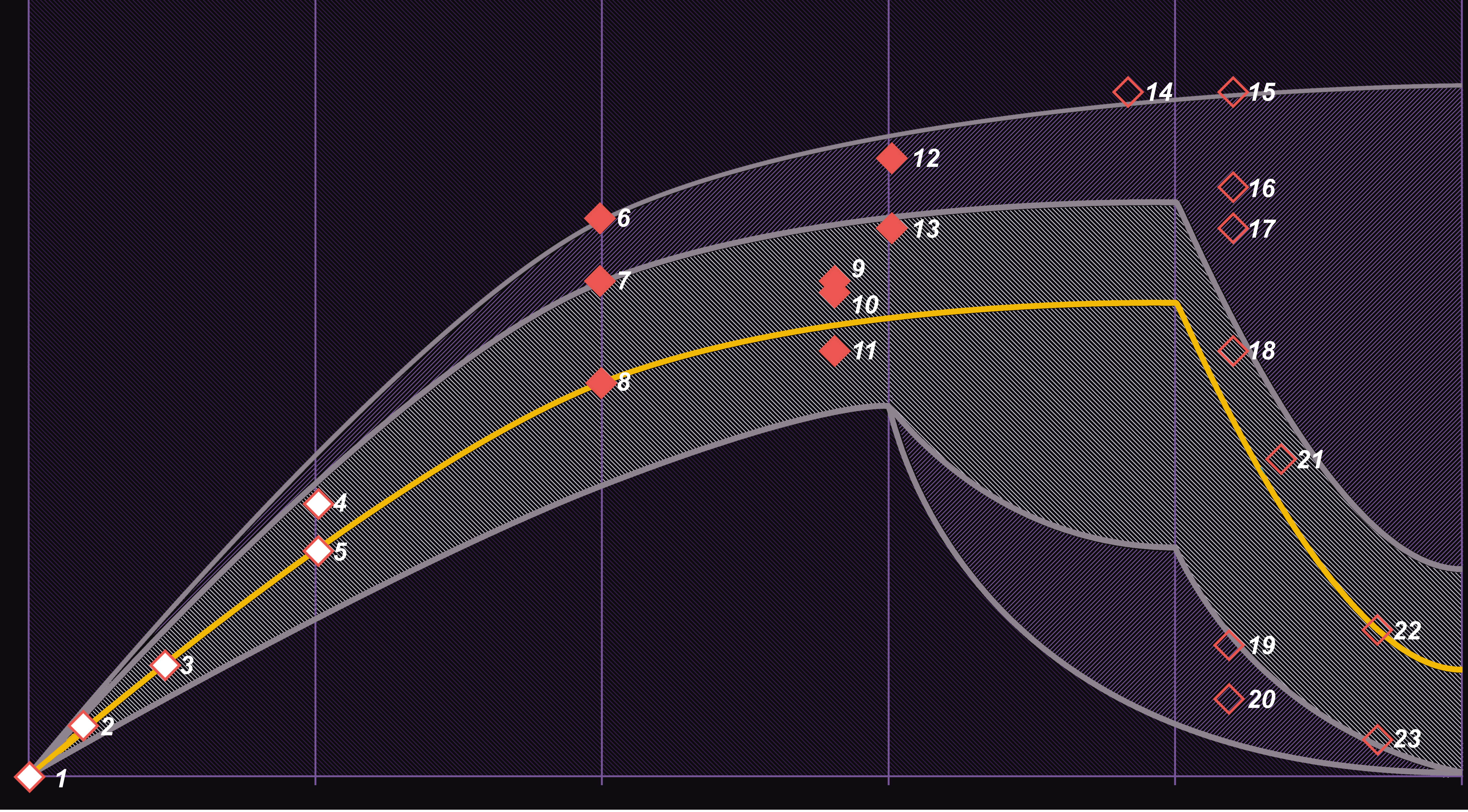


Figure 18 - Interaction complexity graph plotted

1. Motorized Skelter
2. Basic ADAS
3. Cruise Control
4. Lane Keep Assist / Lane Change Assist
5. Adaptive Cruise Control
6. Aston Martin DBX 2020
7. Volvo XC60 2020
8. Tesla Model 3 2020
9. Audi A4 2017
10. Audi A8 2020
11. Tesla Model S 2019
12. Tango HMI
13. Mercedes level 3 concept
14. Byton M-Byte concept
15. Rinspeed XchangE
16. Renault Symbioz
17. Peugeot E-Legend
18. Volvo concept 26
19. Toyota LQ
20. Citroen 19_19
21. Rinspeed Σtos
22. Audi AI:ME
23. Honda Advanced Driving Concept

Cabin restrictions

Interaction placement

Within the drivers section of the cabin, the placement of the controls and feedback mechanics is vital to proper use of the automation. In general, vehicle interiors are not expected to change drastic up to level 4 automation, as can be observed from the concept vehicles. The basics of a dashboard, steering wheel and pedals, seat configuration, and central control panel do vary very little to current generation vehicles. What remains uncertain is the removal of the centre console, especially in level 4 vehicles, to accommodate for swivelling seats.

In the image below, one can observe the schematic design of a car interior to scale (mapped from the interior of a 2019 Honda Civic) (Figure 19). To analyse the optimal placement for visual stimuli, vibrotactile feedback, and input controls various data has been mapped.
These top-down views indicate important optimal zones (green) to impossible zones (Dark shade of blue).

Visual elements

In terms of vision, a driver's main task is to focus on the road ahead, observe the traffic around the vehicle and monitor the condition of the vehicle. The main direction that the driver will be looking is straight ahead. According to Henry Dreyfuss (1993), the human eye is not very capable of focussing on a wide area, but can observe an area of 62 degrees to each side and 50 degrees up and 35 degrees down. However, to distinguish colour, these envelopes are reduced to 37 degrees sideways and 20 degrees up and down. This field of view is widened by turning one's head, which can be done comfortably up to about 45 degrees side to side and 30 degrees up-down.

Turning, however, does change the visible area. To design an element that needs the constant ability to draw attention, the usable field of view is actually limited. In Figure 20, an adjusted field of view is illustrated, which counts eliminates the non-visual areas is the head is turned comfortably to the other side. This leaves a very slim area that remains clearly noticeable at all times. This map is not adjusted for the potential technological development of turning the seat 15 degrees inboard.

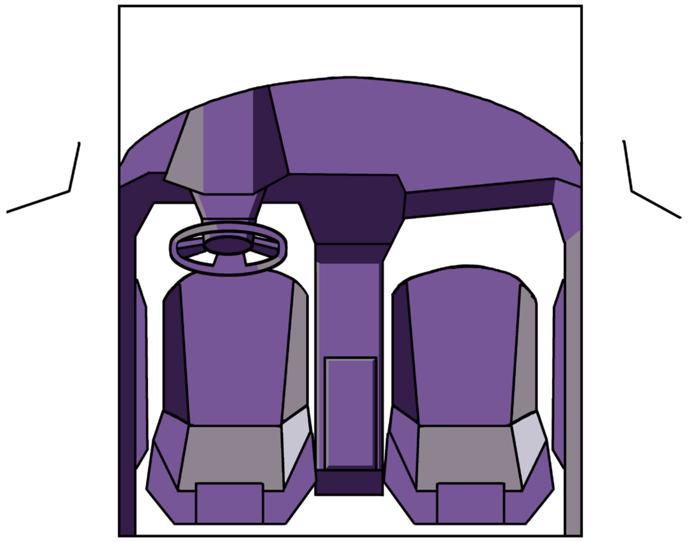


Figure 19 - Schematic top-down view of a car interior´s front row seating and dashboard

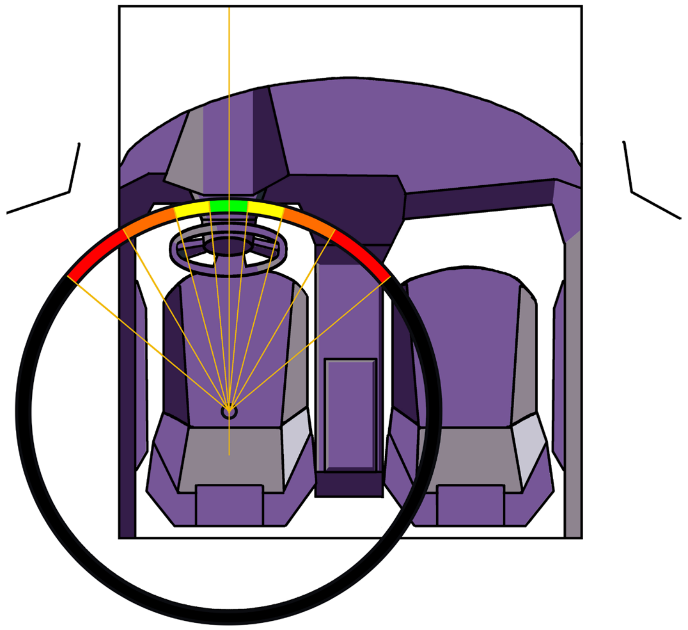


Figure 20 - Overlay out of Measurement of man and woman, Henry Dreyfuss

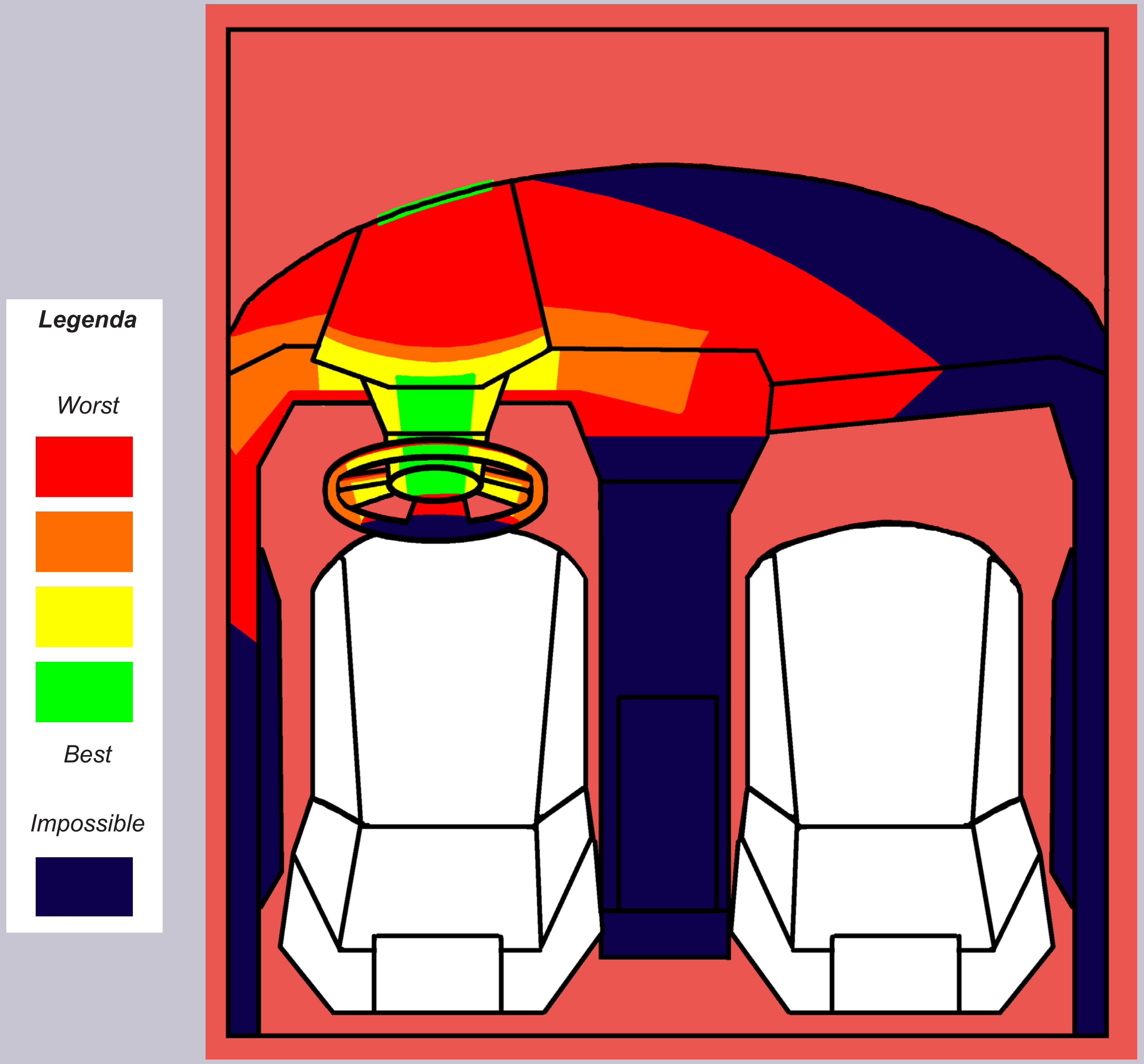


Figure 21 - Heatmap of visible areas

When projected on the actual interior, a map such as Figure 21 can be created. The better options allow for vision in which icons can be distinguished within the turning radius of the head, which is only yellow and green.

Knowledge from Xinji Wang report indicate that information can be conveyed with the use of lightstrips in the A-pillar. By adding a second light, the area of placement becomes vastly larger. Especially when made use of the windscreen area.

An icon to accompany this ambient lighting, however, will have to be either distributed through the cabin or be placed within the specific field of view mentioned before.

Where more information needs to be conveyed, such as feedback text, the urgency level will be reduced. If the driver is not responsible for the driving task, he/she can be distracted by a larger piece of text.

When the driver is responsible for the driving task, feedback and instructions have to be short, concise, and allow for vision on the road. All blue areas would compromise this desire. Note that armrest displays, such as designed on the Peugeot E-Legend would not meet this desire.

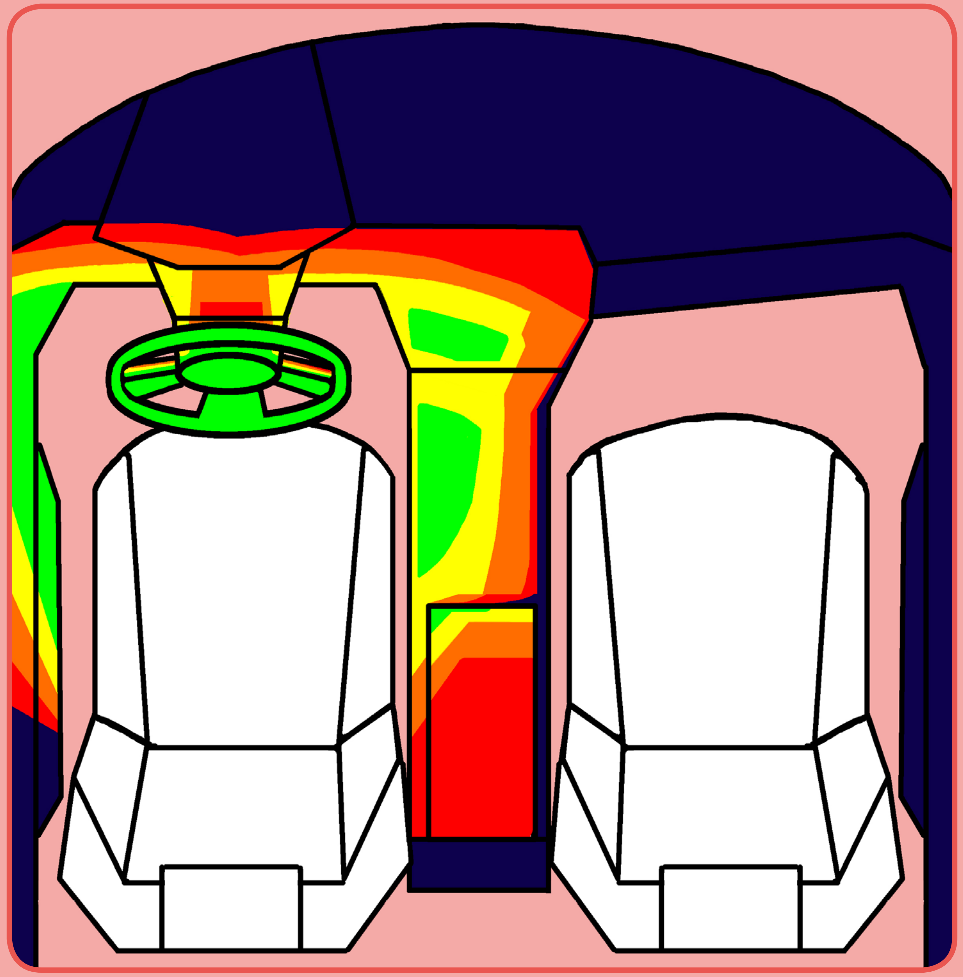


Figure 22 - Heatmap of drivers reach

Drivers reach

In accordance to SAE J287, the driver has a limited reach area. In H-Point (Macey et al, 2014), this envelope is illustrated most clearly and shows the changes in reachability of certain parts of the drivers area. The envelopes are split in inboard and outboard. In relation to the drivers centreline, the inboard envelope is 600 mm, where the outboard envelope is 400 mm. This is representative for both vertical as horizontal movement. In 2003, TU Delft measured reach envelopes for the Dutch population. At age 31-65, the maximum reach ranges between 697 mm at P5 to 885 mm at P95.

A representation of the combined envelopes has been mapped to the top-down view of the Civic. Where the steering wheel is best reachable, the general rule is that reachability declines with the distance from the driver. However, some close-by areas are also harder to reach, as areas too close to the shoulder-joints are actually harder to reach. Furthermore, areas behind the driver requires turning of the upper torso, which also lowers the reachability. Areas in blue are out of reach for the driver.

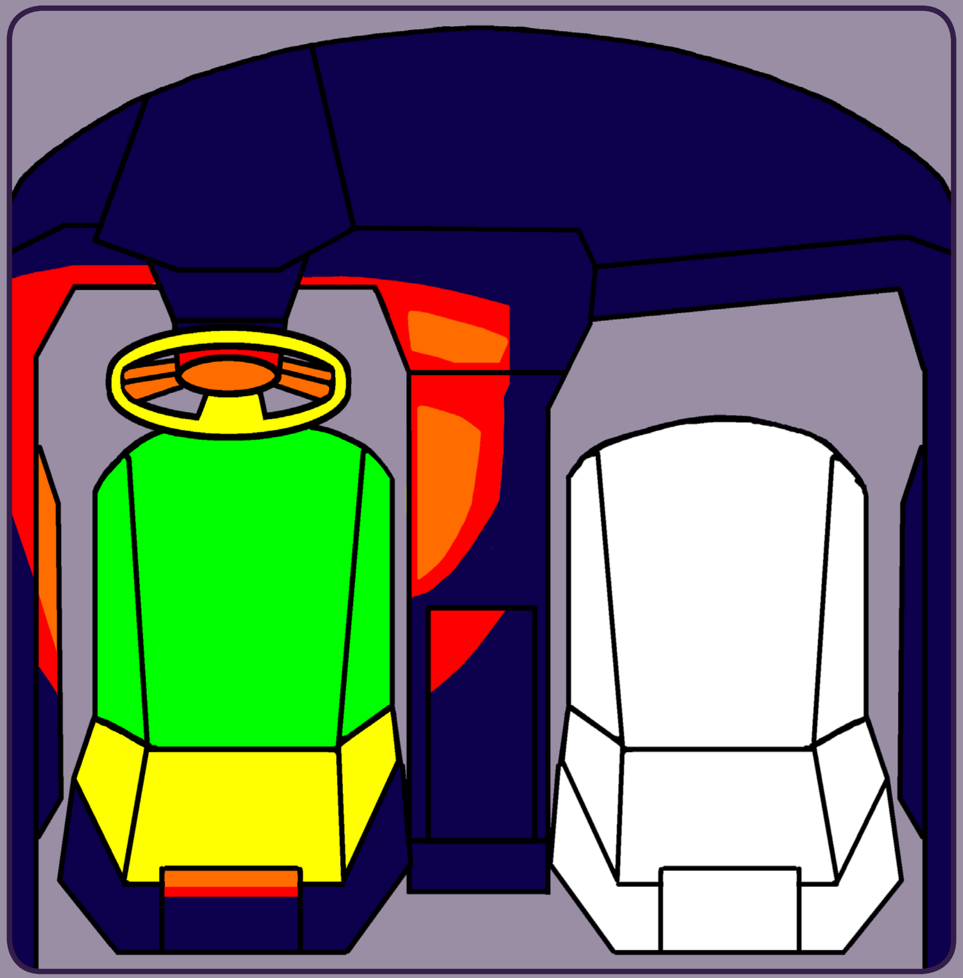
In general, the six main areas that can be derived from this map are 1) placed in the rim or on crossbar of the steering wheel, 2) attached to the steering column, 3) mounted on the junction of the centre console and the dashboard, 4) placed in the lower area of the centre console, 5) seated on the forward areas of the armrests, and 6) placed on the dashboard next to the steering column.

Haptic areas

The usable haptic areas are fairly similar to the reachable areas. However, as vibrotactile mechanics will only be used as feedback mechanism, the seat can also be used as an area of operation. Most promising will be the pan of the seat, as the driver is guaranteed to sit in this seat. The back of the seat and the steering wheel are also very fit for use of vibrotactile feedback, but have a small chance of not being touched. Other areas are interaction hotspots, but less suitable for conveying vibrotactile information.

In general, only the seat and the steering wheel are advised for implementation of (directional) vibrotactile feedback.

Figure 23 - Heatmap of promising haptic areas



To summarize the key findings in the analysis phase of this project, a list of boundaries can be formulated. Such boundaries indicate the requirements that the HMI must fulfil in order to safeguard safe, and usually comfortable, transfer of control. These functional requirements can be split in requirements regarding the machine to human communication, feedback, and human to machine communication, input. The following list consists of important, specific, or controversial functional requirements. In Appendix 3, additional requirements that relate to more straight forward requirements, such as audible frequency and decibel limits, can be found.

GENERAL

- Driving levels should communicate clearly what is expected from the Human Driver. To do so, group the automation modes the Manual, Assisted, and Piloted driving modes.
- Control Transfer Rituals must be distinct in urgency, initiator, original driving mode, and destined driving mode.
- Time intervals between signals vary based on urgency, driver fitness, automation fitness, initiator, original driving mode, and destined driving mode.
- Highly urgent scenarios must prioritize safety over comfort.
- The Control Transfer Rituals must be consistent in execution.
- The user must feel in control of all situation except those that are safety critical.
- The Control Transfer Rituals must include design of MRMs and Error messages
- OEMs must be able to design the non-crucial HMI components
- MEDIATOR must provide a Control Transfer Ritual structure to OEMs for consistent processes over all personal vehicles.
- All components must be safe for all occupants of the cabin and follow ergonomic standards developed by Dreyfuss (2019)
- Automotive legislation is to be considered in all design phases
- The human driver has the ability to override the automation
- The availability of automation must enhance the driving experience, not limit it
- A log of all input and computing can be accessed after a journey (similar to black boxes used in aviation)
- User trust is elicited through stimulating the availability of information, clear feedback, and ease of use, whilst reducing the appearance of complexity.

FEEDBACK

General

- All feedback is unambiguously, concisely, and timely communicated
- All information can be requested by the user
- Unimodal feedback can only be used for signals that may be missed by the user.
- Multimodal signals are mandatory for high urgency signals
- Textual and vocal signals require large timeframes to be executed
- Frequent use lowers the need for explicit signals over time
- Directional signals can be used to attract attention to events both within the cabin as on the road
- Staged signals must correlate to the urgency stages of the situation

Visual

- Ambient cabin lighting attracts attention of non-diving users
- Urgency is communicated through brightness, inter-stimulus intervals, frequency
- The addition of textual feedback makes implicit signals explicit

Auditory

- Urgency is communicated through frequency, amplitude, inter-stimulus interval, stimulus duration, tune, tone and in-harmony.
- Vocal feedback makes implicit signals explicit

Haptic

- Crucial haptic feedback incorporates the actuation of the seat pan
- The location of feedback corresponds to the desired task
- Haptic feedback is always made explicit with textual or vocal feedback

INPUT

- An input device must be easy to reach
- Users must be able to operate the control one-handed
- The input device allows the user to bargain with the Decision Logic over the desired driving mode.
- Operation cannot interfere with the assigned DDT of the human driver
- Accidental activation must be avoided
- The adjustments made with the input device are communicated either directly on the input device or represented in clearly visible visual stimuli
- The selected, and when applicable, destined driving mode must be communicated on the input device or represented in clearly visible visual stimuli
- Comparable functionalities must be clustered
- Steps to communicate intent must be minimized
- Design of the input controls must communicate their functionality

Placement

The functional requirements indicate that the input device the driver operates to communicate with the Decision Logic can be placed in a variety of places within the cabin. Dictated is that the driver has the control in reach at all times and can visually determine its status, whether by line-of-sight or via a display. Furthermore, the control can be easily found without losing sight of the road ahead.
Accumulating this knowledge limits the location of the input device to four potential areas (Figure 24).

Each area has their own upsides and downsides, but are technically all suitable for the placement of an implementation device. As long as the device will hold true to the functional requirements, OEMs should be able to develop their own variant. From here on in the report, the development of the implementation device is done to confirm the found functional requirements and showcase how the transfers of control can be executed. The design of this input device is explored along the list of functional requirements and a design vision.

The design vision is that the final product is a proof of concept, which people can handle and experience. As automation is a successor to cruise control, which is still widely used, the controls should feel and operate in a similar way. The added complexity of the technology should not unnecessarily increase the interaction complexity. This allows a novice to automation to understand the required interactions, limits the added load to the current drivers education and examination programs, and convey a familiarity to more experienced drivers.

To narrow down the search for the best possible placement, several factors are to be considered.

First of all is the removal of the centre console and armrest. Due to the shift from fossil fuelled vehicles to electric, the gearbox and engine no longer exist. Instead, electric motors at the wheels will power the vehicle. Traditionally, the centre console was developed to part the engine and transmission compartments from the participants. Furthermore, the elimination of this centre console would allow the rotation of the front seats, as legroom is opened up. This is a trend that can be observed in conceptual vehicles (Appendix 2).

Second, when assessing the feasibility of placement on the steering wheel the steering wheel itself is flawed. Though both visibility and reach on the steering wheel are excellent, the focal difference between road and steering wheel is usually too distracting for proper placement. Furthermore, moving the steering wheel would move the controls attached, making it even harder to focus on that control.

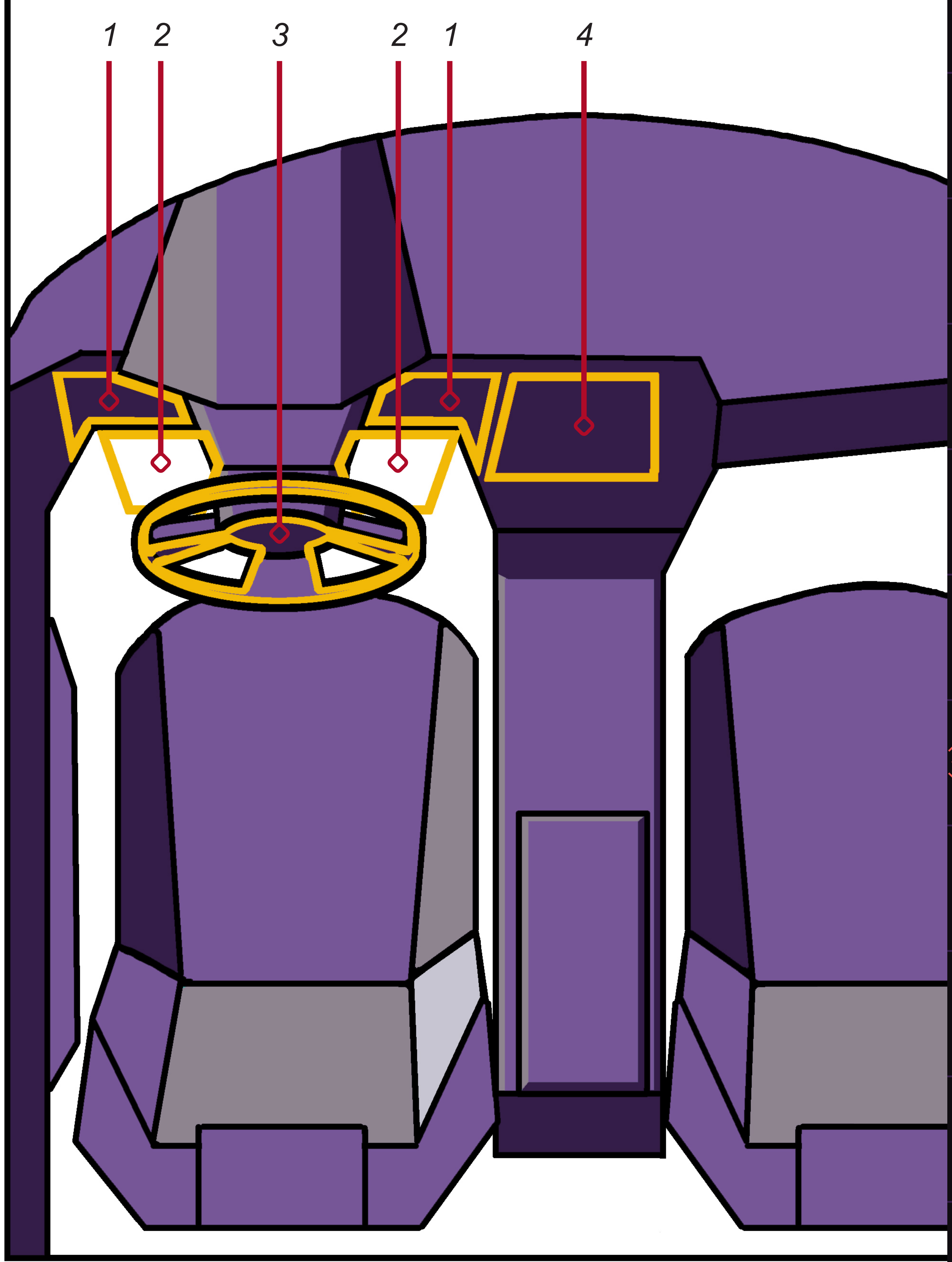


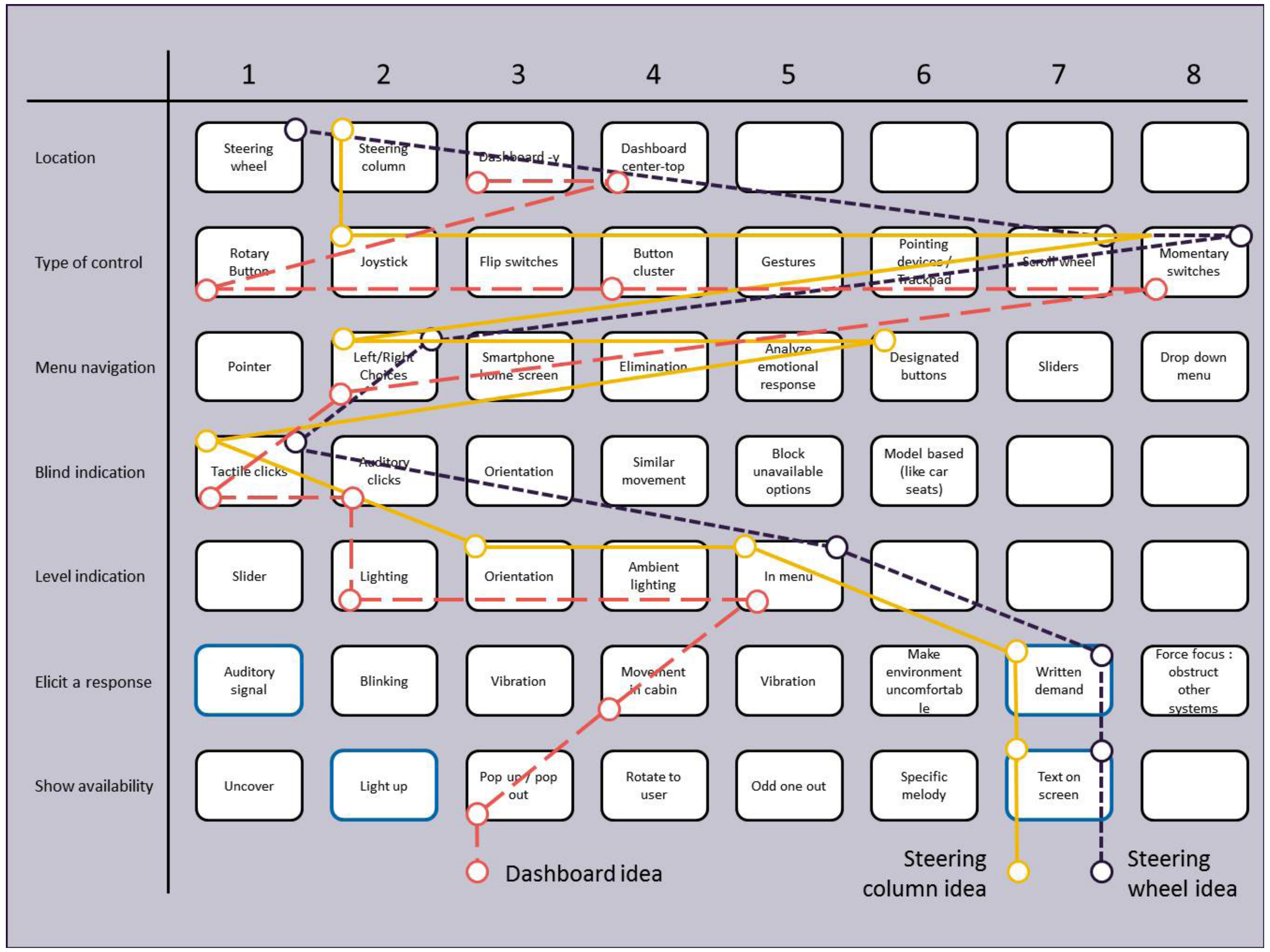
Figure 24 - Promising locations of input device

1. *Placed on the dashboard next to the steering column.*
2. *Attached to the sides of the steering column*
3. *Placed in the rim or on crossbar of the steering wheel*
4. *Mounted on the junction of the centre console and the dashboard*

Ideation

A simulator had to be built in order to test and evaluate the designed Control Transfer Rituals in a representative environment. However, to build the simulator, a realistic input device had to be developed. The Basic Design Cycle process was used to design and produce such a device. With the functional requirements done, the next step was to generate ideas.

Various ideation methods were applied to generate the ideas that would later form the concepts. Through the application of ideation techniques such as how-to's and a morphological chart, several initial ideas were generated (Figure 25) (Appendix 7).



	1	2	3	4	5	6	7	8
Location	Steering wheel	Steering column	Dashboard -y	Dashboard center-top				
Type of control	Rotary Button	Joystick	Flip switches	Button cluster	Gestures	Pointing devices / Trackpad	Scroll wheel	Momentary switches
Menu navigation	Pointer	Left/Right Choices	Smartphone home screen	Elimination	Analyze emotional response	Designated buttons	Sliders	Drop down menu
Blind indication	Tactile clicks	Auditory clicks	Orientation	Similar movement	Block unavailable options	Model based (like car seats)		
Level indication	Slider	Lighting	Orientation	Ambient lighting	In menu			
Elicit a response	Auditory signal	Blinking	Vibration	Movement in cabin	Vibration	Make environment uncomfortable	Written demand	Force focus : obstruct other systems
Show availability	Uncover	Light up	Pop up / pop out	Rotate to user	Odd one out	Specific melody	Text on screen	

Figure 25 - Morphological chart

Figure 26 - Creative session - Design your own UFO cockpit

This collection of ideas was expanded on with the use of a creative session (Figure 27). In this session, other Industrial Designers (both student and professional) helped to generate solutions to different how-to's and ultimately proposed two ideas each, based on the content of the session up to that point. In order to get in the creative mood, the session kick-off was to design and present a UFO cockpit. This was followed with a segment in which they were presented with crucial information on the topic of control transfer rituals. As mentioned, how-to's and idea generation followed and the session was closed after a discussion on the found ideas and solutions.

Such a session allowed for out-of-the-box thinking. Insights of the participants broadened the toolbox to create ideas. Some added to existing ideas, others built the foundation for completely new opportunities. In both ways, this session helped to generate new ideas, but also solidified some from the initial series.

Learned affordances

It is key that the concepts use some affordances that can be found in current generation vehicles, but remain different enough to distinguish themselves as new technology. This balance would allow the innovators and early adapters as described by Evans et all to pick up the technology as it is new and exciting. The majority, both early and late, will adapt the technology relatively fast as the interaction remains familiar. Furthermore, trust is build by, among many other factors, experience. Though experience with a Decision Logic is non-existent, the experience of driving a vehicle is. If prospected users are readily experienced with most interactions, they likely will put in the little effort needed to fully understand the product.

In the context of the cabin of a personal vehicle, users are readily familiar with a wide array of technological systems, both consciously and subconsciously. Every driver can drive with the Anti Lock Breaking ADAS enabled, but little-to-none even realize it is at their disposal.
In the context of this project, more conscious interactions are of interest. Prominent examples are the interaction with the driving controls, the entertainment system, and the shifter.

The more promising concepts that came out of the ideation phase do build on these learned affordances, without forcing the user to learn a vastly different interaction with existing controls. Rather, the concepts enhance or extend the current controls.

Pre-sets

Important to note is that the conceptualisation phase takes into account that the user will switch between driving modes that are distinguished by automation level. The automation level, however, is not fully dictated in these concepts. This is due to the wide variety of approaches to SAE level 2 automation. This is dictated by the fact that the automation can control both longitudinal and lateral movement, but does not specify to what extent. An example of variations within SAE level 2 is Lane Keep Assist versus Lane Change Assist. Both require supervision and both move the vehicle over the mentioned axes.

In order to use the concepts as described in the following pages, choices in this type of functionality need to have been made prior to the drive. This can be done by either of the three parties that have a say: the human driver, also known as the consumer, the OEMs, also known as the supplier, and the government, which dictates the legislative boundaries. In general, little benefit is gained by limiting this in legislation and might even hinder technological advancement in that area. For the users, it is best if the choice is in their control as they are able to choose whichever mode they are comfortable with.

OEMs might be interested in the final say as it provides an opportunity to distinguish themselves on technological level to their competitors. Based on the knowledge that technology is seldom a lasting competitive advantage, this is a rare opportunity.

However, as mentioned, in societies such as the European Union, standardisation is key. It is very important that the lessons learned in one vehicle translate to another. Therefore, a limitation by legislation is an option that cannot be ignored.

In general, the best option would be to standardise the separate packages in legislation, allow OEMs to design their own composition of packages and let users build a personalized package either at purchase or developed structural analysis of their preferences.

Concept 1 - Button

This concept consists of a rotary menu navigation button with an additional button cluster on top (Figure 27). With the use of these controls, the user can navigate menu's, choose options, and control features such as entertainment systems and cruise control speed.

The interaction component that allows users to control driving modes is a ring around the centre button. This ring in embedded with a LED strip that serves as an indicator of the selected driving modes. The driving modes themselves are displayed on the outer ring, indicated with M-A-P, for Manual, Assisted, and Piloted driving modes. Lighting inside these indicators communicate essential information such as currently engaged driving mode (coloured light) and available modes (white light or no lighting).

A lighting base can assist in the communication of the currently engaged driving mode. Furthermore, this light blinks when the Decision Logic is processing input by the driver. On top of that, blinking two colours, the current level and the destination level, communicates a pending transfer. This feature can be used in scenarios where information is gathered on the automation or the human driver. For example, when searching for road markings in order to engage Assisted or Piloted driving modes.

This concept can limit the options of the driver by retracting into the dashboard, covering the driving mode selection ring. In this orientation, the Decision Logic can still change driving modes, but human input is restricted. Menu navigation remains available, as the human driver must be able to communicate with the Decision Logic and other components of the vehicle.

An extended benefit of the retraction and extension of the button is that the sense of motion is engaged. This will attract more attention to the button, alerting the driver of current events in the availability of driving modes.

Lighting and physical indicator to clarify driving mode and driving mode availability

Figure 27 - Button Concept

Concept 2 - Lever

With the introduction of rain detectors, it is feasible that the lever, or stalk, for the windscreen wipers will disappear in the future. This concept capitalizes on the available space that would be created on the right side of the steering column. Such position would make the control as easily reachable as possible, right behind the steering wheel. With motions that are familiar to drivers, the stalk can be build to accommodate many input controls in a seemingly simple package.

To control the driving modes, the stalk has been extended with a sliding mechanism that clicks in a designated slot for each mode. Through a peeping hole, the user can gather what driving mode is currently selected. Again, the driving modes are communicated as M-A-P and show their specific colour to clarify driving mode. However, due to the size and position, these lights will not be suitable as sole indicators and cannot communicate mode availability. This will be done through other elements of the HMI, such as an indicator in the instrument cluster and/or projected heads up display in the windscreen.

As with many stalks seen in current vehicles, this concept can move both horizontal, back and forth, and vertical, up and down. With the addition of a button at the tip, this concept allows users to navigate menu's in the same fashion as blinkers are used, but on the other side of the steering column. An upward push would navigate to the left and a downward push to the right.
Front-back movement is excellent for quick activation and deactivation of the selected automation modes.

An axis that can be utilized as an input is the rotation of the stalk. In the current design, the outer half of the stalk can rotate as a momentary, rotary switch. This control can rotate clockwise and counter clockwise to increase or decrease a certain setting. Prior to the drive, in driver preferences, the user can assign functionalities such as cruise control speed or set distance to the car ahead.

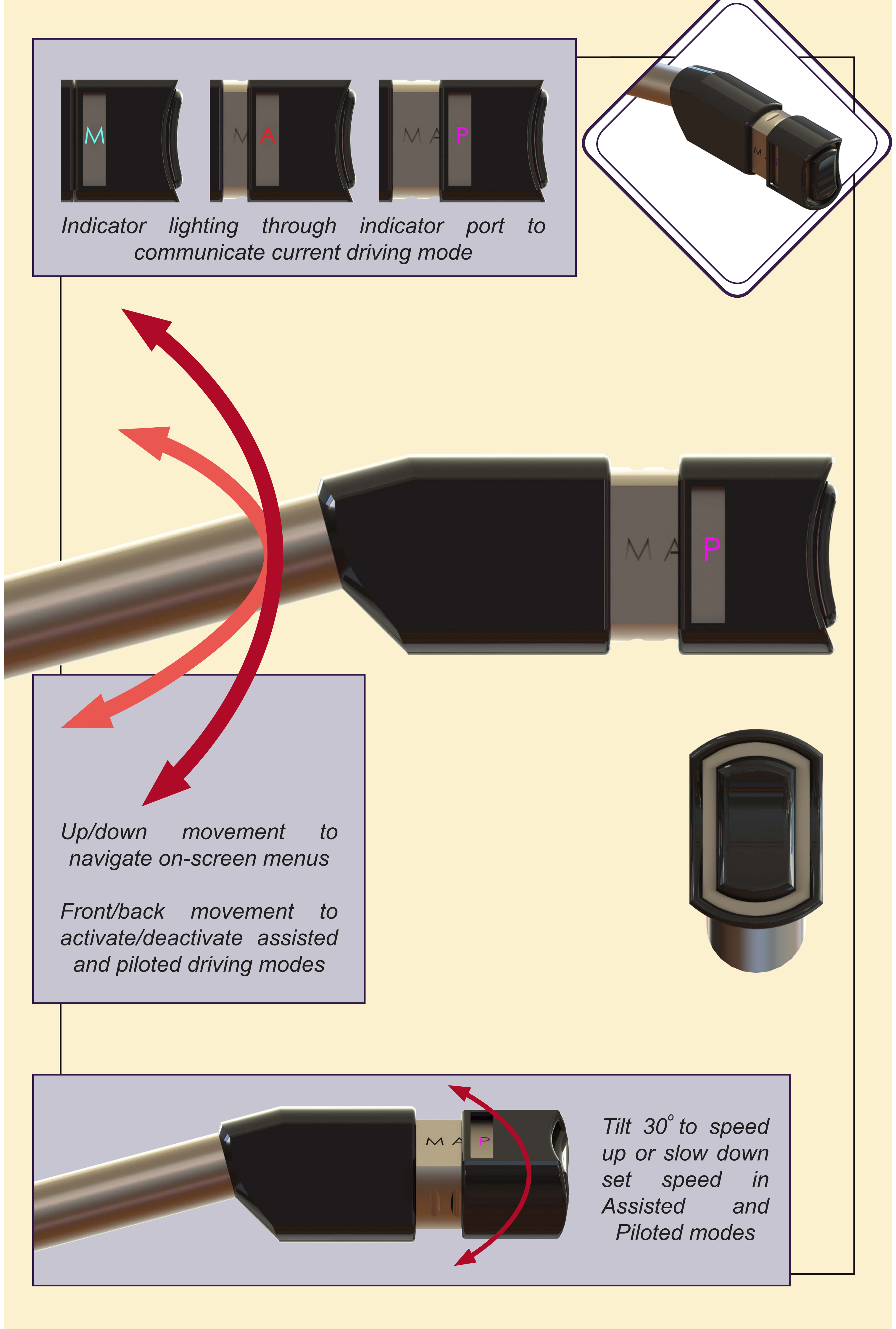


Figure 28 - Lever Concept

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Concept 3 - Stick

With the uprising of electric vehicles, that function without gearbox, the use of manual gearboxes will become obsolete. The use of a stick or lever to change driving mode, as traditionally was done in vehicles with an automatic gearbox, will remain. A driver will continue to select park, neutral, reverse and drive. However, with the development of automation, it makes sense to expand on these driving modes with Assisted driving and Piloted driving. To clarify the distinction with ‘Drive’, this option will be replaced with Manual, once again creating the Manual-Assisted-Piloted driving modes. As with the other two concepts, these will be communicated with corresponding lighting on the control itself. In terms of visual feedback of mode availability, this concept is comparable to Concept 1 - Button.

This concept explores the possibilities of this principle through a redesign of the lever used to select driving modes. Though removal of the centre console was stated to be very likely in the future, that does not include this lever. Likely is that this lever will either move to the dashboard, as can be seen in transport vans, or the steering column, as usual in American trucks. The current iteration focusses on a lever attached to the dashboard.

Because this concept will have a prominent place in the vehicle, it is clearly visible. That is why moment of this lever is an excellent method of communicating decisions made by the Decision Logic. A simple nudge of the lever indicates that the Decision Logic wants to change from one driving mode to another. This can be accompanied with auditory and visual prompts, from the control and other elements of the HMI.

The ability to move the lever with automation allows the exchange of preference between the human driver and the Decision Logic to shift from menu-based to force feedback. User input can be counteracted in varying degrees to communicate compliance of the Decision Logic or the availability of a driving mode. The other way around, the human driver can limit the movement of the lever when the Decision Logic moves the lever out of suggestion/demand. How much play there is on the lever indicates the need to change.

Moving the lever creates an issue where the orientation can create confusing information in relation to current driving mode. To clarify, lit LED strips dictate the current driving mode and will only switch to the LED corresponding with the orientation of the lever when the actual control transfer ritual has ended.

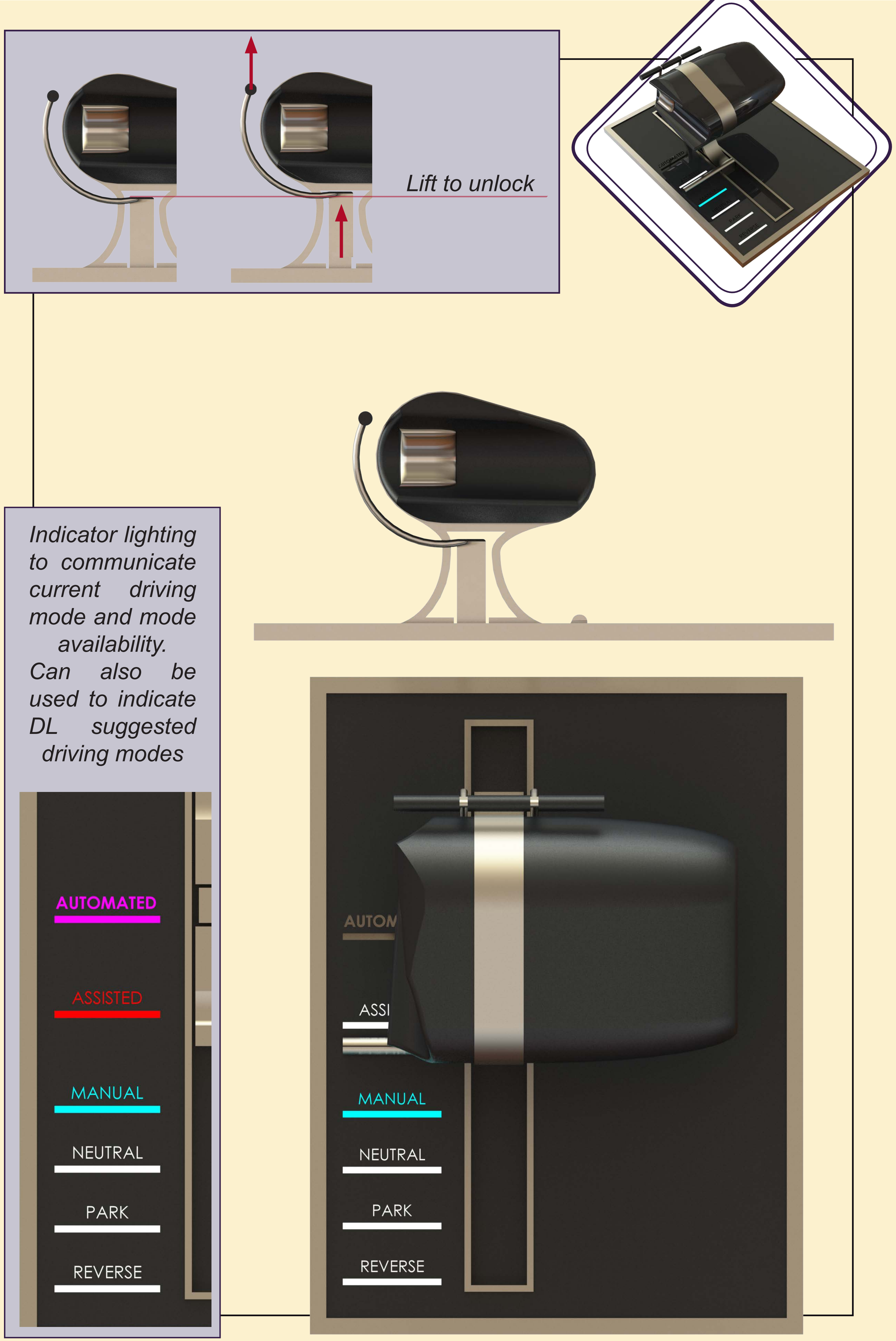

Figure 29 - Stick Concept

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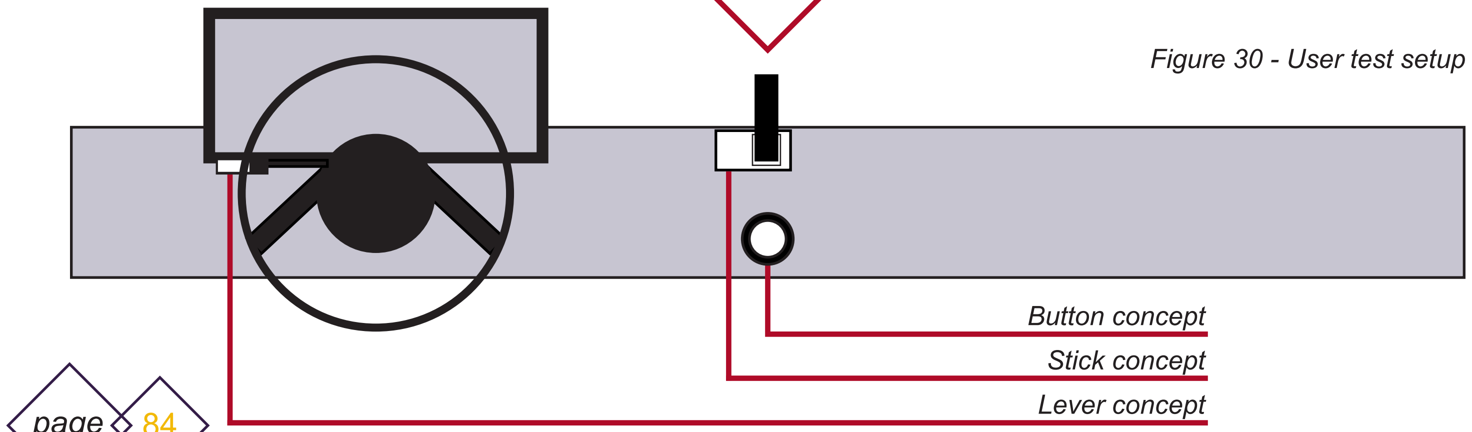
User test

To evaluate the aforementioned concepts of Button, Stick, and Lever, a user test has been conducted (Appendix 5) (Figure 29). In this user test, participants of different driving levels were seated behind a simulator that displayed a scenario. The simulator consisted of a steering wheel, pedals, a monitor as windscreen and instrument cluster, an physical, dummy prototypes of each concept (fig. 30). A questionnaire was filled in by the participants to evaluate the ease of use of each concept and the preferred concept of the participant.

Figure 29 - User testing in progress

Figure 30 - User test setup



User test results

Gathered from the data that came out of the questionnaire filled in by the participants, all concepts were deemed realistic and viable. In future implementation of the MEDIATOR system, all concepts can form the basis of the input device. This indicates that OEMs will be able to use this part of the HMI as one of the areas to exercise design freedom. As for this project, a specific prototype had to be chosen to be build into the final prototype as part of the simulator.

Overall, the lever, or stalk, was deemed as the least favourite concept. Part of this was due to fact that the participants had little time to learn the controls and the lever concept had the highest number of separate input methods. This led to both mixing up input methods and forgetting either the function of an input method or the input method altogether. However, in the questionnaire, it was estimated to be fairly easy to learn and the expectancy to error was deemed lower with more use. This correlates to the cognitive process of Chapter 4.

Evaluation of the results showed that the preferred concept is the stick concept, the extension of the automatic stick-shift (Figure 31). Results aside, comments on the functioning of this concept allowed the real reason behind this preference: no need to consistently bargain through a menu. Where a menu is great for explicit communication, people learn to know what is happening without having to read. In the case of the stick concept, the force feedback allowed for meaningful, implicit communication.

As a control, the participants were asked what concepts they preferred and disliked. This showed similar results, with the stick concept as a clear, near unanimous favourite.

An important take-away was that the name Piloted was very clear in its meaning, but caused confusion when used in the full string of automatic shifters. In the sequence of P-R-N-D, the P has its place for “Park”. Therefore, a new keyword for the Pilot functionality had to be chosen that did not clash with P, R, N, M, or A. The result was “Handsfree”, which clearly communicates that one is allowed to take their hands of the steering wheel. Handsfree is arguably a better alternative, as it also communicates that Assisted is not a mode that allows the driver to take their hands off the steering wheel. From here on out, the mode sequence is PRNMAH.

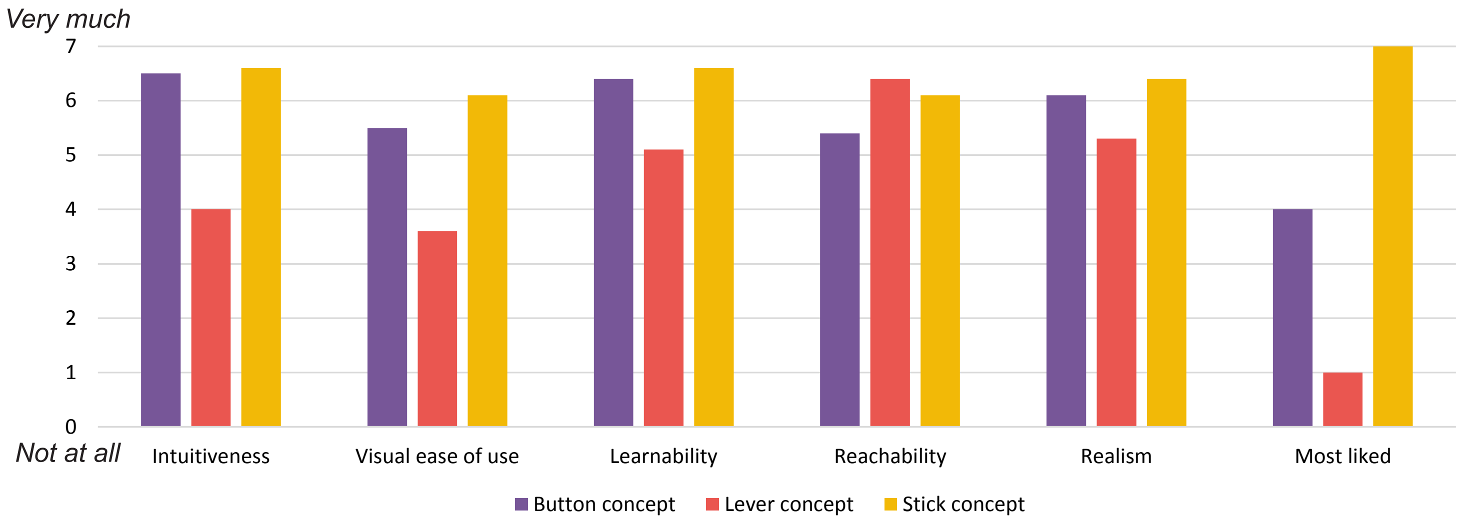


Figure 31 - Interaction complexity graph

6

Control Transfer Rituals

Prototype

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Introduction

To continue the development of an experience environment, a prototype was built. This prototype consisted of a functional selector lever for the driving modes, a virtual driving environment, a dashboard, a dummy Decision Logic, and functional steering wheel and pedals.
This chapter will explain how a human driver will experience control transfer rituals as proposed in this report.

Prototype design

With the goal of communicating all control transfer rituals in mind, the lever was in need of further development. First, the implementation of the newly found “Handsfree” mode instead of “Piloted”. However, to build a good environment, the user needs to be able to experience force feedback and how the control transfer rituals act in certain environments.

In order to create the correct environment, the C,MM,N vehicle prototype was used as a base. This vehicle was readily available at the TU Delft, but lacked a functional dashboard. As user tests were committed on a rudimentary dashboard, the next step was to design and build a new iteration that would fit in the C,MM,N (fig. 32).

Though the dashboard and C,MM,N provided an excellent base for an environment, the experience lacked interactive elements. Therefore, a virtual environment was build using Unity and Arduino. The latter platform was also needed to make a functional variant of the lever design, the dummy Decision Logic and a functional prototype of the lever.

Figure 32 - Prototype and dashboard fitted in the C,MM,N

Lever design

The lever consists of two main components: the handle , which is visible to the user, and the box of essential components that is out of sight (figure 33).

The design of the handle is derived from the C,MM,N and is aimed to have no easily recognisable OEM design elements (figure 34). This is to both fit in the environment and avoid brand associative judgement. The lever consists of thee 3D printed parts: the main handle, a bar and a cover. The cover is purely to fix the bar to the handle due to assembly limitations. The handle is what is turned over an axis of 90 degrees to select the driving modes, which are separated by 18 degree intervals. The new driving modes of Manual, Assisted, and Handsfree are separated from the traditional modes of Park, Reverse, and Neutral by a sloping segment that pushes the lever sideways. This design distinguishes the prototype from common automatic shifters without losing essential learned affordances.
The bar interacts with the interior box of essential components to allow users to ask for a higher than available automation mode.

This interior box consists of a hull with a servo and a DC motor, and two axle components joined by a spring: the handle-axle and the actual-axle. The orientation of these latter two are measured. The user operates the handle-axle with the handle, but is locked in the actual-axle with the bar on the handle. Turning the handle-axle will rotate the actual-axle most of the time. However, when the Decision Logic restricts a certain driving mode, the servo engages on the actual-axle. This way, the users handle-axle can still rotate, but builds an increasing force the further the axle is rotated until the servo releases the actual-axle. The actual-axle is what ultimately determines the driving mode.
Finally, the Decision Logic can enact on the handle by rotating the handle-axle through the DC motor. This can be used to both nudge the handle or fully turn the handle. Again, to actually switch driving modes, the servo needs to unlock the actual-axle.

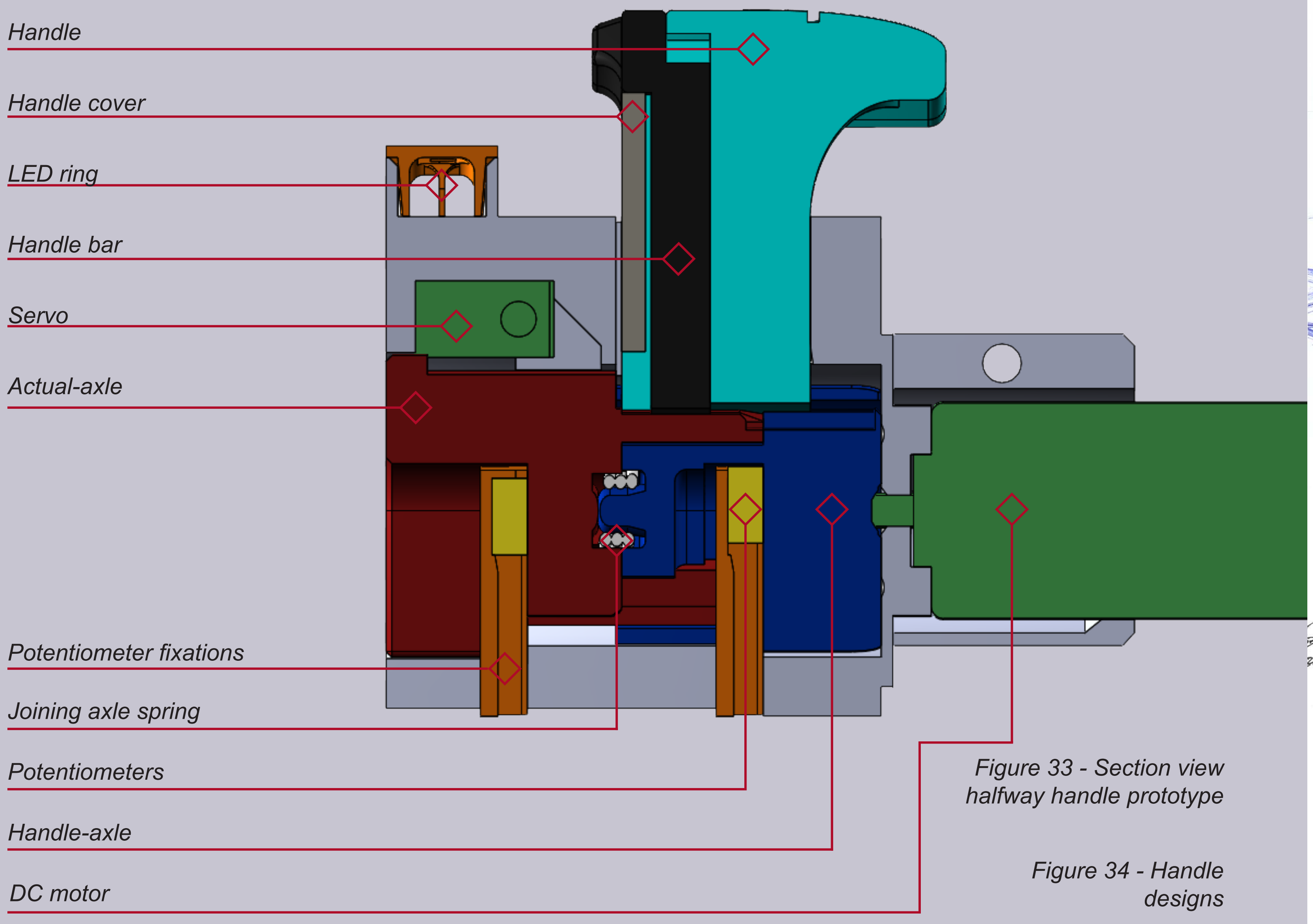


Figure 33 - Section view halfway handle prototype

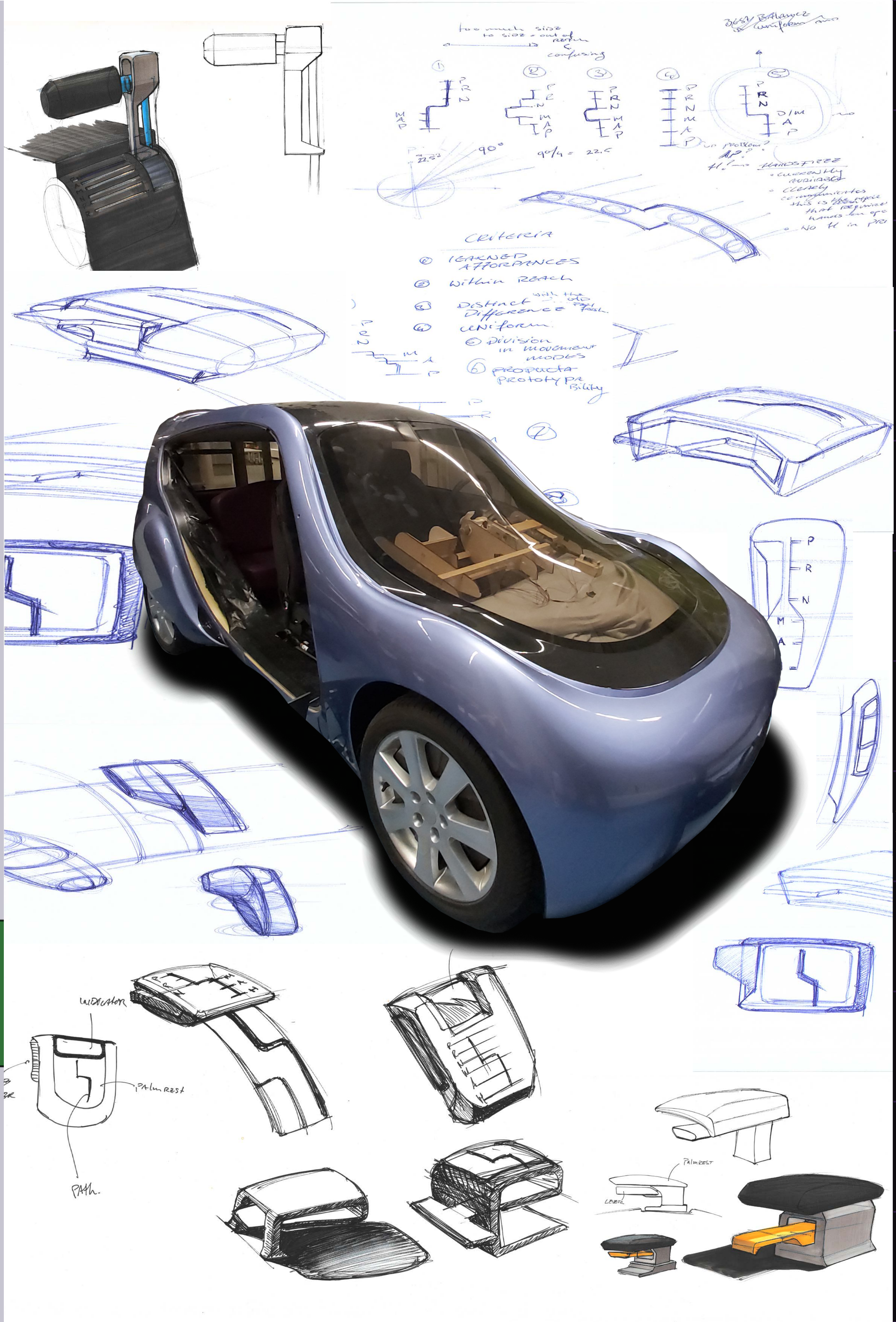


Figure 34 - Handle designs

Feedback design

To communicate this complex interaction to the user, the prototype uses various methods of feedback that were described in chapter 4.

First method is visual feedback. In the prototype, three levels of visual feedback are given: movement of the handle, indicator LED lighting of the modes, and a Heads Up Display (HUD) in the Unity simulation. By moving the handle, attention is attracted to the prototype, but that lacks full information relay. Therefore, both the HUD and LED indicators show the availability and use of the driving modes. A textual prompt on the HUD explains cases initiated by the Decision Logic.

The second method is auditory feedback. To attract the attention of a busy or drowsy human driver, the prototype sounds an alert when a status change has occurred. Furthermore, if by any chance a mistake was made, an alarm will warn the driver that their action was wrong. Finally, the MRM scenario includes the use of tonal feedback to communicate that the vehicle has run into problems.

Finally, the handle provides a tactile feedback through the spring in between the actual-axle and handle-axle if the actual-axle is locked in place by the Decision Logic.

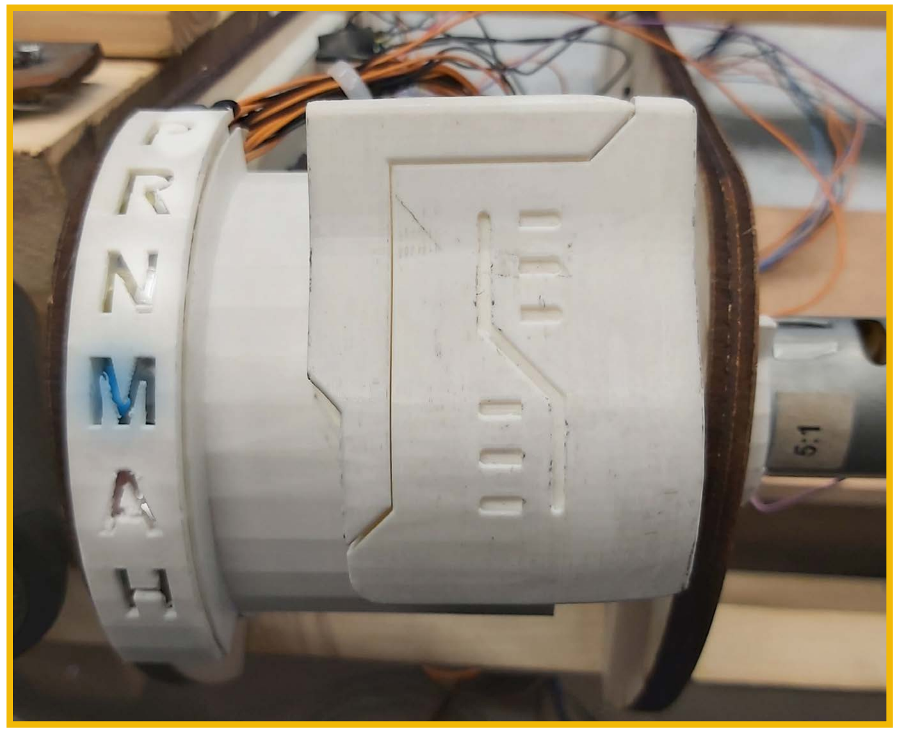
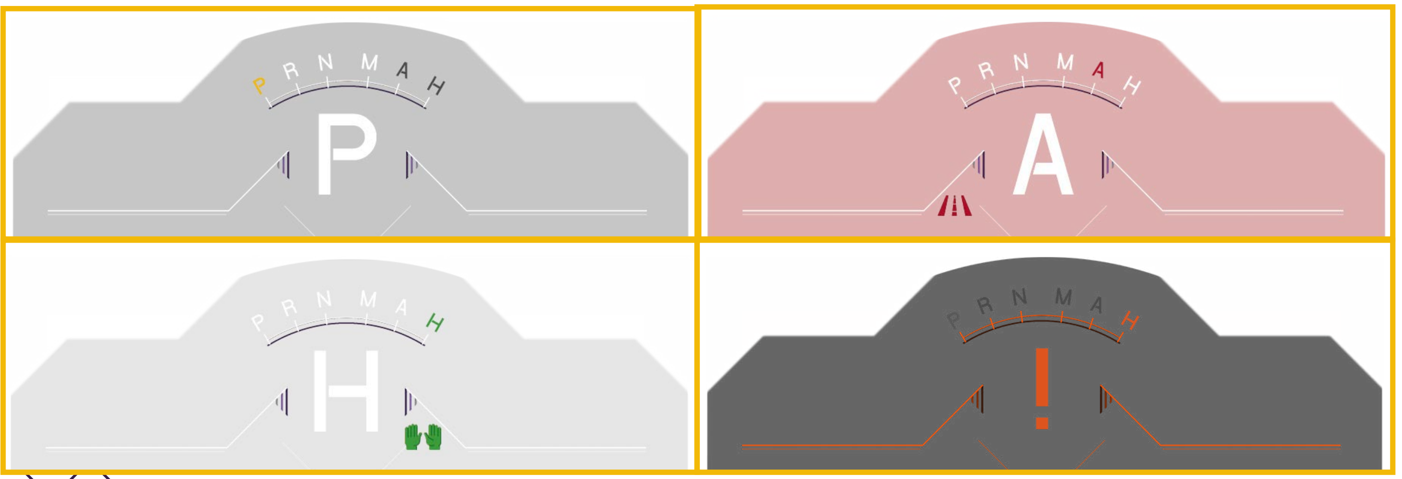


Figure 35 - LED indicators

Figure 36 - HUD examples



The brain

As mentioned, a dummy Decision Logic was used to instigate the control transfer rituals. In reality, this is a control box operated by a human in the passenger seat. This box allows the operation of the two key parameters that dictate Decision Logic initiated Control Transfer Rituals. The level of urgency (high or low) and the availability of driving modes (up to Manual, Assisted, or Handsfree, and MRM scenario), It also sets the Decision Logic initiated movement of the handle to statics, up, or down. Furthermore, key presses on the keyboard of the computer that runs the simulation will prompt different warning messages on the HUD.

To control the vehicle in the simulated environment, potentiometers were fitted to the steering column and the two pedals.

The input travels through an Arduino Mega to either the prototype or Unity. The design of the circuit is shown in figure . The extension to operate the steering wheel and pedals, together with all code, can be found in Appendix 8.

The updated variant uses a L298 motor controller, a 5:1 ratio gearbox reduction, and a 9V adapter to create a more stable prototype.

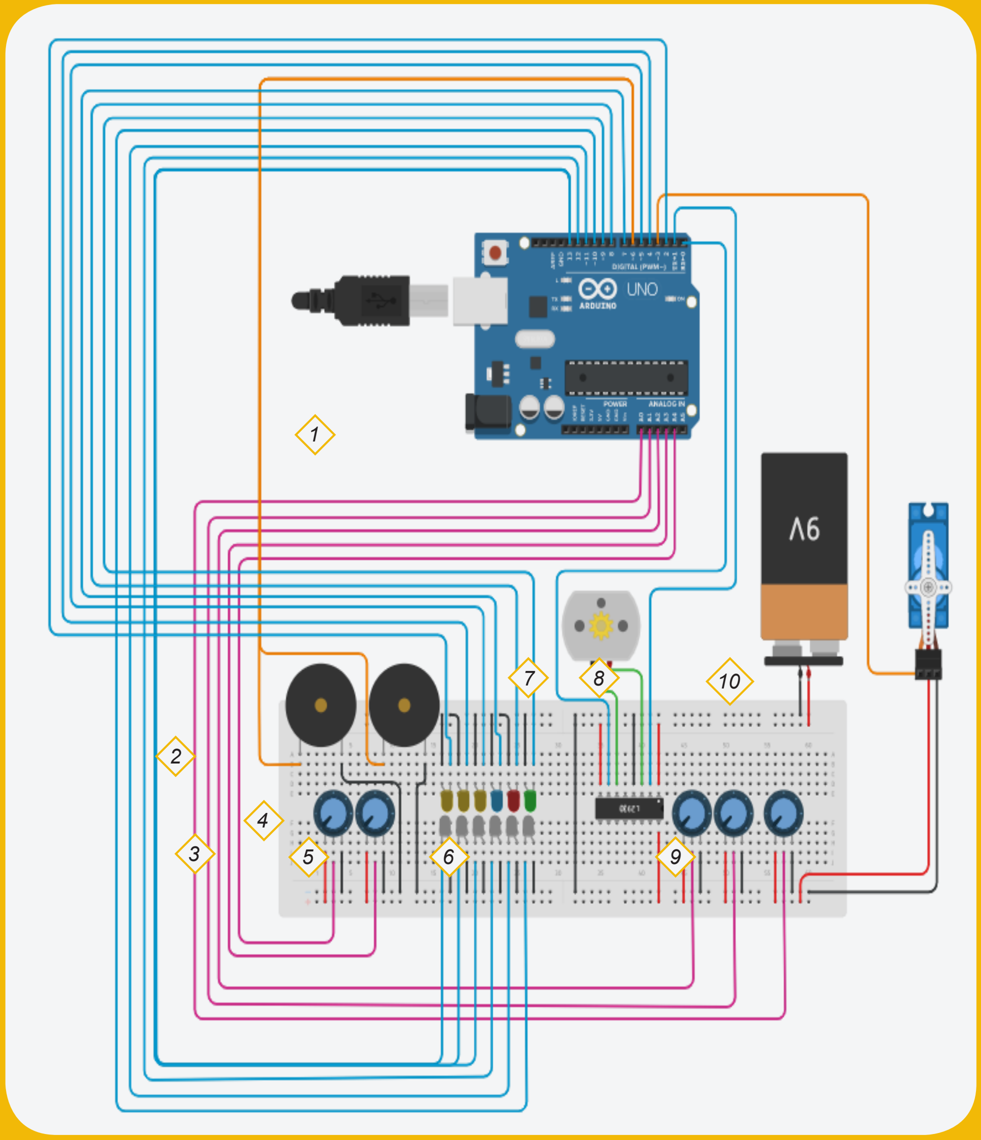


Figure 37 - Layout of the circuit

1. *Arduino (in prototype a Mega2560)*
2. *Piezos (audio)*
3. *Actual-axle potentiometer*
4. *Handle-axle potentiometer*
5. *LED indicators*
6. *L293D (motor controller)*
7. *DC motor*
8. *DC motor 9V power supply*
9. *Control box potentiometers*
10. *Toggle lock servo*

Simulated environment

In total, all designed components are developed to simulate the interaction between vehicle and human driver during Control Transfer Rituals. The immersion into the scenarios is enhanced by the design of a virtual environment in Unity and representative controls on a dashboard.

The environment in Unity represents different scenes that define the availability of automation levels (figure X). These scenes are: inner city, mid-speedway, and highway. These scenes represent “only Manual”, “up to Assisted”, and “up to Handsfree” respectively. Due to the dummy nature of the Decision Logic in the prototype, these limitations are to be controlled manually.

The vehicle within Unity is modelled to interact with its surroundings and is adjustable in many ways that affect the handling, speed and acceleration. Furthermore, if the handle is placed in park, reverse, or neutral, the simulated vehicle will act as if these modes were engaged.

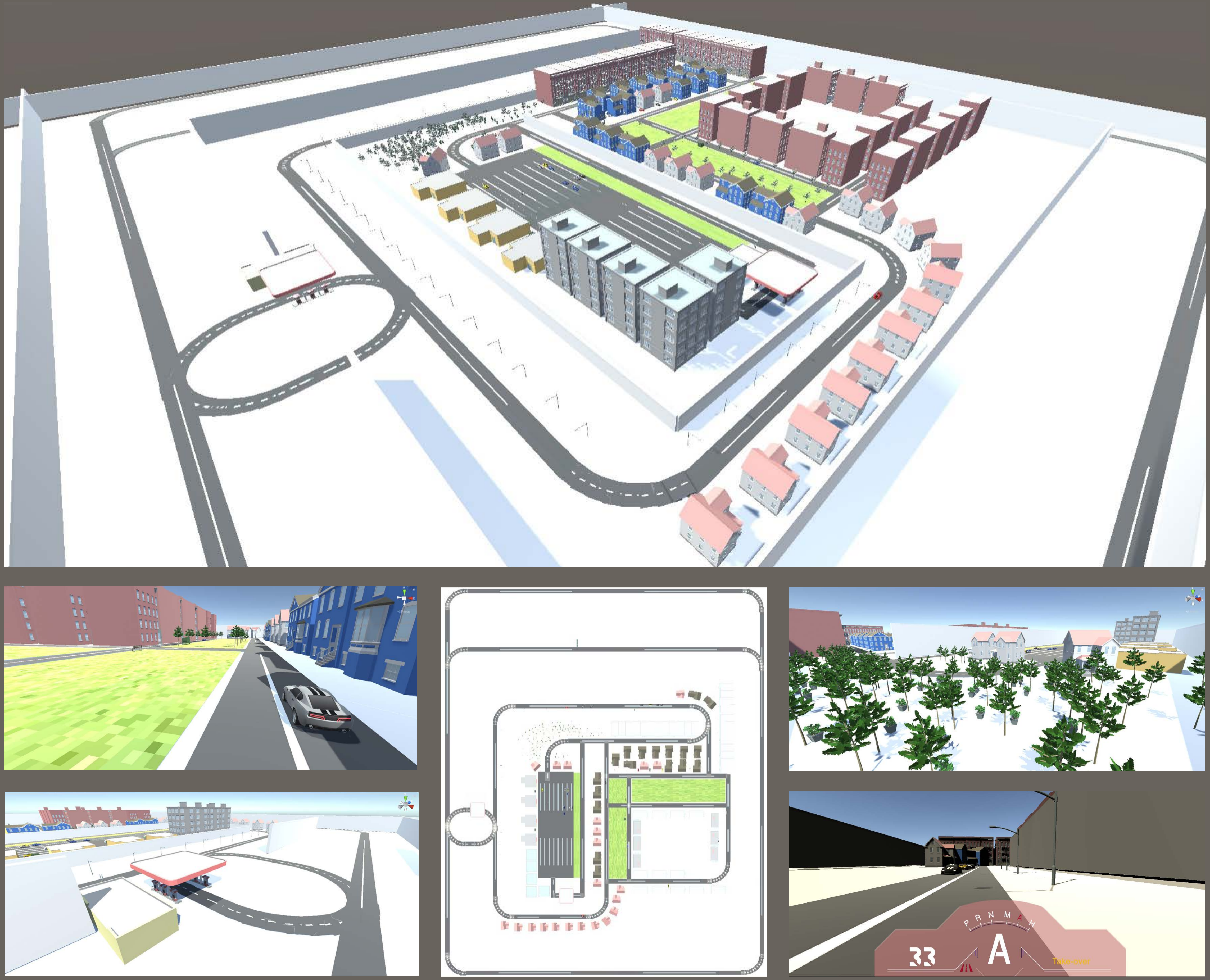


Figure 38 - Simulated Environmen in Unity

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Future

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Introduction

This chapter reflects on the research done and process made. Furthermore, it aims to assist future research, development, and curious readers by stating recommendations and expectation.

Reflection

This project was definitely challenging in many regard. At first, I was curious and eager to start, as I have always wanted to see what the automotive world was all about. However, the project was aimed at the Design For Interaction master programme, and I was looking for one related to Integrated Product Design. However, after talking the project over with my coach and chair, I had no doubt I wanted to try and make the best of it.

The start was definitely interesting, even without the pandemic settling into the daily routine, as I was suddenly part of a consortium funded by the European Union. Moreover, I was working on a cutting edge, automotive related project. With the rise from that behind, I focussed my first major chunk of time delving into the knowledge that was readily available. This was also in line with my planning, as I wanted to create a steady footing for the decisions relating the Control Transfer Rituals.

After midterm, I remained in active pursuit of knowledge, but also had to start to focus on solidifying the knowledge into actual rituals. In hindsight, that should have been the moment to accelerate the use of the knowledge to design and develop, over accumulating more. This would have sped up the process to allow more time to build and design, which I find more enjoyable.

In the end, it turned out that the planning got away from me a little around the Greenlight phase of the project. Due to a mandatory 4 week gap between final presentation and Greenlight I got a little too eager to challenge myself in building a prototype using skills that I always wanted to master, but never had the opportunity to. This build required skills in programming, learning how to use Unity, soldering, and laser cutting.

In the end, the struggle was well worth it to me, as I have learned many new skills. The resulting prototype is something I am proud of. One of the better moments of the project was when someone came over and actually had fun using my prototype, driving around in my rudimentary digital environment (Figure 39).

Figure 39 - Always happy to see someone enjoy something I have built

COVID

2020 is not the year everyone expected it to be. SARS-CoV-2, or COVID-19 / Corona, has thrown a wrench in many plans and expectations, some had an effect on this research.

In practical sense, problems arose with delivery times, available materials and work areas, and test participants.
Due to an increase in online orders, the Dutch package service (PostNL) ran into issues where packages would not be picked up at a vendor until a certain quota was met, not to mention the increase sorting and delivery times.
The university limited the available workspaces due to countermeasures and was practically unable to accommodate a fixed workspace or storage space.
Meetings with my coach were not necessarily hindered by the restrictions to meet physically, as plenty of alternative video-call services were deployed and used. This included, but was not limited to, Skype, Zoom, Teams, and WhatsApp video calls. However, physical builds, such as prototypes, were near impossible to discuss over video. In hindsight, this likely limited the exploration in the conceptualization phase.
Finally, due to countermeasures, it was recommended to work from home and limit travel as much as possible. Especially from the start of the second wave. This heavily limited the options to invite participants to test. In an attempt to work with the rules, the concepts from Chapter 5 were built and tested at home. This heavily limited the availability of tools and materials. Because testing was done at home, I could invite up to four people a day (given they showed up two at a time).

In the sense of mental load, COVID had an interesting effect on work-behaviour. At first, working from home did not seem to be a problem. Actually, quite the opposite: no travel time, no distractions, music over the speakers, no dress-code, my own coffee machine. This was enhanced by me moving into a studio (first time actually alone, no house-mates).
Over time, working and living in this situation was clearly unsustainable, as the transit between workplace and home is a moment of both physical and mental transition. With these two being one, all work time was affected by the relaxation of home and all relaxation time was affected by work. This interesting capillary effect instigated the need to consciously switch mental-states. Due to lack of a baseline, I have no real sense of what impact it has made on this project. I do have to say that working under these conditions caused some major inconveniences and was mentally very different than I was used to both in (long-term) projects and life in general.

In conclusion, COVID has caused problems for everyone and has not passed by this project.

Recommendations

Due to the limitations in time-frame and/or scope of this graduation project, some aspects such as recommended topics, search areas, and potential improvements remain unexplored. Therefore, further research into the following topics is recommended:

- Boundaries considering the design and implementation is within the scope of this report. However, as this is a basic and unrefined version of how transfer of control should be implemented, it is advised to be either revisited and specified in a later stage of the MEDIATOR project or leave this to be done by the industry to create design freedom and brand identity

- Although this report includes a user test of conceptual instruments and ultimately developers a functional prototype, to continue development of an implementation of the Control Transfer Rituals, the Mediator project is advised to keep the options open regarding the physical interaction. Again, the implementation found in this report is to communicate, explain, and experience the created Control Transfer Rituals.

- Both during testing and during ideation, the idea came to mind to allow the steering wheel to retract when handsfree driving was enabled. It is recommended to explore this possibility and the perception of users to a moving steering wheel. A moving steering wheel does not have to disappear into the dashboard per say, it can simply retract a short distance. The exact distance to communicate the change in responsibilities also needs to be explored. The same can be tested for moving pedals.

  One side-note, moving the steering wheel might impact the reachability of any devices/stalks on the steering wheel column.

- Future research should be allocated to finding the guidelines to alerts and alarms over all modalities to balance perceived urgency and perceived annoyance. Wrongful implementation can lead to undesired, potentially dangerous, user behaviour.

- Because all people are different, it is recommended to allow personalized control transfer rituals. For example, the recommendation to relax can be triggered later if the Decision Logic learns that the person is a responsible driver for extended periods of time. This would result in personalised profiles, which can be activated at session start by scanning the facial features of the human driver. A face-scanner is expected to be implemented to assess driver fatigue. MEDIATOR can look into this and other methods to personalize the transfer of control. This might make it both safer and more comfortable

- An important factor of the Control Transfer Rituals has not yet been determined: time intervals. This factor is key to establishing comfortable and safe Control Transfer Rituals. To answer the questions related timeframes, the MEDIATOR project has to advance to a further stage in which people can be tested in a real life scenario. As for now, restricting such an essential factor would be irresponsible and might even skew the scope by over/under estimating human behaviour based on studies in rudimentary simulators.

  It is expected that the necessary precision of the timeframe definition grows with the urgency of a scenario.

- Based on the fact that a proper user test has not been conducted, it is recommended that the designed control transfer rituals are tested with a adequate sample size. Naturally, this can only be done when COVID-19 is no longer a threat. When MEDIATOR arrives in the phase where actual vehicles are tested on a test-track, it is recommended to try and simulate real-life scenarios that test the limits of the designed control transfer rituals.

- Due to technological advancements, it is likely that an OEM will attempt to develop an AI-companion based vehicle. A recommendation would be to test whether that will push people to over-trust the system, similar to Tesla's autopilot. Furthermore, the oversimplification of the interactions might cause the user to unlearn essential driving skills such as monitoring with the intent to respond, which could cause harm if the automation suddenly fails and a take-over is required.

Other

Furthermore, there are some recommendations, remarks, and questions that arose during the project that might influence decisions regarding the development of automated vehicles:

- It is yet to be seen whether all levels of automation remain relevant. As the typewriter was replaced by personal computers, will the need for basic automation diminish? And does manual, unassisted driving?

- As for legislation, the ruling in German court shows that the industry should think twice before implementing crucial new interaction methodology, such as touch-screens. However, as identified in the concept vehicles such as the Peugeot E-Legend and Renault Symbioz, in-vehicle displays become evermore prominent, which might push to reconsider the ruling.

- As automation technology develops, a MRM will grow to the highest available SAE level; the best observing, accounting and handling option.
- In prior MEDIATOR research done by Xinji Wang proposed LED strips in the A-pillars. This would allow directional visual feedback and can prove to be a viable option for OEMs to explore.

- An important notice with the currently developed prototype: this is an example of the application of the found guidelines and requirements. Though the force-feedback operated shifter, in combination with a HUD, lighting and directional audio appears a viable option, it is not he sole solution. Other applications of the guidelines and requirements can result in a vastly different concept, which is equally viable.

- In order to minimize confusion, each driving mode should have its own capital letter. In case of the extension of the automatic shifter, the letters P, R, N, and D are already taken. It is recommended to switch to the P, R, N, M, A, H, format. This format has no repeating capital letters and manual, assisted and handsfree each communicate what can be expected from the automation.

- A majority of the challenges that can be found at the start of this report are relatively easy to answer; keep information to the human driver concise, clear, and relay it at the appropriate time.

Acknowledgements

Finally, I would like to take this opportunity to express my thanks to everyone who helped me throughout this project.

In specific, I would like to thank Elmer and Wouter for giving me this opportunity. Also, they have done an excellent job keeping me on track and working towards the goal of a fulfilling project both in practice and personally. I cannot imagine a better coach and chair.

The other supporting staff from the TU that helped me complete this project deserve a definate shout-out. Thank you Applied Labs and PMB staff for helping me build an awesome prototype. Especially Martin, who endured most of my questions.

I count myself lucky that I can thank many more people, but I would like to point several more out:

A huge thank you to all who let me into their Tesla. That was an awesome learning experience. Your participation helped me gain valuable insight and first hand experience with automated vehicles.

Also, those who were willing to advise me in areas I had little to no knowledge. Thank you all for taking the time to talk to me and especially the patience to teach me.

I would like to thank all my friends and family who came out and supported me. A special mention to Freek, who helped me navigate me through the treacherous mountains of Unity.

Lastly, someone who deserves all my thanks is my girlfriend, Chenyi, who has seen all ups and downs that I went through during this project. Thank you for all your support and for believing in me. She has shown incredible patience when something went a little different that planned and helped heaps in the organizational side of the project.

Figure 40 - The C,MM,N, which has been practically my office during the prototyping phase

References

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References

- Ajzen, I. (1991). Theory of Planned Behavior. Organizational Behaviour And Human Decision Processes, 50, 179-211. doi:10.4135/9781412952576.n208

- Aljazeera (2019). Ethiopian Airlines crew ‘followed rules, unable to control jet’. Retrieved 13 november, 2020, from https://www.aljazeera.com/news/2019/04/04/ethiopian-airlines-crew-followed-rules-unable-to-control-jet/

- Akash, K., Polson, K., Reid, T., & Jain, N. (2019). Improving Human-Machine Collaboration Through Transparency-based Feedback – Part I: Human Trust and Workload Model. IFAC-PapersOnLine, 51(34), 315-321. doi:10.1016/j.ifacol.2019.01.028

- Audi AI:CON. (2020, August 26). Retrieved August 13, 2020, from https://www.audi.com/en/experience-audi/models-and-technology/concept-cars/audi-aicon.html

- Barthès, J. A., & Bonnifait, P. (2015). Multi-Agent Active Collaboration Between Drivers and Assistance Systems. Advances in Artificial Transportation Systems and Simulation, 163-180. doi:10.1016/b978-0-12-397041-1.00009-1

- Bella, F., & Silvestri, M. (2017). Effects of directional auditory and visual warnings at intersections on reaction times and speed reduction times. Transportation Research Part F: Traffic Psychology and Behaviour, 51, 88-102. doi:10.1016/j.trf.2017.09.006

- Bellettiere, J., Hughes, S. C., Liles, S., Boman-Davis, M., Klepeis, N. E., Blumberg, E., . . . Hovell, M. F. (2014). Developing and Selecting Auditory Warnings for a Real-Time Behavioral Intervention. American Journal of Public Health Research, 2(6), 232-238. doi:10.12691/ajphr-2-6-3

- Bjørn Nyland (Channel). (2019, September 10). Byton M-Byte production car interior preview [Video file]. Retrieved August 10, 2020, from https://www.youtube.com/watch?v=AQVi7PWRr8g&ab_channel=BjørnNyland

- Blanco, M., Atwood, J., Vasquez, H. M., Trimble, T. E., Fitchett, V. L., Radlbeck, J., . . . Russell, S. M. (2016). Automated Vehicles: Take-Over Request and System Prompt Evaluation. Road Vehicle Automation 3 Lecture Notes in Mobility, 111-119. doi:10.1007/978-3-319-40503-2_9

- Boeijen, A., Van, Daalhuizen, J., Van der, Zijlstra, J., Schoor-Rombouts, R., & Zijlstra, Y. (2013). Delft design guide. Amsterdam: BIS.

- Byton. (2020). BYTON M-Byte Concept. Retrieved August 10, 2020, from https://www.byton.com/m-byte/experience
- Byton. (2020). BYTON M-Byte. Retrieved August 10, 2020, from https://www.byton.com/m-byte

- Car Throttle (Channel). (2017, December 27). Testing The World’s Smartest Autonomous Car (NOT A Tesla) [Video file]. Retrieved August 07, 2020, from https://www.youtube.com/watch?v=I3ELVACR2VY&&ab_channel=CarThrottle

- Carwow (Channel). (2020, August 10). Aston Martin DBX review: See how quick it is ON & OFF-ROAD! [Video file]. Retrieved August 10, 2020, from https://www.youtube.com/watch?v=VwtT2bUIPCc&ab_channel=carwow

- Choi, Y., Kim, M., & Chun, C. (2019). Effect of temperature on attention ability based on electroencephalogram measurements. Building and Environment, 147, 299-304. doi:10.1016/j.buildenv.2018.10.020

- Citroen. (2019, May 16). Citroën 19_19 Concept - Experience Movie [Video file]. Retrieved August 10, 2020, from https://www.youtube.com/watch?v=4UA73BxoEnU&ab_channel=CitroenEspana

- Cohen-Lazry, G., Katzman, N., Borowsky, A., & Oron-Gilad, T. (2019). Directional tactile alerts for take-over requests in highly-automated driving. Transportation Research Part F: Traffic Psychology and Behaviour, 65, 217-226. doi:10.1016/j.trf.2019.07.025

- Cristoph, M., Ahlström, H., Bakker, B., Beggiato, M., Borowsky, A., Egmond, R., Van, . . . Ridder, H., De. (2019). Mediating between human driver and automation: State-of the artand knowledge gaps : D1.1 of the H2020 project MEDIATOR. Mediator Consortium.

- Daimler. (2020, June 23). Mercedes-Benz and NVIDIA. Retrieved August 03, 2020, from https://www.daimler.com/innovation/product-innovation/autonomous-driving/mercedes-benz-and-nvidia-plan-cooperation.html

- Danner, S., Pfromm, M., Limbacher, R., & Bengler, K. (2020). Information needs regarding the purposeful activation of automated friving functions - an exploratory study.

- Dreyfuss, H. (1967). The measure of man human factores in design. New York: Whitney.

- Endgadget (Channel). (2017, December 13). Renault Symbioz self-driving EV hands-on [Video file]. Retrieved August 10, 2020, from https://www.youtube.com/watch?v=D5-URu0Xqnw&ab_channel=Engadget

- Erp, J. B., Toet, A., & Janssen, J. B. (2015). Uni-, bi- and tri-modal warning signals: Effects of temporal parameters and sensory modality on perceived urgency. Safety Science, 72, 1-8. doi:10.1016/j.ssci.2014.07.022

- Evans, M., Foxall, G., & Jamal, A. (2009). Consumer Behaviour (2nd ed.). Chichester: John Wiley & Sons.

- Forster, Y., Naujoks, F., Neukum, A., & Huestegge, L. (2017). Driver compliance to take-over requests with different auditory outputs in conditional automation. Accident Analysis & Prevention, 109, 18-28. doi:10.1016/j.aap.2017.09.019

- Frazer, A. (2018, May 8). The Highways. Audi.com. Retrieved July 21, 2020, from https://www.audi.com/en/experience-audi/mobility-and-trends/autonomous-driving/piloted-driving-youth.html

- Gastaldi, M., Rossi, R., & Gecchele, G. (2014). Effects of Driver Task-related Fatigue on Driving Performance. Procedia - Social and Behavioral Sciences, 111, 955-964. doi:10.1016/j.sbspro.2014.01.130

- Gibbs, N. (2017, July 11). Audi A8 adopts new level of autonomous driving. Automotive News. Retrieved July 21, 2020, from https://www.autonews.com/article/20170711/COPY01/307119971/audi-a8-adopts-new-level-of-autonomous-driving

- Guo, C., Sentouh, C., Popieul, J., & Haué, J. (2019). Predictive shared steering control for driver override in automated driving: A simulator study. Transportation Research Part F: Traffic Psychology and Behaviour, 61, 326-336. doi:10.1016/j.trf.2017.12.005

- Hammond, D. C., & Roe, R. W. (1972). SAE Controls Reach Study. SAE Transactions, 81, 765-785. doi:10.4271/720199

- Hellier, E., & Edworthy, J. (1999). On using psychophysical techniques to achieve urgency mapping in auditory warnings. Applied Ergonomics, 30(2), 167-171. doi:10.1016/s0003-6870(97)00013-6

- Hetzner, C. (2020, April 28). Audi quits bid to give A8 level 3 autonomy. Automotive News. Retrieved July 21, 2020, from https://www.autonews.com/cars-concepts/audi-quits-bid-give-a8-level-3-autonomy

- Hoff, K., & Bashir, M. (2013). A theoretical model for trust in automated systems. CHI 13 Extended Abstracts on Human Factors in Computing Systems on - CHI EA 13. doi:10.1145/2468356.2468378
- Honda. (2020). Honda’s Augmented Driving

Concept: CES 2020. Retrieved August 10, 2020, from https://www.honda.com/mobility/ces

- Jang, P. (2007). Designing acoustic and non-acoustic parameters of synthesized speech warnings to control perceived urgency. International Journal of Industrial Ergonomics, 37(3), 213-223. doi:10.1016/j.ergon.2006.10.018
- Kala, R. (2016). On-road intelligent vehicles: Motion planning for intelligent transportation systems (pp. 59-82). Kidlington, Oxford UK: Butterworth-Heinemann.
- Kolodny, L. (2020). “German court rules that Tesla misled consumers on Autopilot and Full Self Driving”. Retrieved on November 17, 2020, from https://www.cnbc.com/2020/07/14/tesla-autopilot-self-driving-false-advertising-germany.html
- Körber, M., Cingel, A., Zimmermann, M., & Bengler, K. (2015). Vigilance Decrement and Passive Fatigue Caused by Monotony in Automated Driving. Procedia Manufacturing, 3, 2403-2409. doi:10.1016/j.promfg.2015.07.499
- Kristensen, M. S., Edworthy, J., & Özcan, E. (2016). Alarm fatigue in the ward: An acoustical problem? SoundEffects - An Interdisciplinary Journal of Sound and Sound Experience, 6(1), 88-104. doi:10.7146/se.v6i1.24915
- Lan, L., Lian, Z., Pan, L., & Ye, Q. (2009). Neurobehavioral approach for evaluation of office workers productivity: The effects of room temperature. Building and Environment, 44(8), 1578-1588. doi:10.1016/j.buildenv.2008.10.004
- Large, D. R., Kim, H., Merenda, C., Leong, S., Harvey, C., Burnett, G., & Gabbard, J. (2019). Investigating the effect of urgency and modality of pedestrian alert warnings on driver acceptance and performance. Transportation Research Part F: Traffic Psychology and Behaviour, 60, 11-24. doi:10.1016/j.trf.2018.09.028
- Laßmann, P., Othersen, I., Fischer, M., Reichelt, F., Jenke, M., Tüzün, G. J., . . . Maier, T. (2020). Driver’s Experience and Mode Awareness in between and during Transitions of different Levels of Car Automation.
- Lu, Z., Coster, X., & Winter, J. D. (2017). How much time do drivers need to obtain situation awareness? A laboratory-based study of automated driving. Applied Ergonomics, 60, 293-304. doi:10.1016/j.apergo.2016.12.003
- Macey, S., & Wardle, G. (2014). H-point: The fundamentals of car design & packaging (2nd ed.). Culver City, CA: Design Studio Press.
- MacKenzie, A. (2019, November 20). Revealed! The 2021 Aston Martin DBX Aims to be the World’s Most Desirable SUV. Retrieved August 10, 2020, from https://www.motortrend.com/cars/aston-martin/dbx/2021/2021-aston-martin-dbx-first-look-review/
- Marshall, D. C., Lee, J. D., & Austria, P. A. (2007). Alerts for In-Vehicle Information Systems: Annoyance, Urgency, and Appropriateness. Human Factors: The Journal of the Human Factors and Ergonomics Society, 49(1), 145-157. doi:10.1518/001872007779598145
- Mediator (2020). About Mediator. Retrieved July 7, 2020 mediatorproject.eu/about/about-mediator.
- Meng, F., & Spence, C. (2015). Tactile warning signals for in-vehicle systems. Accident Analysis & Prevention, 75, 333-346. doi:10.1016/j.aap.2014.12.013
- Mössinger, P. (2017). AI Companion - Trust in Piloted Driving
- Motor1 (Channel). (2015, December 15). Rinspeed Etos concept [Video file]. Retrieved August 13, 2020, from https://www.youtube.com/watch?v=nrdxgMasV7s&ab_channel=Motor1
- Naujoks, F., Purucker, C., Neukum, A., Wolter, S., & Steiger, R. (2015). Controllability of Partially Automated Driving functions – Does it matter whether drivers are allowed to take their hands off the steering wheel? Transportation Research Part F: Traffic Psychology and Behaviour, 35, 185-198. doi:10.1016/j.trf.2015.10.022
- Naujoks, F., Wiedemann, K., Schömig, N., Hergeth, S., & Keinath, A. (2019). Towards guidelines and verification methods for automated vehicle HMIs. Transportation Research Part F: Traffic Psychology and Behaviour, 60, 121-136. doi:10.1016/j.trf.2018.10.012
- NiceCarsInfoTeam. (2016, January 17). Volvo Concept 26 Interior design study, Images. Retrieved August 13, 2020, from https://nicecarsinfo.com/volvo-concept-26/
- Norman, D. A. (1990). The design of everyday things. New York: Doubleday/Currency.
- Patterson, R. D. (1982). Guidelines for auditory warning systems on civil aircraft (England, Civil Aviation Authority). London: Civil Aviation Authority.
- Petermeijer, S., Bazilinskyy, P., Bengler, K., & Winter, J. D. (2017). Take-over again: Investigating multimodal and directional TORs to get the driver back into the loop. Applied Ergonomics, 62, 204-215. doi:10.1016/j.apergo.2017.02.023
- Petermeijer, S., Cieler, S., & Winter, J. D. (2017). Comparing spatially static and dynamic vibrotactile take-over requests in the driver seat. Accident Analysis & Prevention, 99, 218-227. doi:10.1016/j.aap.2016.12.001
- Pilditch, T. D., Madsen, J. K., & Custers, R. (2020). False prophets and Cassandras curse: The role of credibility in belief updating. Acta Psychologica, 202, 102956. doi:10.1016/j.actpsy.2019.102956
- Reed, M. P., Parkinson, M. B., & Chaffin, D. B. (2003). A New Approach to Modeling Driver Reach. SAE Technical Paper Series. doi:10.4271/2003-01-0587
- Rinspeed AG. (2014). RINSPEED XCHANGE. Retrieved August 13, 2020, from https://www.rinspeed.com/en/XchangE_24_concept-car.html
- Rinspeed AG. (2016). Rinspeed Σtos. Retrieved August 13, 2020, from https://www.rinspeed.com/en/Sigmatos_22_concept-car.html
- SAE International (2018). SAE International Releases Updated Visual Chart for Its “Levels of Driving Automation” Standard for Self-Driving Vehicles. Retrieved 21 July, 2020, from https://www.sae.org/news/press-room/2018/12/sae-international-releases-updated-visual-chart-for-its-%E2%80%9Clevels-of-driving-automation%E2%80%9D-standard-for-self-driving-vehicles
- Schniter, E., Shields, T., & Sznycer, D. (2020). Trust in humans and robots: Economically similar but emotionally different. Journal of Economic Psychology, 78, 102253. doi:10.1016/j.joep.2020.102253
- Schwalk, M., Kalogerakis, N., & Maier, T. (2015). Driver Support by a Vibrotactile Seat Matrix – Recognition, Adequacy and Workload of Tactile Patterns in Take-over Scenarios During Automated Driving. Procedia Manufacturing, 3, 2466-2473. doi:10.1016/j.promfg.2015.07.507
- Seppänen, O. J., Fisk, W. J., & Faulkner, D. J. (2004). Control of temperature for health and productivity in offices. ASHRAE Transactions, 111.
- Spacey, J. (2017, august 13). 11 Examles of Ease of Use. Retried August 24, 2020 from https://simplicable.com/new/ease-of-use
- Strand, N., Nilsson, J., Karlsson, I. M., & Nilsson, L. (2014). Semi-automated versus highly automated driving in critical situations caused by automation failures.

Transportation Research Part F: Traffic Psychology and Behaviour, 27, 218-228. doi:10.1016/j.trf.2014.04.005

- Supercar Blondie (Channel). (2019, May 26). The Car With No Driver | ft. Peugeot E-Legend Concept [Video file]. Retrieved August 07, 2020, from https://www.youtube.com/watch?v=KU5M8_fZcwY&ab_channel=SupercarBlondie
- Talamonti, W., Tijerina, L., Blommer, M., Swaminathan, R., Curry, R., & Ellis, R. D. (2017). Mirage events & driver haptic steering alerts in a motion-base driving simulator: A method for selecting an optimal HMI. Applied Ergonomics, 65, 90-104. doi:10.1016/j.apergo.2017.05.009
- Tesla (2020). Tesla App Support. Retrieved November 13, 2020, from https://www.Tesla.com/support/Tesla-app
- Tesla touchscreen wiper controls land driver with fine after crash. (2020, August 5). BBC. Retrieved August 7, 2020, from https://www.bbc.com/news/technology-53666222
- Toyota Motor Corporation. (2020). Toyota's New "LQ" Wants to Build an Emotional Bond with Its Driver: Corporate: Global Newsroom. Retrieved August 10, 2020, from https://global.toyota/en/newsroom/corporate/30063126.html
- Uber ATG. (2020). We are on a mission. Retrieved August 03, 2020, from https://www.uber.com/us/en/atg/cities/
- Uber ATG. (2020). We believe in the power of technology. Retrieved from https://www.uber.com/us/en/atg/technology/
- Verpraet, I. (2018, August 8). The history of adaptive cruise control. Autonomous Vehicle International. Retrieved July 22, 2020, from https://www.autonomousvehicleinternational.com/features/adas-3.html
- Visser, E. J., Monfort, S. S., Mckendrick, R., Smith, M. A., Mcknight, P. E., Krueger, F., & Parasuraman, R. (2016). Almost human: Anthropomorphism increases trust resilience in cognitive agents. Journal of Experimental Psychology: Applied, 22(3), 331-349. doi:10.1037/xap0000092
- Volvo Cars. (2015, November 22). Volvo Cars: Concept 26 [Video file]. Retrieved August 11, 2020, from https://www.youtube.com/watch?v=UAH9igexgtQ&ab_channel=VolvoCars
- Volvo Cars. (2017, September 15). Volvo Cars How-To: Pilot Assist [Video file]. Retrieved August 13, 2020, from https://www.youtube.com/watch?v=N5gmgqXY5FI&ab_channel=VolvoCars
- Volvo Cars. (2015). Concept 26 animation. Retrieved August 13, 2020, from https://www.media.volvocars.com/us/en-us/media/videos/169536/concept-26-animation
- Volvo Cars. (2015). Volvo Cars Debuts Concept 26 – An Autonomous Drive Concept. Retrieved August 13, 2020, from https://www.media.volvocars.com/us/en-us/media/pressreleases/169493/volvo-cars-debuts-concept-26-an-autonomous-drive-concept
- Volvo Cars. (2020). A new way to travel. Retrieved August 13, 2020, from https://www.volvocars.com/intl/cars/concepts/360c?redirect=true
- Wang, X. (2020). Driver-centered Human-machine interface design.
- Waymo. (2020). FAQ. Retrieved August 03, 2020, from https://waymo.com/faq/
- Waymo. (2020). Journey. Retrieved August 03, 2020, from https://waymo.com/journey/
- White, T. L., & Krausman, A. S. (2015). Effects of inter-stimulus interval and intensity on the perceived urgency of tactile patterns. Applied Ergonomics, 48, 121-129. doi:10.1016/j.apergo.2014.11.010
- Wickens, C. D., & Hollands, J. G. (2000). Engineering psychology and human performance. Upper Saddle River, NJ: Prentice Hall.
- Zeeb, K., Buchner, A., & Schrauf, M. (2015). What determines the take-over time? An integrated model approach of driver take-over after automated driving. Accident Analysis & Prevention, 78, 212-221. doi:10.1016/j.aap.2015.02.023
- Zeeb, K., Buchner, A., & Schrauf, M. (2016). Is take-over time all that matters? The impact of visual-cognitive load on driver take-over quality after conditionally automated driving. Accident Analysis & Prevention, 92, 230-239. doi:10.1016/j.aap.2016.04.002
- トヨタ自動車株式会社 / Toyota Motor Corporation. (2017, January 5). TOYOTA Concept-愛i コンセプト映像 [Video file]. Retrieved August 11, 2020, from https://www.youtube.com/watch?v=gtr9axXm4TE&ab_channel=トヨタ自動車株式会社

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